Reconfiguring business processes in the new political and technological landscape

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Reconfiguring business processes in the new political and technological landscape

Digital supply chains are being used to inform new requirements for digital infrastructures and standards and the potential for connecting App and Device-aware consumers with their product-service supply chains (Boston Consulting Group, 2015). At the heart of digital supply chains are big data analytics and cloud-based sensor intelligence (Manyika et al., 2011). It is therefore necessary to explore how big data, industrial Internet of Things and cloud computing will combine with alternative production processes such as continuous, additive, flexible/collaborative automation. The emergence of digital technologies is driving innovations, in terms of “processes”, “products” (Hennelly et al., 2019) and “services” (Anderson, 2013). This requires greater visibility, alignment and integration across an increasingly complex network of multiple partners, to deliver better “service outcomes” and “customer experience” (D’Aveni, 2015). Yet, very few empirical studies have been conducted to assess the real business value of digitalisation at the firm and supply chain levels, and its impact on BPM. The main objective of this special issue is to collate and present recent research examinations in the field of digitalisation in global manufacturing, end-to-end supply chains, service operations and BPM. Specifically, various scholars and practitioners are invited to help explain and understand new antecedents to supply chain digitalisation – human, machine, process and information technology (IT) based – and their singular and combinatorial impacts on flexibility and performance outcomes. All of the articles submitted and included in the special issue went through a double-blind review process. The introductory article was reviewed and handled by the editor-in-chief of the journal.

Synopsis of articles

Below, a synopsis of the articles included in this special issue is provided.

In the paper “From the boundaries of management to the management of boundaries: business processes, capabilities and negotiations”, the authors Andrea Caputo, Raffaele Fiorentino and Stefano Garzella make a theoretical contribution by advancing knowledge through the systematisation and rationalisation of studies focussed on boundary management and, in particular, through the development of a conceptual framework for boundary capabilities. Findings suggest that “boundary management” – how managers coordinate resources, activities and business processes on the boundaries of the firm – should play a key role in the new competitive contexts, provided by the technological landscape. The analysis suggests that there are some strategic relevant factors for the management of boundaries. These factors are related to three highly related dimensions such as technological, cultural and relational. The boundaries management need to adequately consider these factors when confronting with multiple actors inside, outside and on firm boundaries (Fiorentino, 2016). Specifically, it is easy to recognise the need for delicate relational activity involving compromise and negotiation that organises, structures and formalises in ways considered
appropriate, while supporting relationships of trust, opportunism, power and dependence. Moreover, as managers must continuously interact with multiple partners in digital supply chains, the organisational model of negotiation (OMoN) serves as a means of effectively managing firm boundaries. In this sense, the manuscript finds support for extending the OMoN model (Borbély and Caputo, 2017a) to the management of boundaries. The authors encourage a focus on business processes occurring at firm boundaries and the development of new capabilities in response to the needs of practitioners to ensure best practices of negotiation.

In the paper “Intelligent autonomous vehicles in digital supply chains: from conceptualisation, to simulation modelling, to real-world operations” written by Naoum Tsolakis, Dimitrios Bechtsis and Jagjit Singh Srai, the authors discuss the key challenges associated with existing techniques on the assessment of intelligent autonomous vehicles in supply networks. In this regard, this research proposes a theoretically and empirically derived methodological framework and a practical “toolbox” for the integrated application of conceptualisation, simulation, emulation and physical application of testbeds for the effective design and ex-ante evaluation of digitally enabled supply network operations.

In the paper “Electric sports cars and their impact on the sourcing process” by Gary Graham, Laird Burns, Patrick Hennelly and Roy Meriton, the authors argue that (resulting from the trend towards electric cars) the automobile industry supply chain is expected to be fundamentally reshaped. This will include “network re-design” and a change in the nature of “actor relationships”. In addition, there is a plethora of new, one could define “left of field” suppliers with unique technological capabilities entering the electric vehicle supply chain. Even though they have no previous “legacy”, “experience”, “competence” or “capability” of the sector. Such is the speed of technological disruption and industry shake up. Therefore, the European sports car manufacturers will need to rethink and adjust their business, supply chain and sourcing strategy (processes). This is vital, if they are to keep their superior global brand and market leader competitive position. The authors work identifies that one crucial strategic decision these firms will need to take is the “make” or “buy” decision. Furthermore, which of the parts of the value creation process should be kept “internal” and which parts should be “outsourced”. Throughout their adaption of McIvor’s “sourcing framework” the authors identify and analyse the operational capabilities needed to sustain competitive advantage at their case study organisation. Four key operational capabilities are emerging in the operating model. The first links to “capacity” and the ability of suppliers to be locally based so that they can deliver high quality products and services in the minimum time (optimising the “time-value” configuration). The second is the “design” of the supplier network. The third relates to “supplier management”. Suppliers will add capability through their ability to be innovative and creative and increasingly be strategically positioned as service innovators and service solution providers, rather than product manufacturers. Finally, the fourth capability relates to the ability of the firm to “integrate” and “align” their marketing and IT planning processes with their sourcing process. From these initial findings, the authors intend to expand their investigation through more advanced case study work with their organisation. This will involve detailed empirical modelling of process efficiency and inventory management.

In the paper “Unlocking innovation in the sport industry through additive manufacturing” by Marlon Meier, Kim Hua Tan, Ming K Lim and Leanne Chung, the authors argue fast changing customer demands and rising requirements in product performance constantly challenge sports equipment manufacturers to come up with new and improved products to stay competitive. This article focusses on how additive manufacturing AM (aka 3D Printing) can enhance the development of new products in the sport industry. Case studies and interview results in several companies were used to analyse the current adoption of AM technologies in the innovation process of the sports
industry, i.e. level of awareness; how it is implemented; and its impact on the innovation process. The findings show that AM provides several benefits when it comes to the innovation process, such as a faster development process, an optimised output, as well as the possibility to create new designs. However, companies are not yet able to enhance the innovation process in a way that leads to new products and new markets with AM. Limitations, including a small range of processable materials and an inefficient mass production system are restraining the full capability of the AM applications.

In the paper “IT capabilities, firm performance and the mediating role of ISRM: a case study from a developing country”, the authors Jean Robert Kala Kamdjoug, Harold Nguegang and Samuel Fosso Wamba conduct a case study applying a hypothetic-deductive approach based on quantitative data collected from 136 surveyed professionals in the field of IS, IT and the related security environment. This paper focuses on the direct impact of IT capabilities on firm performance and the mediating effects of the information security management system (ISMS) on this relationship. The research question developed in this study is: does information security risk management (ISRM) mediate the relation between IT capabilities and firm performance? The findings confirm the direct impact of IT capabilities on firm performance and show that ISMS mediates the relationship between IT capabilities and firm performance. Originality of this paper is that it is among the first to evaluate the mediating role of information security with ISRM on the relationship between IT capabilities and firm performance. In fact, the previous studies establish positive impact of IT capabilities on firm performance where authors recommend the continuous improvement of the maturity level of ISRM process which is expected to produce an enhanced quality of ISMS.

In the paper “Internet of Things adoption for reconfiguring decision-making processes in asset management” by Paul Brous, Marijn Janssen and Paulien Herder, the authors argue that data provenance is necessary to be able to understand the value and the quality of data generated by IoT within organisations and that managers need to adapt new capabilities to be able to interpret the data. The use of IoT can yield many benefits for organisations, but these benefits might be difficult to realise as many organisations are not yet equipped to handle and interpret this data. As such, the objective of this research is to understand how IoT adoption affects decision-making processes. In this paper, the changes in the business processes for managing civil infrastructure assets brought about by IoT adoption are analysed by investigating two case studies within the water management domain and propositions for effective IoT adoption in decision-making processes are derived. The results of the case studies show that IoT can have a transformative effect on business processes and decision processes in civil infrastructure asset management have been transformed to deal with the real-time nature of the data. It is necessary to make organisational and business process changes, develop new capabilities, and implement data provenance and data governance.

The paper “Quality dominant logic in big data analytics and firm performance” by Samuel Fosso Wamba, Shahriar Akter and Marc de Bourmont draws on the resource-based view and information systems quality to develop a big data analytics quality (BDAQ) model. Then, the paper measures the impact of BDAQ on firm performance. The study uses an online survey to collect data from 150 business analysts and IT managers with analytics experience from France. The study confirms that perceived technology, talent and information quality are significant determinants of BDAQ. It also identifies that alignment between analytics quality and firm strategy moderates the relationship between BDAQ and firm performance. The findings inform practitioners that BDAQ is a hierarchical, multi-dimensional and context-specific model. The study advances theoretical understanding of the relationship between BDAQ and firm performance under the influence of firm strategy alignment.
The article entitled “Performance landscape modelling in digital manufacturing firm” is written by Sourabh Kulkarni, Priyanka Verma and Mukundan R. The aim of this research is to update the existing Kauffmann’s NK model to evaluate the manufacturing fitness of strategic business capabilities. Authors propose the grey-DEMATEL-NK based updated model and illustrate its application in a digital manufacturing setting to investigate the sequence for developing cumulative capabilities that can yield the maximum payoff. The pilot model proposed in this article presents Q–F–C–D is the optimal sequence for achieving maximum manufacturing fitness (competitive payoff). Interestingly, this sequence is different from that of traditional manufacturing (Q–D–F–C), proposed in line with the cumulative capabilities’ theory. In this way, the article opens the need for investigating the firm-specific sequence of cumulative capabilities across traditional and digital manufacturing context.

In the paper “How to turn managers into data-driven decision makers: measuring attitudes towards business analytics” written by Kevin Carillo, Nadine Galy, Cameron Guthrie and Anne Vanhems, the authors implement a multi-stage research design in order to develop and validate a measurement instrument that captures the attitude towards business statistics, the foundation of business analytics. The rationale behind such development is that it is crucial for organisations engaging the path of the data-driven transformation, to engender among their employees, a positive attitude towards business analytics. This research also has direct implications for business schools as it can help to better prepare future managers to evolve successfully in a data-driven business world.

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Gary Graham’s work to date focusses on the impact of the internet and digital technologies on supply chains, logistics and distribution operations. He has authored 3 books, 30 research papers and has worked on ESRC/EPSRC, British Academy, the Foreign and Commonwealth Office and EU research grants investigating the economic and social consequences of disruptive innovation on the music, news media and information intensive sectors. His recent work focusses on the deployment of creative ethnographic “bridging techniques”. This includes both between business and users and universities and communities.

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From the boundaries of management to the management of boundaries

Business processes, capabilities and negotiations

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Abstract

Purpose – The purpose of this paper is to examine some of the new capabilities that are required for the facilitation of business processes management (BPM) in the current political and technological landscape. Specifically, the goal is to investigate the role of firm boundaries, from a business processes perspective, in new contexts in which the affirmation of digitalization requires more integration across a complex network of partners.

Design/methodology/approach – The paper is based on a review of relevant literature on BPM, firm boundaries and negotiation. By critically integrating this literature, a framework is developed with the objective of supporting the management of boundaries.

Findings – BPM, new competitive contexts, and the technological landscape require the development and management of boundary capabilities. Among these capabilities, “boundary management” – how managers coordinate resources, activities and business processes on the boundaries of the firm – should play a key role. Moreover, as managers must continuously interact with multiple partners in digital supply chains, the organizational model of negotiation serves as a means of effectively managing firm boundaries.

Practical implications – The framework offers insights and guidelines that can help practitioners manage the boundaries of business processes. The authors encourage a focus on business processes occurring at firm boundaries. Furthermore, the authors encourage the development of new capabilities in response to the needs of practitioners to ensure best practices of negotiation.

Originality/value – This study shifts the emphasis of BPM from the boundaries of management to the management of boundaries. By shedding light on new capabilities required, this paper enriches the BPM literature and can assist, on the other hand, in facilitating effective negotiation.

Keywords BPM, Digitalization, Boundary management, Boundary capabilities, Partnership, Negotiation

Paper type Conceptual paper

1. Introduction

New competitive contexts, digital innovations and big data analytics present a continuous stimulus to renew sources of competitive advantage (Fosso Wamba and Mishra, 2017). Markets are currently witnessing a rapid increase in digital infrastructures and network dynamics (Karmarkar et al., 2015). Similarly, the Internet of Things is having a pivotal impact on manufacturing systems (Caputo et al., 2016). Digitalization affects several aspects of business, including business supply chains and operations, pushing firms toward the use of new “sharing economy” business models (BCG, 2015; Cohen and Kietzmann, 2014; Holweg and Helo, 2014; Roden et al., 2017; Sundararajan, 2013; WEF, 2016). We witness a constant physicalization of what used to be the digital world, with tech companies often

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looking to give a physical dimension to their services, and a digitalization of what used to be the physical world, with traditional companies digitalizing products and services that used to need a physical space. Such trends have been so powerful that nowadays a clear distinction between the two worlds makes every day less sense (Capurro et al., 2018; Davenport and Ronanki, 2018).

These trends can enhance supply chain flexibility to increase the quality of production while shortening delivery times to more quickly address variations in product demand and to reduce crossing times while ensuring necessary stocks by partnering with flexible suppliers. At the same time, digitalization should increase levels of production efficiency to reduce production costs while optimizing immobilized capital such that plants can be used properly while minimizing inventories by employing systems that can streamline information flows. Indeed, firms can limit risks by sharing processes and activities to reduce risks of flow interruption along the supply chain, minimizing operational risks contingent on operating costs (Fiorentino, 2016). The affirmation of digitalization spurs new interactions between companies and between companies and customers (Rosenzweig, 2009). In digital supply chains, the development of information technologies and digital infrastructures render it possible to share large volumes of data and information that, on the one hand, offer considerable opportunities but, on the other hand, present problems related to their organization and correct use (Capgemini, 2011; Kumar et al., 2016; Papadopoulos et al., 2017).

While it is clear that digital technologies will transform business processes, there are a number of challenges that firms must address. These challenges must be addressed by managers and executives.

For example, Michelin – a leader in the tire industry – has advanced a comprehensive ecosystem that involves the use of sophisticated telematics and an optimized tire management system that orients logics of business processes toward “service models.” However, while this approach was developed internally, Michelin identified a need to partner, especially in the field of big data analytics.

In such contexts, business processes management (BPM) will increasingly involve more integration across a complex network of partners (D’Aveni, 2015; Mindruta et al., 2016; PWC, 2016). The relevance of network models and of the development of digital society stresses BPM at firm boundaries (Schotter et al., 2017). Boundaries are defined transitional areas between inside and outside (Håkansson and Snehota, 1989). Business models currently include a “border area” in which it is not easy to distinguish firms from the external environment (Spring and Araujo, 2014). These boundaries circumscribe resources and capabilities over which firms extend their governance and control (Pfeffer and Salancik, 1978). Basic criteria used for the identification of firm boundaries (Sarkis, 2012) can be determined from a firm’s system of governance, whereas “instrumental roles” useful for understanding the strength and extent of said actions can be attributed to other factors such as legal (Coase, 1937; Williamson, 1975), physical (Scott, 2003), communication and organizational elements (Weber, 2002).

Therefore, the ability of the firm to consistently negotiate within and beyond its boundaries serves as an important strategic driver in achieving and sustaining a competitive advantage (Brown and Duguid, 1998; Drori et al., 2013). Negotiation is commonly defined in the relevant literature as a process through which two or more parties reach a required joint decision while having different preferences (e.g. Rubin and Brown, 1975; Zartman, 1977; Fisher et al., 1981; Pruitt, 1981; Lax and Sebenius, 1986; Raiffa et al., 2002; Caputo, 2016). Due to the interdependence that reigns over and within multi-actor decision processes (Thompson, 1967), negotiation outcomes are affected by all decisions made by parties involved. According to this perspective, the case of Lego – the toy company – is an illustrative one. The company, from the launch of its “Lego Mindstorms,”
has had to manage new interactions with customers since the product also became successful among adult enthusiasts of mechanics and robotics. Fans gather on the Adult Fans of Lego online community and propose reprogramming sensors and control systems as custom versions of the Mindstorm software and as improvements to Lego’s products. Initially, the company considered acting legally against its customers, but after some initial disruption, it decided not to limit the creativity of its fans, which had the potential to stimulate firm creativity and innovation. Since 2004, the company has decided to negotiate with its customers and to develop a new line of Mindstorm robots in collaboration with fans in the design of a new product through a platform (Lego Digital Designer), a software program that allows fans to virtually create their own Lego projects and to share their creations on the internet. From this experience, Lego has entered a new digital business arena (e.g. film and video games) (Lakhani et al., 2013). Effectively improving upon negotiation capacities is crucial in managerial, political, and business contexts.

However, the current literature in terms of strategies, operations management and negotiation seems to overlook the role of boundary management and negotiation in the organizational capabilities of the firm (Borbély and Caputo, 2017a). Prior studies merely highlight the role of firm boundaries in BPM (Fiorentino, 2016) and define boundary management as the negotiation of knowledge (Roberts and Beamish, 2017). As supply chain management is predominantly represented through relationship management, critical issues involve managing relationships between processes, activities and people (Luvison and de Man, 2015; Niesten and Jolink, 2015). Thus, scholars and practitioners must identify ways to face such issues. From calls for what new capabilities are required in terms of BPM, this study investigates the role of boundaries in the new political and technological landscape from a business process perspective. Specifically, to achieve systematic conceptualization, we advance a framework of BPM based on a critical review of boundary capabilities, that allows to further our understanding of the overlap among digitalization, boundary management and negotiation.

This conceptual paper contributes to the fields of BPM, strategy and negotiation by bridging a pool of concepts and frameworks that thus far have been limited to the specificities of their original field. Moreover, the paper makes a theoretical contribution by advancing knowledge through the systematization and rationalization of studies focused on boundary management and through the development of a conceptual framework for boundary capabilities. Finally, the managerial and theoretical implications of this framework shift the focus from the boundaries of management to the management of boundaries, in which negotiation capabilities play a key role.

This paper is structured as follows. Section 2 presents a theoretical background on firm boundaries. Section 3 analyses the role of boundary management as a key to supporting BPM in new competitive contexts. Section 4 advances an organizational model of negotiation (OMoN) for effectively managing firm boundaries. Finally, Section 5 summarizes the main contributions of the paper and presents the study’s implications and avenues for future research.

2. Theoretical underpinnings of firm boundaries
Boundaries have been analyzed by scholars of economics, management and organizational behavior (Villalonga and McGahan, 2005). Traditional theories such as those of “transaction cost economics” and “resource-based views” generally investigate boundaries through a “make or buy” lens (Barney, 1991; Coase, 1937; Williamson, 1975). Transaction cost economics focuses on the benefits and costs of managing activities within or outside of boundaries. The resource-based view (RBV) suggests that the analysis of boundaries should encompass the traditional dichotomy between benefits and costs to integrate the analysis of resources with capabilities development. These theories have been recently
developed based on the evolution of competitive and technological landscapes that necessitate collaborative decision making in resource, knowledge and BPM (Foss, 1996; Milgrom and Roberts, 1990; Parmigiani and Mitchell, 2009; Santos and Eisenhardt, 2005; Tortoriello and Krackhardt, 2010).

The RBV of the firm serves an explanation for the management of boundaries and for the role of negotiations in this process. The RBV seeks to understand how competitive advantage is created and sustained over time by focusing on the internal organization of firms (Wernerfelt, 1984; Prahalad and Hamel, 1990; Barney, 1991; Nelson, 1991; Peteraf, 1993) rather than stressing industry structures and firms' positioning within a given industry (Porter, 1979; Hatten et al., 1978). The conceptualization of firms as clusters of resources heterogeneously distributed across firms is the underlying assumption of the RBV (Newbert, 2007; Wernerfelt, 1984).

The literature of this area argues that when through development or acquisition a firm possesses resources that are valuable, inimitable, rare, and non-substitutable, a competitive advantage can be achieved and sustained. This allows the firm to implement value-creating and difficult-to-duplicate strategies (Allred et al., 2011; Barney, 1991; Nelson, 1991; Peteraf, 1993; Wernerfelt, 1984). Dynamism has been included by Teece et al. (1997) into the RBV, highlighting that most environments in which firms compete are dynamic. This suggests that the structure of an industry evolves at different rates and that the ways in which companies achieve a competitive advantage in dynamic environments cannot be explained by a static approach to the RBV. Instead, firms with dynamic capabilities outperform their competition, as they can “integrate, build, and reconfigure internal and external competencies to address rapidly changing environments” (Teece et al., 1997, p. 516).

The literature on dynamic capabilities has developed and expanded, often in different directions (Mintzberg et al., 1998; Williamson, 1996) with no agreement on the definition of the term “capabilities” and, as a consequence, with a certain degree of heterogeneity in terminology used (Hine et al., 2014). In their seminal article Eisenhardt and Martin (2000) claimed that dynamic capabilities actually consist of identifiable and specific routines. Some integrate resources, such as product development routines (e.g. Toyota). Strategic decision making is considered a dynamic capability whereby “managers pool their various business, functional, and personal expertise to make the choices that shape the major strategic moves of the firm” (Eisenhardt and Martin, 2000, p. 1107). Other routines involve retaining and releasing resources (e.g. knowledge creation or alliance and acquisition capabilities) (Eisenhardt and Martin, 2000). Finally, others relate to the reconfiguration of resources within a firm via transfer, resource allocation, and synergistic processes. Dynamic capabilities developed from the path-dependent histories of individual firms are characterized as unique and idiosyncratic (Teece et al., 1997) while they also present common features associated with effective processes facilitated across firms (Eisenhardt and Martin, 2000). In this vein, we can configure an organizational capability in negotiating within the dynamic capabilities of boundary management. Wang and Rajagopalan (2015) argue that negotiation can be considered a firm-level ability among a firm’s individual alliance capabilities. Individual alliance capabilities, according to the RBV, can be defined as a firm’s ability to search for, negotiate, manage, and terminate an individual alliance (Kale and Singh, 2007; Simonin, 1999; Wang and Rajagopalan, 2015). For this reason, negotiation is considered a stage of the life cycle of an alliance (Wang and Rajagopalan, 2015) and it is defined as a firm’s ability to negotiate “the terms and structures of the collaborative agreement” (Simonin, 1999, p. 1155). Nevertheless, this definition is slightly limited and could benefit from further development, and it is thus developed in this paper.

3. Toward a new perspective on firm boundaries
Environmental dynamics currently call for new perspectives on BPM. In this way, the management of boundary processes has become a key variable of new competitive contexts
(Adamides, 2015; Foss et al., 2013; Gonzalez-Benito and Lannelongue, 2014; Schmenner et al., 2009; Swink et al., 2007).

Studies are increasingly focusing on firm boundaries as a third alternative over integration and markets, and the joint use of skills and knowledge has highlighted the role of boundary management (Alexander, 1997). Boundary processes embrace the activities through which companies select joint relationships. The boundary concept emerged as a means to analyze activities and processes that can be jointly controlled and influenced by several organizations (Yang and Lin, 2010). "Control" becomes the criterion used to define where firm boundaries should be placed: “the organization ends where its discretion ends and another begins” (Pfeffer and Salancik, 1978, p. 32). Specifically, boundaries should be viewed as a continuum that represents an intermediate form of hybrid governance in network dynamics, digital innovations and sharing economy perspectives (Normann and Ramirez, 1993; Håkansson and Snehota, 2006). This continuum constitutes a “border area” in which it is not easy to distinguish firms from the external environment. Consequently, it is increasingly becoming necessary to use the concept of boundaries and of the “boundary zone” as a central element of BPM. The management of resources, knowledge and activities along firm boundaries should be used as a new paradigm for obtaining and sustaining a competitive advantage (Dyer and Singh, 1998; Garzella, 2000; Wagner, 2003).

Boundary management should be used to integrate the benefits of internal and external growth strategies (Hargadon, 2002; McEvily and Zaheer, 1999; Steensma and Corley, 2001; Takeishi, 2001). Scholars have identified advantages of managing business processes in hedging against demand uncertainty and in acquiring and developing new capabilities from partners (Cao and Zhang, 2011; Cassiman and Veugelers, 2006; Parmigiani and Mitchell, 2009). Other studies show that boundary management favors the integration of coordination and flexibility benefits by jointly developing both (Park et al., 2004; Lavie, 2006). Another literature stream focuses on the chance of facing relevant risks in current contexts (e.g. the full outsourcing of key activities by partial outsourcing to enhance resource and knowledge portfolios from relationships with external actors). These findings have caused business process scholars to shift from the analysis of the management of boundaries to the study of boundary management (Blocker et al., 2012; Fiorentino, 2016; Troilo et al., 2009) and have helped managers overcome traditional trade-offs between internal and external processes.

The management of boundaries involves making decisions on “how” to define activities that integrate and interface a firm with the external environment. This approach implies the involvement of several subjects with strategic autonomy and generally affects business processes that can neither be considered fully internal nor fully external. Such management should design and manage business processes based on a broader perspective to identify new integration and coordination opportunities among firms’ value chains and those of external “partners” (Boddy et al., 2000; Pil and Holweg, 2006; Porter, 1987) by “linking” and “bearing” strategies for managing relationships with suppliers and customers (Scott, 2003). Boundary strategies encourage an organization to adopt a win-win approach to the supply chain where each actor collaborates to compete with other chains. Such “linking strategies” seek to internalize the resources and skills of partners. Firms, in pursuing information sharing and the alignment of internal and external business processes, should allow for the innovative redesign of the entire supply chain to satisfy customers more effectively and to improve overall operating efficiency levels. At the same time, however, firms must supervise business processes by developing “bearing” strategies that prevent external actors of the supply chain from acquiring key information through their relationships with the firm. Competitive expectations should lead other parties of boundary operations to promote their own interests at the expense of firm interests.
The management of boundaries is designed to create value by focusing on business processes and activities that occur at firm boundaries. The following section furthers our analysis on the role of boundary management with the aim of identifying capabilities that can support it.

4. The role of “boundary management”

The adoption of boundary strategies implies that essential decisions have been made to shift the attention of corporate leaders and of strategic management in the business process periphery. Making the decision to strategically manage boundaries involves first understanding opportunities inherent of this perspective and then considering its effective, efficient and correct implementation.

Boundary strategies contribute specific potential to the strengths that characterize other traditional development models. In contexts in which new communication tools and new ways of governing relationships are established, the choice of bringing to the boundaries the center of the strategy promotes the bearing or linking of strategies and can promote creativity and innovation (Adamides, 2015; Foss et al., 2013; Garzella, 2000; Gonzalez-Benito and Lannelongue, 2014; Lorenzoni and Lipparini, 1999; Möller and Halinen, 1999; Parolini, 1999; Ritter et al., 2004; Schmenner et al., 2009; Swink et al., 2007; Villalonga and McGahan, 2005).

We also understand that a successful boundary strategy requires the involvement and participation of a plurality of autonomous subjects. The greater autonomy that characterizes boundary elements and resources improves boundary strategies. The choice to focus on resources that are not internal (and that are not even external) favours strategic intent. Strategic creativity derives from individual contributions of subjects and from strategic freedoms for “joint fertilization” and to prefigure a stronger ability to organize innovative actions, the primary source of competitive advantage (Biemans, 1996; Björk and Magnusson, 2009; Fronterre, 1991; Leenders et al., 2003). The company can thus realize an organization capable of ensuring creativity, flexibility and responsiveness (Capaldo, 2007).

However, the decision to share processes with other subjects involves focusing special attention on the management of boundaries. Boundary management thus becomes a cornerstone of boundary strategies. Boundary managers are the guarantors of the consistency of operations. Their goal is to forge balance and harmony between various elements and activities facilitated in the boundary area by combining them effectively and efficiently with internal and external forces to achieve excellence relative to competitors. The importance of management is well recognized; Chandler (1990) has already stated that while a company leads its own life beyond its individual executives and while technological and market requirements limit its development, a company’s health and efficiency in meeting its economic functions are almost always dependent on the talent of its managers.

In covering and remaining with this essential function, management personnel attitudes have evolved and boundaries strategies emphasize the importance of governing relational, organizational and technological factors. The skills and professionalism required from management personnel become more complex and articulated. Alongside typically technical knowledge, leadership, communication and relational abilities are emphasized and entrepreneurial attitudes become fundamental (Pearce, 2004).

The ability to capture weak signs, to anticipate the future, to spur innovation and to govern change is a key element of entrepreneurship with increasing enthusiasm for magnanimity (Dyer and Hatch, 2006). Management personnel must be able to manage a system of increasing complexity and of varied factors, giving rise to a harmonious combination capable of interpreting environmental and competitive dynamics. These include intangible factors and IT technologies that have had a considerable impact on management strategies in recent years. The strategic importance of intangible resources
depends largely on their limited reproducibility and incremental nature. Here, we refer to the abilities of most immaterial elements to simultaneously produce inputs and outputs of the production process. Most resources are consumed during production while intangible resources, rather than diminishing as a result of their use, when used well enhance or at least retain their potential (Hussi, 2004; Hussi and Ahonen, 2002; Teece, 2000).

Likewise, the establishment of “boundaries” in strategic processes draws attention to the deepening of the role played by information and specifically information technology as a factor that allows for the integration of elements that carry out critical tasks of resource linking and development while facilitating continuous isomorphisms of a given company and environment by means of strategic boundary management in the search for optimal competitive positioning.

The need for a set of technical, mechanical and informatics tools that can support a company’s information and knowledge needs has revealed a link between information technologies and information systems (Kern and Willcocks, 2000). Moreover, the study of the development of information technologies and specifically of their applications to the field of business shows how, in addition to offering information support for decisions, they are decisive in the traditional task of automating production processes and more recently in artificial intelligence and the development of modern and innovative interactions that characterize the relationship between a company and its environment (Powell and Dent-Micallef, 1997; Sher and Lee, 2004).

In any case, it is overwhelming that the management of intangible and relational capital and the strategic use of resources related to information technology are elements that are difficult to spontaneously realize. Their harmonic integration and progressive development within corporate settings must be achieved through wise, careful and forward-looking governance that views management as a privileged actor.

In line with the growing importance of boundary strategies, boundary management teams must express the increasingly urgent need to organize innovative relational systems (Brusoni et al., 2001). This effort must extend beyond classical business boundaries and must interpret new ways of managing processes that move resources from within to boundaries (e.g. issues related to the development of telework or the “internet of things”) and those that approach resources from the outside (e.g. the creation of inter-company networks or “big data analytics”).

The boundary manager is a communications expert who governs, organizes and controls the flow of information. The boundary manager must ensure that corporate communications internally, externally, commercially and operationally support the company’s mission and represent its values and culture. The belief that organizations are also supported by and take part in their systematics by sharing a culture and values that are somewhat homogeneous shows how the task of management ends up assuming a significant symbolic-communicational component and how important its leadership talents truly are.

Leadership and communicational skills in turn become indispensable and irreplaceable tools for overcoming conflicting antagonisms and interests and for achieving a convergence of goals that enable more people to interact in the pursuit of common economic goals (Denis et al., 2001; Dhanaraj and Parkhe, 2006; Dyer et al., 2001; Paulraj et al., 2008).

All of these considerations and the delicate role played by management teams are even more relevant to strategy development and to the governance of boundary relations, which is often characterized by weak links.

The boundary manager must be able to design and organize values, information flows, and operational processes to maximize organizational efficiency while ensuring a high degree of flexibility. Management teams must be able to exploit potentialities of the human system and to allow individuals to develop their creativity and to encourage their participation.
The boundary manager, to render the information system and the circulation of information effective, must organize the flow of information itself in a bidirectional manner to identify weak signals received from inside and outside. The need to deliver creativity and flexibility to the corporate system while maintaining stability implies the need to redefine interpersonal relationships, the role system, and control methods (Chenhall et al., 2011). Increasing levels of complexity require the careful management of organizational dynamics that in the absence of proper government action would end up creating dangerous centrifugal and conflicting situations.

Boundary management must, on the one hand, manage the delicate balance between inter-organizational relations, cooperation and collaboration with organizational repercussions of technological change and cultural evolution lead to and, on the other hand, integrate the various activities to ensure the coherence and harmony of production.

In other words, it must be able to overcome the trade-off resulting from the need to ensure the diversity and variance of the organizational system in promoting its creativity and flexibility, to enhance strategic-organizational development, and to limit the occurrence of centrifugal and conflicting situations with repercussions on the company’s economic viability (Dalton and Lawrence, 1970; D’Aveni, 2015; Dhanaraj and Parkhe, 2006; Kale et al., 2000; Lawrence and Lorsch, 1967).

Typical management and organizational issues of boundary strategies are above all represented by the difficulty of “controlling” organizations and individuals gravitating to the boundary area overtime and representing the strategies of strategically relevant resources (Berglund and Sandström, 2013; Katz and Kahn, 1966; Pfeffer and Salancik, 1978). To limit risks associated with dangerous centrifugal forces, with boundary variables and resources becoming external and competing with the company, there is a need to constantly seek arrangements that give relative cohesion to resources and boundary organizations often based on the ability to reach a strategic convergence of interests although starting from dissimilar and sometimes even apparently conflicting positions.

In any case, however, it is necessary to ensure and develop a sense of belonging in an organization to discourage dangerous opportunistic behaviors (Lado et al., 2008; Parkhe, 1991; Thompson, 1988; Williamson, 1996). Such physiological autonomy and flexibility in boundary relations emphasize the need for forms of cultural, strategic and operational coordination that are more advanced than traditional ones (Fronterre, 1991). Otherwise, bankruptcy risks become pronounced and the severity of effects on the company is proportionally correlated with the importance of tangible and intangible assets concerned.

Thus, how can organizations and subjects that are essentially autonomous combine specific interests and achieve “strategic consistency”? What are the main factors that ensure stability in the boundary relations? What factors control and govern coalitions?

Our analysis suggests that there are some strategic relevant factors for the management of boundaries. These factors are related to three highly related dimensions such as technological, cultural and relational (Table I). The boundaries management needs to

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<td>Weak signs capture and big data analytics</td>
<td>Sense of belonging</td>
<td>Linking actions</td>
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Table I. Strategic relevant factors for the management of boundaries
adequately consider these factors when confronting with multiple actors inside, outside and on firm boundaries. Specifically, it is easy to recognize the need for delicate relational activity involving compromise and negotiation that organizes, structures and formalizes in ways considered appropriate while supporting relationships of trust, opportunism, power and dependence. Hence, the next section introduces concepts and theories of the negotiation literature and relates these to the strategic literature to reflect on and discuss the need for negotiation capabilities within the realm of capabilities required for boundary management.

5. Negotiation for “boundary management”

The deepening of decision-making processes commonly known as “negotiations” has been always been considered dear to scholars of management, who have focused on strategic cooperation forged between companies and their stakeholders at large (e.g. Fisher et al., 1981; Komorita, 1985; Kramer, 1991; Lax and Sebenius, 1986; Lewicki et al., 1992; Raiffa, 1982; Walton and McKersie, 1965; Zartman, 1977). Mostly influenced by the fields of political science, organizational psychology and management, over the years, these studies have contributed to the construction of so-called negotiation theory, which has assumed the development of techniques and models designed to solve political problems as a primary target of investigation.

Management studies relating to negotiations have mainly focused on negotiation processes occurring between companies, customers, suppliers, and industrial relations. However, the vast majority of studies consider negotiation an individual activity rather than organizational activity, and even the few that recognize that organizations indeed negotiate largely fail to apply a systematic approach to the entire spectrum of negotiation activities while focusing on few functions and mostly on sales and purchasing (e.g. Borbély and Caputo, 2017a). Instead, the large collection of literature of political science has long acknowledged the role of institutional negotiation in describing how modern states negotiate (e.g. Zartman, 1977). Famous statements such as G.W. Bush’s note on not negotiating with terrorists have formed a negotiation culture or imprint that has fostered the ways in which the U.S. has negotiated thus far. Similarly, the CEO of budget airline Ryanair has consistently exhibited a negotiation-based attitude toward the take or leave it approach that has permeated the entire company (e.g. Borbély and Caputo, 2017b). However, most management studies assume that organizations do not negotiate and that only people do. However, it is clear that any organization wishing to negotiate effectively and efficiently must make a coordinated effort to develop negotiation capacities at the organizational level. For example, Borbély and Caputo (2017a) theoretically developed a framework for the development of organizational capabilities of negotiation in unveiling how organizations can develop a negotiation capability. As such, a negotiation capability development should be pivotal to the management of firm boundaries and particularly in contexts of rapid technological change given the need for continuous innovation through cooperation and coetition and given the quest for new markets.

In a global environment where the digital revolution has substantially enhanced the rate of competition, the literature agrees that cooperation strategies applied within company departments and between companies can often have a number of benefits, including improved levels of communication, stronger relationships between suppliers and customers, and process sharing (e.g. co-design and co-production). This scenario is significant when businesses, due to a lack of know-how or funds, can hardly self-generate the innovation needed to effectively respond to market needs.

Competitive positions are selected by companies acting as rational systems through choices made based on more strategic options. Scholars argue that several benefits can result from cooperation strategies such as a stronger communication, sharing processes such as those of co-design and co-production and closer interactions between suppliers
and customers. This has important meaning in a context in which a lack of know-how or funds renders innovation needed to efficiently address market needs can hardly be automatically generated by businesses.

An essential characteristic of cooperation activities is the negotiation process. Negotiation skills are improved and the ability to negotiate effectively is enhanced through negotiation processes that are crucial to political, managerial, and business contexts.

Negotiation theory, in its prescriptive form, arises as a synthesis between economic-mathematic and socio-psychological approaches. Two main studies can be considered landmark works: Fisher et al. (1981) study influenced by psychological and behavioral doctrines and Raiffa’s (1982) analysis based on game theory and the mathematical and statistical disciplines. The relationship between these works and Lax and Sebenius’ (1986) work has contributed to the adoption of negotiation theory in management.

Over the years scholars have debated ways to locate, expand, or even create a Zone of Possible Agreement, which can be represented by an Euler-Venn diagram and which is defined as the intersection set of sets representing several stakeholder interest configurations (Figure 1). This is done by determining the strategic manipulation of elements of a negotiating structure as the main method, which is defined as components and relationships between components forming the basis of negotiation as a joint decision-making process.

Three basic elements compose the negotiating structure: the parties involved, the subjects or issues under negotiation and preferences, and thus the interests and positions of the parties involved. Negotiations can be categorized according to these elements as follows. Regarding the number of parties involved: two negotiating sides can be distinguished (bilateral or dyadic) from negotiating with more parties or with multilateral ones (Raiffa, 1982). Parties can also be configured depending on whether they negotiate as an individual or as a group/organization or as an individual or collective. Regarding the number of issues involved, there are two different types: one-question negotiations and those covering more issues (Raiffa, 1982; Sebenius, 1983). Finally, on the configuration of interests, a distinction is made on the distributive from integrative negotiations. The first distributives are also known as win-lose (a fixed pie) and are configured for conflicting interests between parties. The latter distributives are defined as win-win (an expandable pie) due to the possibility of reaching an agreement that is satisfactory for all parties (Pruitt, 1981; Walton and McKersie, 1965).

In the management of firm boundaries, these three aspects play an important role in increasing the complexity of such negotiations; this is mainly attributed to the interdependence between the many parties involved. Certainly, scholars stress that multilateral negotiations often present very different dynamics of development from those of bilateral negotiations according to three dimensions: their larger size and higher levels of complexity and stronger diversity (Kramer, 1991).

Figure 1.
Representation of a generic ZOPA with the Euler-Venn diagram
Of the several parties involved in boundary negotiations, there are the heterogeneous ones with their own conformation of interests and issues. This complicates the process by broadening the scope of negotiations. For example, the blurred and interdependent systems of governance that interplay within the boundaries of a firm (Normann and Ramirez, 1993; Håkansson and Snehota, 2006) constitute at the same time a complexity factor as well as an opportunity factor for the negotiation taking place. The possibility for parties to form coalitions to influence the outcomes of negotiations represents a further source of complexity in multilateral negotiations recognized in the literature (e.g. Raiffa, 1992; Komorita and Kravitz, 1983; Murninghan and Brass, 1991; Polzer et al., 1998).

We propose that coalitions, for example, should be particularly critical for the management of boundaries where a firm must govern relationships in an efficient and effective fashion.

Integrative potential, which can be defined as an increase in the joint gain available to negotiators over and above the joint gain afforded by a fixed-sum solution, is included in many negotiation situations, and it is a primary topic of negotiation research as it concerns the achievement of integrative agreements. Integrative agreements can be made through the use of different specific negotiation strategies where several issues are considered or where several parties are involved (Sebenius, 1992). Thus, we argue that integrative negotiations are fundamental for successful boundary management, where several interests need to be jointly satisfied to exploit opportunities for competitive advantage.

Managers, as behavioral studies on negotiation and conflict resolution show, are often inefficient, and integrative agreements are not typically reached by them, although such agreements are frequently available, mutually beneficial, and therefore desirable (Moran and Ritov, 2007). The possibility of changing the game as a distinctive element of the negotiation process was first identified by Sebenius (1983, 1992), who argues how elements of negotiation structures, issues, parties, interests and positions change during negotiations. This issue can be considered an implicit and natural evolution of the process itself and can be tactically guided by parties involved. This manipulation, which is known as Negotiation Arithmetic, allows the elements of a structure to be changed by parties in a strategic manner and together with the adoption of conduct aimed at creating or claiming value allows, depending on the goal to be achieved by parties involved, the shifting of negotiations from distribution to integration and vice versa.

To create value by extending the range of potential agreements, the addition of issues that exploit differences in interests among parties involved can be considered a useful strategy. Likewise, this can complicate the negotiation process or destroy the possibility of solving other issues. The separation or setting aside of issues can simplify the negotiation process, but this can lead to complications in the achievement of agreements on other issues; in turn, there are trade-offs that must be evaluated.

Such interests and positions can be strategically manipulated by parties involved through appropriate actions (e.g. by linking issues) during or outside of negotiations (Lax and Sebenius, 1986).

The manipulation of the number of parties through the same negotiation or by external facilitators can be considered another potential strategic approach to the shift toward an integrated approach.

To reach an agreement and to spur a significant influence on the conduct of negotiations, the absence or presence of an interested party may be required. Clearly, complications in of negotiation process result from changes made to the number of parties and issues involved and especially in the case of an increase in abundance (Sebenius, 1983). Therefore, adding parties to a negotiation can be a successful choice only when this may materially influence the negotiation or realize tangible interests. Such parties are typically allowed to participate to reinforce existing coalitions or to help form one by leveraging links to new interests and
issues (Murningham and Brass, 1991; Polzer et al., 1998; Raiffa et al., 2002). On the other hand, the release of parties from a negotiation can occur to reduce information costs, to reduce the complexity of the negotiation process, or to forge agreements shared by most of the original participants (Lax and Sebenius, 1986, 2002; Sebenius, 1983).

Scholars have examined specific strategic negotiations rather than considering negotiation as a whole from a strategic point of view. Jemison and Sitkin (1986), in their study on the acquisition process as a determinant of acquisition activities and outcomes, argue that the importance of negotiating practices lies in the acquisition process with reference to the success of operations (and particularly with regard to the acceptance of operations by personnel). Indeed, dissatisfaction and low levels of productivity can result from a lack of transitional support (Jemison and Sitkin, 1986). Furthermore, controversial research has been conducted on acquisitions in relation to the reasons why well-designed acquisition processes fail; in this regard, strategic fit cannot be considered as the only variable. Other drivers of success include the process of negotiating acquisition and the integration of a target into the parent company (e.g. Dierickx and Koza, 1991; Jemison and Sitkin, 1986). Likewise, studies show that joint venture negotiations differ from those of cross-cultural businesses because levels of firm motivation, project longevity, and resource commitment are different in the case of this form of negotiation (Luo, 1999; Luo and Shenkar, 2002), revealing a pattern in organizational behavior and especially with reference to contract negotiations (Lee et al., 1998; Luo, 1999; Luo and Shenkar, 2002).

Dierickx and Koza (1991) argue that individuals with prior negotiation experience should have an easier time managing information asymmetries and thereby achieving their strategic objectives such that information asymmetries can be considered endemic to merger and acquisition negotiations; similarly, they always exist during negotiations.

Recently, institutional studies have drawn a similar link between negotiation and strategies with the importance of negotiations in institutional settings being found to be useful in understanding dimensions of organization behaviors in negotiations (Helfen and Sydow, 2013; Helms et al., 2012). Scholars highlight that new practices sometimes arise “from the efforts of numerous and different organizations that work together to negotiate a settlement on a new institutional arrangement (trade associations, e.g. working to develop novel industry standards)” (Helms et al., 2012, p. 1120). The imprint of organizational culture appears through negotiations even when it is believed that “organizations do not negotiate, individuals do” (Sydow et al., 2009). Negotiation strategies of unions or institutional organizations are typically quite consistent regardless of changes made by the negotiating team, showing some form of institutional movement behind individual practices. The organization acts as an individual entity that brings issues and interests to the table, causing such strategies to represent behaviors of the organization itself (Helms et al., 2012; Weiss, 1990).

As noted above, negotiation plays an important role in the effectiveness of boundary management. Negotiation capabilities developed by boundary managers can favor information sharing (Aldrich and Herker, 1977), knowledge flows (Patriotta et al., 2013; Tushman and Scanlan, 1981), and conflict resolution (Schotter and Beamish, 2011). However, in the new competitive contexts created by a strong digitalization and expansions of the firm boundaries, how can organizations develop a negotiation capability in support of effective boundary management?

The recently developed OMoN (Borbély and Caputo, 2017a) can support the answer to such question by drawing attention on where a negotiation capability can be created. The OMoN model consists of four levels (individuals, linkages, infrastructure and organizational capabilities) and prescribes stages for developing a negotiation infrastructure (Figure 2). The OMoN theoretically assumes that when it is applied to a company strategy, in our case a boundary strategy, it can ensure consistency in
negotiations, hence improving the competitive advantages of a firm. Its application to the management of boundaries can be highly beneficial in supporting coordinated actions among actors who come into contact along boundaries.

The first level of the model is the individual level, which relates to the training and development of firm employee negotiation skills (Borbély and Caputo, 2017a). Stemming from the vast body of organizational psychology research investigating how people negotiate, this level concerns how boundary actors interact at the negotiation table. Variables to take into consideration at this level include characteristics of negotiations and their performance, processes and outcomes; satisfaction levels and the ethical views of negotiators. Successful boundary managers should, therefore, be conscious and knowledgeable about the behavioral aspect of negotiation. For example, they could put in place appropriate training and development actions for employees involved in boundary management that allows for integrative negotiations to take place.

The second level of the model considers linkages, which relate to the development of a system of negotiations within an organization (Borbély and Caputo, 2017a). In particular, this level prescribes how an organization should understand how different individual negotiations that take place impact one another. As such, previous negotiations are considered to serve as a context for subsequent negotiations, spurring the path-dependent evolution of how an organization negotiate. The boundary manager should be, therefore, aware of the interdependence among different negotiations taking place within the boundary and support effective knowledge exchange, through business processes, that allow to leverage on collaboration, trust and reciprocity. Variables to consider at this stage include the histories of previous negotiations, the contexts of negotiations, levels of situational awareness and how knowledge and experience are shared among employees and managers. It is fundamental for the management of boundaries to promote an environment of trust within boundaries to allow for information sharing. For example, interventions should take place to raise awareness of the benefits of relationships occurring along boundaries.
The third level of the model is the infrastructure level, which relates to the development of an organizational infrastructure in support of negotiations (Borbély and Caputo, 2017a). This level is concerned with the organization of a negotiation function that improves the efficiency and consistency of negotiations. In boundary management, this could be assimilated to a formal knowledge management system for negotiations, designed with a variable geometry that allows it to be dynamically opened to different actors in the boundary, even if external to the organization. Variables covered at this level include infrastructure characteristics, management practices, incentive systems, KPIs, and the transferring of knowledge.

The fourth level of the model is the capability level, which relates to the development of negotiation as a strategic resource (Borbély and Caputo, 2017a). It is concerned with the strategic understanding of negotiation as a major source of competitive advantage in the boundary management, making the negotiation capability a pillar of the boundary management capability. Variables to be considered at this level may include organizational performance, upper management commitment and idiosyncrasies found between organizations.

6. Conclusions
From a business processes perspective, the paper examined the role of boundaries in the new political and technological landscape. Our analysis suggested that in digital supply chains, boundary management and negotiation should be developed as key capabilities in aligning and integrating complex networks of partners interacting along firm boundaries.

We exhibit how the digital transformations of our time are creating new competitive contexts, such contexts are having a major impact on firms and business processes, making the boundary of the firms dynamic, expanding and more blurred than in the past. It is therefore necessary for managers to understand these dynamics and move the perspective from the boundary of management to the management of the boundaries, which should be done by developing a boundary management capability. This capability relies upon the opportunities provided by the digital transformation and includes as its pivotal part a negotiation organizational capability, which allows for a more effective and proactive management of the boundaries (Figure 3).

Figure 3. An explicative framework for boundary management
Our findings show that the choice to consider boundaries as the basis of a strategy promotes the design and management of business processes from a broader perspective. In using this perspective, firms should develop new capabilities (e.g. boundary management) to effectively connect firm value chains to those of “partners” (Schotter et al., 2017). Specifically, negotiations should deeply impact flexibility/performance outcomes (Caputo et al., 2018).

In the context of digitization, we provide theoretical and managerial contributions to three main areas of the literature and a first attempt of integration of these three bodies of work together. First, from a theoretical point of view, we contribute to studies on BPM. We develop a matching framework for studying BPM by applying a perspective on firm boundaries that explicitly considers key features of negotiation (Fiorentino, 2016). In competitive contexts where digitalisation and intelligence are emerging, boundary management has become relevant as a means to affect the future development of business processes. Based on our findings, firms should increasingly determine whether business processes flexibly support partnerships by forging their own boundary capabilities or by “plugging in” to partners’ capabilities (Luvison and de Man, 2015; Niesten and Jolink, 2015).

Second, we contribute to studies on supply chain management. Digitalization has spurred value creation managed in the firm “periphery” and in interfirrm relationships (Kumar et al., 2016). We suggest that to overcome limits of traditional supply chain models, which generally involve rigid organizational structures, unapproachable data, and disjointed relationships with partners, firms should develop boundary capabilities such as those of boundary management. A critical question facing supply chain managers who seek to benefit from boundary capabilities concerns ways to face the complex relationships of firm boundaries. Negotiations can drive a transition from the “current view” of supply chains to a “future vision” of digital supply chains to enable automation, flexibility and partner management (Papadopoulos et al., 2017).

Third, we contribute to strategic negotiation studies. We find support for extending the OMoN model to the management of boundaries (Borbély and Caputo, 2017a). This extension offers useful insights to scholars of negotiation, a very new field of management, in proposing opportunities to adapt and deepen current frameworks of specific research domains.

Practical implications of our study include the need for managers to ask questions, such as: How are we placed on the various levels of the OMoN? Which stages may prove useful in developing the targeted negotiation infrastructure? How can partners be persuaded to approve of boundary strategies used and of processes of digital transformation? More generally, managers may benefit from our propositions by reflecting on how boundaries are impacting their business and how they can manage both the current impacts and the future ones. A first action for managers interested in developing a boundary management capability would be to develop a role into the organization for a boundary manager, who oversees the business processes on the boundaries, assesses skill needs and implements appropriate trainings, develops an infrastructure that exploit the benefits of digitalization in fostering collaboration and trust among the boundary actors.

Future studies may empirically develop our work from the existing literature. Our findings suggest that digitization should transform boundary management systems, supply chains and negotiation patterns. Future studies may pose “where” and “how” questions.

Scholars of BPM may extend our framework to explore the effects of subcomponents of boundary capabilities and negotiations to better understand subtle effects on business process performance and partner management. Empirical studies should test our conceptualization and apply our framework to specific cases. In addition, future studies should explore how digitalization is being used in boundary business processes, how digitalization has transformed boundary resources and capabilities, and how these shifts may continue to manifest in the future. Similarly, another promising avenue for future
research is the further investigation of the knowledge gaps related to boundary management (in terms of challenges, value, data, etc.) and negotiation (in terms of organizational, skills, capabilities, and processes). Moreover, our study should promote the investigation of new challenges of boundary management in relation to digital supply chains. Studies should discuss ways to identify opportunities and risks related to the management of big data along firm boundaries. Specifically, reflections drawn from this paper may trigger scholars to investigate the role of data generated from increasingly broad boundaries that characterize contemporary firms. As such, questions related to data protection and cybersecurity and especially in the light of recent scandals that have affected Facebook and Cambridge Analytica may serve as another line of investigation. Similarly, ethical concerns related to the management of boundaries may offer interesting avenues for future research. The management of information and data sharing across and within boundaries must be ethical and carefully managed between partners. Companies developing boundary management capabilities must consider ethical issues related to data protection and storage, as data are increasingly becoming of strategic importance as a shared environment with decisions to be made on the access and ownership of such information.

Finally, the findings of this study may be extended to inform negotiation research on which factors affect partner selection and negotiation. In particular, studies may focus on the implications of boundary management for human skills, as well as training and development. Future studies with this focus could examine changes affecting skills needed to engage in negotiations along boundaries and what this may mean for negotiators. Such studies may examine whether negotiators must become data scientists or analytics experts, whether the rate of skills obsolescence is expected to increase or ways to use digital data to drive boundary management in negotiations as a profitable line of investigation.

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Further reading


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Intelligent autonomous vehicles in digital supply chains
From conceptualisation, to simulation modelling, to real-world operations

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Abstract
Purpose – The purpose of this paper is twofold: first, to discuss key challenges associated with the use of either simulation or real-world application of intelligent autonomous vehicles (IAVs) in supply network operations; and second, to provide a theoretical and empirical evidence-based methodological framework that supports the integrated application of conceptualisation, simulation, emulation and physical application of IAVs for the effective design of digital supply networks.

Design/methodology/approach – First, this study performs a critical review of the extant literature to identify major benefits and shortcomings related to the use of either simulation modelling or real-word application of physical IAVs. Second, commercial and bespoke software applications, along with a three-dimensional validation and verification emulation tool, are developed to evaluate an IAV’s operations in a conceptual warehouse. Third, a commercial depth-sensor is used as a test bed in a physical setting.

Findings – The results demonstrate that conceptual and simulation modelling should be initially used to explore alternative supply chain operations in terms of ideal performance while emulation tools and real-world IAV test beds are eminent in validating preferred digital supply chain design options.

Research limitations/implications – The provided analysis framework was developed using literature evidence along with experimental work and research experience, without consulting any industry experts. In addition, this study was developed based on the application of a single physical device application as a test bed and, thus, the authors should further progress with the testing of a physical IAV in an industrial warehouse.

Practical implications – The study provides bespoke simulation modelling and emulation tools that can be useful for supply chain practitioners in effectively designing network operations.

Originality/value – This work contributes in the operations management field by providing both a multi-stage methodological framework and a practical “toolbox” for the proactive assessment and incorporation of IAVs in supply network operations.

Keywords Intelligent autonomous vehicles, Conceptualisation, Simulation, Emulation, Depth-sensor application

Paper type Research paper

1. Introduction
The digitalisation discourse in the manufacturing landscape motivates advancements in intelligent vehicles (Scarinci et al., 2017) and further fuels growth opportunities stemming from the utilisation of autonomous production and distribution systems across supply chain operations (Bechtsis, Tsolakis, Vlachos and Iakovou, 2017). Innovations in the information
technology field and particularly the incorporation of Internet of Things technologies can guide the design of digitally-driven business processes with improved performance (Ferretti and Schiavone, 2016); however, the selection and implementation of intelligent autonomous vehicles (IAVs) in actual industrial settings requires effective strategic planning owing to the involved operational complexities and significant capital investment considerations (Chen et al., 2017). In the light of such intricacies, operations research and management science scholars explore and devise a range of modelling techniques that could inform stakeholders about the operational (Ji and Xia, 2010) and financial (Kavakeb et al., 2015) aspects of the associated strategic decision over the adoption of IAVs. However, the existing modelling approaches about IAV systems myopically focus either on subjective conceptual designs or fragmented mathematical programs and simulation applications, hence failing to comprehensively tackle a spectrum of realistic challenges, especially at the operational level (Mourtzis et al., 2014). Therefore, in this digital and smart manufacturing context, the objective of the present research is to support the effective integration and efficient use of vehicle automations in supply chain operations through providing a methodological framework that informs stakeholders about the integrated conceptualisation, simulation and emulation modelling, assessment and implementation of IAVs towards establishing digitalised supply networks.

Concept generation and evaluation are critical processes in the design of intelligent supply chain operations; however, conceptual evaluation of engineering systems is governed by great subjectivity (Moulianitis et al., 2018). In this sense, simulation of IAVs in supply chain operations is essential to objectively model and proactively assess network performance under a gamut of possible scenarios (Lu et al., 2017). General purpose and commercial off-the-self software tools and platforms enable simulation modelling and analysis of production and distribution processes, along with the involved entities, in diverse industrial application cases (Ali et al., 2014). Nevertheless, simulation modelling cannot capture the detailed and complex interactions among global supply network entities (Dias and Ierapetritou, 2017), while bespoke simulation packages that enable the modelling of realistic non-standard vehicle components and industrial manufacturing level configurations are still limited (Briggs et al., 2017). In this regard, the development of three-dimensional (3D) validation and verification emulation techniques, which could be used to “mirror” the utilisation of IAVs in industrial manufacturing and distribution operations (Sharif and Sadeghi-Niaraki, 2017), are motivated. Emulation offers most simulation advantages while further benefiting from tight control of implementation and a certain degree of realistic results (Sharif and Sadeghi-Niaraki, 2017).

The merit of using conceptual designs and simulation in tandem with emulation to proactively evaluate business operations is evident, but the application of physical IAVs is nonetheless essential to assess and validate a corresponding intelligent system’s appropriateness on specific operational settings and justify the associated capital investment (Briggs et al., 2017). However, typical simulation and emulation modelling and analysis approaches cannot reveal IAV-related management and coordination challenges at shop floor level (Pacaux-Lemoine et al., 2017). Indicative challenges include the inability of a human vehicle (e.g. forklift) operator to have an overview of the entire manufacturing system, the real-time constraints, and the machinery or shuttles’ technical failures that are not captured by standard simulation and emulation modelling solutions. Except for the operational impact, challenges regarding an intelligent system’s technical aspects are critical and need to be considered in real-word settings as they could result in major financial and safety repercussions (Shi et al., 2017).

Notwithstanding the evident need for the conceptualisation, simulation, emulation and experimentation of IAV systems, prior to their real-world industrial-scale implementation, such integrated analysis is often neglected due to either the lack of specific knowledge over existing technology capabilities and requirements or the misconception of gaining immediate
competitive advantages by adopting such technologically advanced applications. The limited volume of the related published literature (Briggs et al., 2017), especially over autonomous applications in the non-automotive sector, highlights the underlining ambiguity and complexity of the issue under study.

This research presents a theoretically and empirically derived multi-stage methodological framework for the integrated conceptual design, simulation modelling, emulation development and deployment of physical test beds (as hardware components of automated vehicles) for the efficient incorporation of IAV systems in supply network operations. In particular, the aim of the present research is to exemplify critical issues and guide academics and practitioners alike towards the effective integration and efficient use of vehicle automations in supply networks, by attempting to answer the following research questions (RQs):

**RQ1.** What are the benefits and shortcomings associated with the application of either simulation modelling or real-word application of physical IAVs?

**RQ2.** Which theoretically and empirically-driven methodological framework could support the effective evaluation and integration of alternative IAV technologies in digital supply chain operations?

**RQ3.** How plausible is the application of the proposed methodological process?

The above RQs are critical to be addressed, since smart manufacturing and distribution systems are regarded as the ideal technological solution in a range of network operations across diverse economic sectors (Bechtis, Tsolakis, Vouzas and Vlachos, 2017); however, the appropriateness of such intelligent technological approaches for the effective design, planning and execution of end-to-end supply chain operations has not been validated yet. Especially, the answer to **RQ1** will compare the benefits and disadvantages related to simulation modelling and real-world applications of physical IAVs. Following that, **RQ2** will provide a theoretically and empirically derived multi-stage process that guides the analysis and effective integration of IAV systems in digital supply chain operations. Finally, as the proposed multi-stage methodological framework is defined by the answer to **RQ2**, we tackle **RQ3** as we conceptualise, analytically model, simulate and emulate an IAV to the case study of a conceptual warehouse while we apply a commercial sensor, as a test bed, to an actual cold storage facility.

This paper follows a multi-method approach to answer the aforementioned questions. More specifically, literature findings along with empirical evidence and experimental results are utilised to address both **RQ1** and **RQ2**. Following that, the analysis of conceptual modelling, simulation and emulation scenarios, along with the real-world application of a commercial depth-sensor camera, demonstrate the applicability of the proposed multi-stage process and help to address **RQ3**. Overall, the abovementioned research activities yield useful findings which provide answers to the enunciated RQs and unveil a plethora of future research potentials.

The remainder of the paper is structured as follows. Section 2 sets out the terminology, theoretical lens and materials and methods that underpin this research. Section 3 explores the existing research on information technology enabled innovations to support supply network operations, focussing mainly on automated guided vehicles, a well-established class of transporters preceding IAVs. In Section 4, we critically discuss the advantages and disadvantages associated with the use of either simulation or physical autonomous vehicles in a supply chain context. In this regard, in Section 5, we explore the synergistic value of these analysis approaches by conceiving the design along with developing simulation and emulation models, and implementing a real-world sensory device, as a test bed, to the case of an actual warehouse. This four-stage analysis assisted in yielding experimental evidence-based findings that can promote the effective integration of IAVs in supply chain operations. In Section 6, we propose a multi-stage methodological framework for the integrated use of conceptualisation, simulation, emulation and physical test bed application...
of sensory equipment on the design and planning of operations in digital supply chains. The proposed methodological process is driven by both theoretical evidence and our empirical and experimental research related to autonomous vehicles. Critical evaluation of the study findings along with conclusions, limitations and future research potentials are discussed in the final Section 7.

2. Materials and methods

The object of scrutiny in the present study is multi-faceted, including: synthesis of the extant literature (Aivazidou et al., 2016); system identification and conceptualisation (Carter et al., 2015); simulation modelling (Min and Zhou, 2002); emulation (Ko et al., 2010) and real-world experimentation with visual perception equipment (Shi et al., 2017). The rationale of such a multi-faceted process is to achieve a coherent multi-dimensional construct about the complex subject under study (Espinasse et al., 2000). The basic terminology, theoretical lens, research approach relevant to this study are specified in the subsections that follow.

2.1 Basic terminology

Considering that the focus of this research is system conceptualisation, simulation, emulation and application of physical IAVs, it is necessary to define the meaning of the terms in this context. Therefore, adopted definitions for the purposes of this research are described below.

In the supply chain management field, operations research and management scholars need to tackle a range of strategic, tactical and operational challenges within and between network actors (Hennies et al., 2014), such as, sourcing strategies and resource planning, production and lead time planning, inventory management and information sharing. In this regard, conceptual modelling is the first step to define a specific problem under investigation and mentally perceive systems’ functions and related business process solutions that can later facilitate the development of supporting software tools and platforms (Aguilar-Savén, 2004). Conceptual models are, thus, simplistic formalised descriptions in diverse forms, such as supply network maps, pictorial representations or process diagrams (Settanni et al., 2017).

Furthermore, simulation has emerged as a prominent approach to limit subjective evaluation and address a variety of problems in the supply chain management arena. The definitions of simulation that are most relevant, and which are being adopted, to this study, are: “Simulation modelling and analysis is the process of creating and experimenting with a computerised mathematical model of a physical system” (Chung, 2004), and “Simulation is the imitation of the operation of a real-world process or system over time. Simulation involves the generation of an artificial history of the system, and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system that is represented” (Banks et al., 2000).

Moreover, the concept of emulation, especially for the case of vehicles, has been significant in the development of generic test prototypes (Lee, 1995). The tools which comprise of software and hardware layers to perform the simulation and mimic the behaviour of real-life systems are typically known as emulators (Prieto-Araujo et al., 2015). The software layer is used to simulate the represented system’s variables under the same real-world conditions, based on both static and dynamic operations. Following that, the hardware layer imposes the software simulated variables, by means of electro-mechanical machinery, to represent the real-world system behaviour. This definition implies that any system could be emulated. However, the present research mainly focuses on analysing the emulation structures that are used to represent IAVs in intra-logistics operations.

Finally, IAVs can be defined as vehicles that can navigate in space without pilot assistance (Loureiro et al., 2012). The intelligent automated guidance is typically achieved
by (Bahnes et al., 2016): first, environmental context awareness, through cameras, radars or other embedded sensors, and second, interpretation of the retrieved sensory data into possible manoeuvres, through analysing and compiling a list of possible actions.

2.2 Theoretical lens

The present research adopts the systems view of operations research, outlined by Sagasti and Mitroff (Sagasti and Mitroff, 1973), as a theoretical lens. The research model proposed in Sagasti and Mitroff (1973) is used as a reference to capture the dynamic behaviour of complex operational elements at each supply chain echelon, that could then inform methodological discussions in the operations management domain (Bertrand and Fransoo, 2002). More particularly, several techniques have been introduced for the evaluation of intelligent applications in a supply chain context, including conceptual design, analytical modelling, simulation, emulation, test bed application and real-world experimentation (Sharif and Sadeghi-Niaraki, 2017). In this sense, the fundamental dimensions to enable the transition from conceptualisation and simulation modelling to real-word application and assessment of IAV systems were derived from the research model suggested by Sagasti and Mitroff (1973), as depicted in Figure 1. The operations research process transition grid in Figure 1 begins with an understanding of a conceptual model in the form of supply network maps and mathematical programs. An IAV system’s modelling and performance evaluation at each of the subsequent simulation, emulation, test bed and actual implementation phases requires proportional engagement to the cyber and real space.

Figure 1. Operations research process transition grid

Source: Adapted by Sagasti and Mitroff (1973)
2.3 Research approach

The main objective of this research is to support academics and practitioners alike towards integrating intelligent distribution systems across supply chain operations by specifically providing a methodological framework that supports the effective modelling, assessment and implementation of IAVs in digital supply networks. Ideally, the experimentation and testing of physical IAVs would be preferable; however, key challenges like considerable capital requirements and technical complexities inhibit extensive real-world investigations (Browne et al., 2012). In this regard, the first methodological step in this research is to conduct a literature review to recognise the dichotomy that impedes the effective integration of IAVs across supply network operations and to identify major research and business-related advantages and challenges. At a second stage, we elaborate software platforms and develop both simulation and emulation-based tools to empirically examine IAVs in supply network operations and/or verify/reject the literature findings. Finally, the third methodological step includes the real-world application of a sensory device as a test bed that could be used to navigate an IAV to perform specific intra-logistics operations. Overall, we follow the workflow structure described by Sharif and Sadeghi-Niaraki (2017) for the case of ubiquitous computing technology and we specifically focus on the conceptualisation-simulation-emulation-test bed nexus.

In particular, at a first stage, the object of scrutiny is secondary research. To ensure a high scientific integrity, the extant literature review comprises articles retrieved from the Scopus® of Elsevier and Web of Science® of Thomson Reuters databases. These databases were selected as they capture a wide range of peer-reviewed journals, especially in the fields of Natural Sciences and Engineering (Mongeon and Paul-Hus, 2016). The following Boolean query was formulated to content search for secondary scientific studies:

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(intelligent autonomous vehicles) AND (supply chain OR supply network) AND (manufacturing)
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The authors utilised the “Article Title, Abstract, Keywords” categories in Scopus® as well as in Web of Science® while the timespan was set from “All years” to “Present”. The analysis was limited only to contributions which investigate both simulation and real-world implementation aspects of IAVs to capture integrated views about the issue under study. Additionally, all reviewed studies are written in English. To increase consistency, all retrieved papers were counter-checked. Pertinent references cited in the retrieved papers were used as secondary sources for complementing the literature review and better reflect the emerging theme. By 8 November 2016, the refined search yielded 13 research papers, 10 of which were retained for review. The number of the retrieved contributions is judged sufficient as our intention is to identify key benefits and shortcomings associated with simulating and actually implementing IAVs to further motivate our empirical research. An extensive literature review is out of the scope of the present research.

Second, following the identification of the research dichotomy, we use simulation and emulation modelling approaches to create interfaces between the cyber space and the real space, and further facilitate the study of IAV-to-environment interactions. Software applications provide the capability to recreate real-world systems in the cyber space to such a degree that today “cyber space is becoming a part of our real space” (Sharif and Sadeghi-Niaraki, 2017). This confluence of cyber space and real space generates opportunities for performance evaluation of applications, protocols and algorithms in diverse economic sectors. In order to increase the consistency and robustness of our study findings, we developed our simulation models through using both commercial off-the-self software and bespoke applications.

Third, we apply a depth-sensor camera, as a physical test bed, to allow experiments and also support the evaluation of both the simulation and emulation models developed here. Generally, test beds are reported to bridge the gap between simulation and real-world deployment of physical devices (Kiess and Mauve, 2007).
3. Information technology in supply chain management
Advancements in the information technology field have fuelled the prominent appearance of IAVs in industrial supply networks (Van Brummelen et al., 2018). In this regard, in the subsections that follow we first examine the evolution of information technology enabled innovations in supply chains. The historical background is followed by the analysis of information technology focussed studies that specifically investigate the adoption of automated guided vehicles in supply network operations. The review focusses on automated guided vehicles as they refer to a well-established and extensively-studied class of transporters which precede the technologically superior IAVs.

3.1 Evolution of information and communication technologies
Information and communication technology is an integral part of supply chain management systems that supports the effective integration of industry network processes, from an end-to-end perspective, hence providing value to customers and stakeholders (Gunasekaran and Ngai, 2004). Initially, during the second supply chain evolution era (often referred to as the “Integration Era”, 1960s–1990s), business stakeholders elaborated on the electronic data interchange prototype as the innovative information-based technology to facilitate transactions across supply networks (Jain et al., 2010). Enterprise resource planning systems have descended from electronic data interchange tools and are supported by technological breakthroughs, such as the World Wide Web, Cloud Computing and Internet of Things. To this effect, information-based systems enable the provision of advanced visibility and traceability services to the supply chain ecosystem (Helo and Szekely, 2005; Wu et al., 2013), specifically facilitating the control of critical upstream and downstream information flows to improve supply chain performance (Vanpoucke et al., 2017). Considering the catalytic role of information and communication technologies towards supply chain innovation and competitiveness (Gunasekaran et al., 2017), strategic decision-making processes support the adoption of information-based technologies (Qrunfleh and Tarafdar, 2014) to promote new growth opportunities (Fosso Wamba et al., 2015).

3.2 Automated guided vehicles in supply chain operations
Information technology provides the digital layer to enable information flow integration and collaboration across different vendors and legacy systems over global supply chains. Automated guided vehicles enable the translation of these information flows into actual supervision and real-time control of material flows in industrial supply networks (Hsu and Wallace, 2007), thus further enabling the development of flexible manufacturing systems (Viswanadham, 2002). To this effect, automated guided vehicles enhance the efficiency of material handling processes while reducing time and cost of performed operations (Zhang et al., 2017). Indicatively, advanced planning, execution and manufacturing information technologies supported by automated staging systems allow BMW, a major German automobile manufacturer, to control the necessary material flows and manufacture customer-specified vehicles (BMW Motors, 2004). Generally, automated guided vehicles pioneered the integration of a variety of advanced information-based technologies to enhance manufacturing and supply chain efficiency, thus, enabling the realisation of direct economic and social benefits at an operational level (Tu et al., 2017).

4. IAVs: a research dichotomy
The effective incorporation of IAVs in a digital manufacturing and supply chain context is a complex process that requires background scientific knowledge with regards to conceptual designing and supply chain mapping, mathematical programming and analytical problem
solving, discrete-event simulation modelling and 3D emulation tools’ development. Following that, prototyping and testing of physical equipment and IAV systems should be performed to validate the developed scientific models and verify the generated research results. To this effect, the interoperability of intelligent vehicles with existing infrastructure, personnel, resources, information systems and communication protocols is ensured for delivering increased efficiency and effectiveness in supply chain operations.

Considering the inherent limitations governing each of the aforesaid analysis approaches for IAVs, a combined implementation of research skills and methods is recommended to proactively assess and thus better inform the IAVs-centric decision-making process at strategic, tactical and operational levels (Bechtsis et al., 2018). To the best of our knowledge, analysis approaches are often myopically applied in functional silos within single institutions and organisations, hence leading to suboptimal decisions. On the one hand, several researchers and academics tend to focus on sophisticated data-driven analysis approaches aiming to unveil academic contributions whilst often neglecting any practical and/or technical implications of IAVs on the physical structure of a supply chain. On the contrary, part of the academic and research community lays great emphasis on the actual application and proven functionality of innovative technologies, hence overlooking the potential inferences and greater impact of IAVs on the supply chain management field. In this sense, this observed research dichotomy underlining the analysis of IAVs along with a discussion of key associated advantages and limitations identified in existing research efforts are provided in the following subsections. We specifically focus on the interfaces between conceptualisation/simulation modelling and emulation/testing of physical equipment and other IAV system-specific entities as these analysis approaches are prevalent in current research developments, globally.

4.1 From conceptualisation to simulation modelling

In today’s digital epoch, simulation-based analysis approaches are a focal point in terms of experimentation, validation and verification of alternative network configuration options in the industrial manufacturing and distribution landscape (Mourtzis et al., 2014). At preliminary analysis stages of an IAV’s operations, simulation modelling allows for the fast representation of the physical counterpart (Briggs et al., 2017), under limited data availability, which can support the often time-consuming and funding-constrained decision-making process. In this sense, simulation allows for the assessment of an IAV system’s techno-economic feasibility at a strategic/tactical/operational horizon under risk management, cost estimation, manufacturing and distribution planning considerations (Uzzafer, 2013). Simulations can also assist in capturing an intelligent vehicle’s efficiency in terms of mean values of selected key performance indicators (Bietresato et al., 2012) with regards to diverse manufacturing and distribution operations (Schmidt et al., 2015). In the particular case of intra-logistics operations, simulation results can indicate the optimal facility layout configuration in terms of accomplishing certain objectives (e.g. minimum operational cost, maximum service level) for a specified intelligent fleet capacity (Cardona et al., 2015). A key contribution of simulating IAV systems in manufacturing and distribution operations refers to the resulting reduction in a vehicle’s development time and cost, while the identification and elimination of any conflicts, deadlocks and integration risks is detrimental (Hsueh, 2010).

Despite simulation enabling the facile symbolic representation and analysis of industrial manufacturing systems and entities, commercial off-the-shelf software often provide limited flexibility in developing accurate and customised models of the corresponding IAVs’ operations. Moreover, commercial software packages typically contain in-built libraries of manufacturing and distribution systems’ components
which might be either outdated, meaning that the software package contains databases of obsolete equipment, or limited in terms of range of covered equipment. Consequently, these limited parameterisation capabilities render the modelling of novel IAV systems challenging, thus, leading to a gamut of non-realistic assumptions. In addition, particularly for distribution operations, simulation drive cycles do not usually consider hoisting, tilting and lifting operations that could impact the performance of an entire supply system (Briggs et al., 2017). In this regard, simulation models cannot capture the majority of dynamic operating conditions (Wu et al., 2008), like for example fuel cell consumption in electric vehicles (Schell et al., 2005) or a driver’s response to disruptions during material handling and navigation operations (Seelinger and Yoder, 2006). A key drawback of existing software tools and platforms is that individual simulation modelling approaches cannot capture the different time scales of operations performed both horizontally and vertically across a supply system so as to inform about the optimal planning and scheduling of IAVs (Garcia and You, 2015). From a technical viewpoint, computational/processing power could be a practical constraint (Mourtzis et al., 2014). Table I presents a synopsis of the main advantages and limitations associated with the myopic use of simulation modelling towards capturing and evaluating IAVs in supply network echelon-specific operations, as justified by relevant research efforts.

4.2 From emulation to physical entities’ application

While simulation tools have reached an adequate level of maturity and can be even used to emulate 3D real-world robotic/machinery functionalities, the physical IAVs’ experience is,

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<td>2. Minimises potential IAV operational-related risks</td>
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<td>3. Allows feasibility assessment of different IAV scenarios at a strategic/tactical/operational horizon</td>
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<td>5. Enables rapid understanding about IAV’s operations, under limited data availability</td>
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<td>6. Identifies improvement opportunities in facility layout configurations accommodating IAVs</td>
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<td>3. Provides limited flexibility in accurately capturing actual IAVs’ dynamic operations</td>
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<td>4. Requires sophisticated data and non-realistic assumptions to capture and model the actual operations of IAVs</td>
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<td>5. Provides limited capability to model novel IAVs in detail and validate the models</td>
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<td>6. Requires significant computational/processing power</td>
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**Table I.** Key advantages and limitations of the exclusive use of simulation in evaluating IAV’s operations, across supply chain echelons

**Notes:** Contributions: (1) Zulkifli et al. (2017); (2) Babić et al. (2012); (3) Watanabe et al. (2001); (4) Berger and Rumpe (2010); (5) Fazlollahtabar et al. (2015); (6) Berman et al. (2002); (7) Samu et al. (1996); (8) Albus et al. (2008); (9) Draganjac et al. (2016); (10) Watanabe et al. (2000)
nonetheless, indispensable in industrial manufacturing and distribution environments. In principle, the real-world experimentation and testing of physical intelligent vehicles allows four key functions to be performed (Kim and Kim, 2017), under complex environmental conditions, namely: sense; perception; cognition; and behaviour.

In general, IAVs can operate on a 24/7 basis without human intervention, thus promoting labour cost savings, while they associate to lower maintenance cost compared to conventional vehicles (Bechtsis, Tsolakis, Vlachos and Iakovou, 2017). Furthermore, IAVs provide increased safety levels in a workplace that might be challenging to simulate under dynamic working conditions and perturbations, especially for the case of hazardous environments (Vale et al., 2017). The emerging trend towards the adoption of IAVs in supply chains is nonetheless mainly motivated by the associated increased accuracy and productivity (Lu et al., 2017), which is challenging to evaluate with existing conceptual designs, analytical models and simulation techniques.

The capital expenditure required to develop/acquire, install and operate IAVs is a significant factor that greatly impacts the total cost of a manufacturing facility (Kavakeb et al., 2015), at least for heavy duty and customised vehicles designed to perform specialised logistics operations. In this vein, installation and standardisation of supporting facility infrastructure (e.g. parking and charging stations, communication centres) could have practical along with capital and maintenance cost ramifications (Chen et al., 2016), especially for the case of an electric vehicle fleet. In addition, considering an intelligent vehicle's dimensional specifications, along with the dimensional and geometrical characteristics of possible carrying load volumes, an IAV's navigation might require modifications in a workplace's layout to further allow the realisation of the necessary routing trajectories (Martínez-Barberá and Herrero-Pérez, 2010). To this end, the application of real-world physical systems can reveal practical operational issues to such an extent which might be challenging to capture with standard simulation techniques. Table II summarises the main benefits and shortcomings associated with the exclusive application of real-word physical IAVs in a manufacturing setting.

5. IAVs in supply networks: from conceptual to real space

Considering the myopic and disintegrated approach towards the adoption of IAV systems in supply chain ecosystems, as previously discussed, in this research we apply conceptualisation and simulation modelling analysis approaches along with emulation and real-world implementation of a physical depth-sensor as a test bed to an actual warehouse facility of a cold food supply chain. The integrated investigation of these four approaches is proposed as a knowledge-based synergistic analysis option, comprising of four corresponding stages, that offers increased study efficiency compared to the opposite extremes of conceptual and real space. We envisage to contribute to the gradual transition of industrial supply systems towards the digital manufacturing era through motivating the integrated application of analysis methods at four sequential stages, namely: first, conceptualisation; second, simulation; third, emulation, and fourth, test bed application.

5.1 Conceptualisation

Initially, we identify a conceptual industrial warehouse facility (Figure 2), which is reproduced from Bechtsis, Tsolakis, Vouzas and Vlachos (2017). The conceptual facility acts as a case with the scope of monitoring and optimising the associated material handling operations performed by an installed IAV system.

Following the initial conceptual design and our work with leading business and academic stakeholders in digital manufacturing and smart distribution systems, we then performed manual calculations, considering alternative market demand scenarios, in
order to determine the number of required intelligent vehicles that could serve this conceptual facility. The determination of the number of operational IAV units allows stakeholders to provide a rationale about the necessity of an associated investment. Following the simple calculations, we developed a corresponding mixed-integer linear programming model to derive optimal values about basic system’s elements, including: first, number of IAV units to serve the facility layout under study; second, number of IAV’s navigation pathways (i.e. unidirectional, bidirectional); and third, allocation of IAVs’ parking/charging stations along with the starting, ending and pick-up/drop-off points that characterise the facility. In addition to the analytical modelling efforts, we proceeded to more sophisticated analysis approaches as general mathematical solvers usually generate static numerical results; however, graphical representation of a mathematical model’s output can provide better insights about the installation prerequisites and operational performance of IAVs.

5.2 Simulation
Based on the theoretical approach underpinning this research and following the conceptualisation stage, we leveraged a commercial discrete-event simulation software (i.e. ARENA® Simulation Software) to model and simulate material handling operations in the identified conceptual warehouse. The developed simulation model presented in Figure 3 can be applied independently from corresponding complex mathematical formulations. Simulation outputs include: first, optimal fleet size; second, capacity and bottlenecks of the facility layout; third, service level of the warehouse; and fourth, sustainability performance of the intra-logistics system.

Following the simulation modelling with commercial software, we identified a gamut of practical challenges that cannot be captured from standard simulation software, thus

<table>
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<tr>
<th>Advantages</th>
<th>Contributions</th>
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<tr>
<td>1. Allows the real-time perception and dynamic response to the working environment as to perform operations</td>
<td>(1) (2) (3) (4) (5) (6) (7) (8) (9) (10)</td>
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<td>2. Requires minimum labour intervention and ensures increased safety in the working environment</td>
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<td>3. Ensures increased accuracy and productivity in operations</td>
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<td>4. Promotes environmental sustainability</td>
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<table>
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<th>Disadvantages</th>
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<tr>
<td>1. Requires significant capital investment on vehicles’ acquisition/development</td>
</tr>
<tr>
<td>2. Requires capital expenditure on supporting infrastructure development and equipment instalment</td>
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<td>3. Requires technical modifications in the facility layout and sensing algorithms for testing and implementation</td>
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<td>4. Associates to significant time-consuming experimentation, testing and configuration tasks</td>
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<td>5. Requires in-house technical expertise and skills to overview and maintain the system</td>
</tr>
<tr>
<td>6. Requires sophisticated technical and financial capacity to apply a collaborative system</td>
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Table II. Key benefits and shortcomings associated with the exclusive application of real-word physical IAVs, across supply chain echelons

Notes: Contributions: (1) Zulkefli et al. (2017); (2) Babić et al. (2012); (3) Watanabe et al. (2001); (4) Berger and Rumpe (2010); (5) Fazlollahtabar et al. (2015); (6) Berman et al. (2002); (7) Samu et al. (1996); (8) Albus et al. (2008); (9) Draganjac et al. (2016); (10) Watanabe et al. (2000)
highlighting commercial simulation software packages’ limitations and the need to make a plethora of assumptions regarding the modelling of both the working environment and the IAV system per se. Often, the fixed input data structure of commercial simulation software does not allow the modeller to capture particular aspects of an investigated supply chain system, while the algorithmic process used to process the model’s data.
inputs to yield simulation results is not disclosed. In this regard, we developed a bespoke simulation tool through using the Microsoft Visual C# 2010 programming language. The model building module of the tool requires four implementation steps and allows the representation of a customised plant or warehouse facility by manually determining the layout and load parameters, including: entry points; crates; storage separators (walls); charging stations and exit points (Figure 4). This first pilot version of the tool includes only manual controls for the vehicle’s movements while the vehicle management interface allows the real-time reporting of the IAV’s sustainability performance by indicating the resulting environmental impact in terms of energy consumption and greenhouse gas emissions.

5.3 Emulation
The analysis approach at the simulation stage presented in Section 5.2 allows the quantification of IAVs’ performance with respect to intra-logistics operations in every working environment under consideration. More specifically, the simulation results of the elaborated simulation model capture the following performance indicators: vehicle schedules; vehicle utilisation; service level; energy consumption and environmental sustainability performance. Nevertheless, simulation modelling provides an overarching view of the specific system’s behaviour under certain and pre-defined inputs, hence failing to represent useful operational details in a near to the real-world facility layout. Especially, simulation algorithms do not capture a system’s physical parameters and operational constraints. For example, it is typical that in a simulation model the routing trajectories of IAVs coincide; hence, standard simulations neglect any traffic-related accidents and vehicles’ crash as well as incidents regarding pallets’ collapse during pick-up/drop-off or delivery operations. To this end, 3D validation and verification emulation software tools could be utilised to represent the actual operations of intelligent vehicles in a dynamic setting so as to generate practical insights and verify any obtained simulation results.

![Figure 4. Simulation model of an IAV system's operations in a conceptual warehouse facility layout: bespoke software](image-url)
Notably, emulation tools are often used in tandem with real-world physical applications. Emulation tools can implement multiple interfaces to replicate the functionality and interaction of physical machinery/equipment to the operational environment. More specifically, in the present study we emulated the Husky autonomous vehicle at the identified conceptual warehouse and we further equipped the vehicle with two emulated sensors (Figure 5): first, a light detection and ranging sensor to scan the emulated warehouse’s layout via its optical distance measurement capabilities; and a Microsoft Kinect depth-sensor with barcode/item scanning capabilities that is used to navigate the IAV and locate the preferred crate, based on the incoming demand signal. The emulation model records a set of specific interfaces including scanning capability, colour image attributes and depth attributes. The warehouse’s layout is created at the Gazebo simulation tool while the Robot Operating System is used to simulate the considered IAV’s intra-logistics activities.

5.4 Test bed application
At the last stage of our research we applied a physical Microsoft Kinect depth-sensor to an actual warehouse of a cold food supply chain. More specifically, we used this depth-sensor as a test bed to explore the interfaces between the real-time captured 3D structure of the warehouse and its physical counterpart. In this regard, we could evaluate the test bed’s working space perception capabilities and scanning potential, while further understanding the manner it could apprehend any shop floor dynamic scenes to inform and guide an IAV (i.e. control the speed, steering and real-time trajectory paths) about the required logistics operations and any necessary manoeuvres. The Microsoft Kinect sensor was selected as a test bed considering that it is commonly used in autonomous vehicles as a sensing input device (Hedenberg and Åstrand, 2016), and because a corresponding well-established digital model is supplied. The sensor transmits instantaneous sampling signals to the surrounding environment and captures spatial information, in real-time, thus providing the ability to identify dynamic obstacles (e.g. other vehicles, employees, crates, etc.), surface textures and variant environmental/workspace conditions (Figure 6). Scanning, detection and tracking technical capabilities within the immediate vicinity of the IAV are essential to ensure robust operations in a real-world setting. Specific purpose algorithms are needed to process the
sensory-captured data and enable each of the aforesaid features. Furthermore, the sensor can operate under different lighting conditions and on all scanning angles. Respectively, to the emulation stage, in case the camera captures a specific barcode/item then a reference point (with the relevant coordinates to the real space) is set and is used to inform the logistics operations of an IAV. As expected, the retrieved interfaces outnumber the simulation interfaces and provide detailed information and managerial insights about the performed operations.

The empirical evidence clearly indicates that the interfaces provided by the emulation tools are limited while physical test beds can deliver a complete list of features which outperform the emulation analogues. To that end, emulation-focussed steps should be initially used to capture specific facility conditions and IAVs’ respective operations. Nevertheless, the need for real-world physical test beds is prominent in validating preferred digital supply chain design options to tackle specific technical and operational challenges.

6. Bridging the dichotomy: an integration methodological framework
Considering that alternative supply chain configurations entail diverse echelon-specific operational needs and uncertainty types, across spatial and temporal dimensions, we recommend the adoption of a hybrid approach for the effective design and assessment of IAV systems. Provided that conceptualisation is fundamental in analysing any techno-economic system, let alone IAVs, we argue that the proposed hybrid approach should integrate three subsequent discrete analysis stages, namely: first, simulation; second, emulation, and third, physical test bed’s application, to allow for adaptive and collaborative decision-making in end-to-end network operations. Figure 7 depicts the proposed methodological framework for particularly guiding the effective incorporation of IAVs in digital supply chains. The framework is based on five key factors whose applicability impact needs to be evaluated and reassessed to successfully verify and validate obtained results at each of the abovementioned analysis stages. These key factors include: first, physical characteristics of the facility and the IAV system (F1—allocation of space, arrangement of equipment and products, paths, aisles width/height, floor type, lighting conditions); second, environmental conditions at the workspace (F2—preservation conditions of materials and equipment, health, safety and ergonomics for the workers); third, operational characteristics (F3—demand, flow of people/equipment/material, IAV’s
characteristics, bin/pallet size/weight, scheduling, planning); fourth, equipment’s hardware requirements (F4—type, material handling, coordination, communication, interoperability, compatibility); and fifth, software requirements of the equipment (F5—interface type, coordination, communication, interoperability, compatibility). The impact of each key factor

Figure 7. Methodological framework for integrating IAVs in digital supply chain operations
has five levels of applicability, namely: excellent; above average; average; below average; and poor. As we progress with the implementation of the framework downstream at stage level, the key factors’ applicability increases along with the complexity at each stage. Stakeholders could gain useful information at early stages of the implementation phase with minimum complexity. Progress to the next stage is advised only in case the current-stage analysis results are validated while different aspects of the key factors have been examined.

For incorporating IAVs in an industrial supply network, stakeholders need to apply the proposed analysis process by gathering information at the fundamental conceptual stage. More specifically, at the conceptualisation stage stakeholders have an overview of the issue under study and gain knowledge about the generic operations that could be performed using IAV technologies. Following that, at the simulation stage, users with minimum experience can have a basic understanding about the physical characteristics of the facility and the IAV system, the hardware and software utilisation, and can fully perform operational activity performance assessments. In case, the impact of each key factor (i.e. from F1 to F5) is evaluated as sufficient, analysis can proceed to the emulation stage. On the contrary, in case the analysis results are not encouraging, stakeholders should attempt to adjust the simulation model’s settings or conclude that no sufficient techno-economic analysis impact can be achieved, thus terminating the analysis procedure. Emulation can provide a detailed factor analysis with the burden of additional effort by the involved experts. At the emulation stage, decision-makers gain critical insights for the physical, operational and environmental activities of an IAV and can have an average understanding over hardware and software compatibility issues. Finally, in case the model meets the pre-defined criteria at the emulation stage, stakeholders can start developing a physical test bed in order to have a near to the real-world hardware module in their disposal and be able to complete a feasibility analysis at the prototype level before considering the procurement of corresponding physical real-world IAVs.

7. Discussion and conclusions
This research sets out the process for the systematic assessment of IAVs prior to their actual implementation in supply networks enabled by digital technologies. A multi-stage, integrated analysis approach is adopted beginning with the conceptualisation of an IAV’s operations, progressing to simulation, emulation and physical test bed application on an actual warehouse facility.

Within the Internet of Things discourse, advances in automated manufacturing and intelligent distribution technologies promote changes in the established economies of scale production patterns and highlight novel progression pathways for the industrial supply networks of the future (Srai et al., 2016). The transition from traditional manufacturing and distribution systems to digitally enabled supply networks in a viable manner is an example of the Internet of Things approach as part of the operations research and management fields (Al-Turjman, 2017). In this perspective, this research contributes to operations management research by providing; first, a multi-stage methodological approach that informs about the integrated and complementary utilisation of conceptual designs, analytical programs, simulation models, emulation tools and physical test beds to support digital transformations in supply networks; and second, a practical “toolbox” for the proactive assessment and effective incorporation of IAVs in supply network operations.

This paper grounded three RQs and applied alternative methodologies in an attempt to address them. First, RQ1 concerns the benefits and shortcomings associated with the application of either simulation modelling or real-word application of physical IAVs and was answered with a critical analysis of the extant literature. Existing research evidence reveals that simulation modelling has been extensively used in the past for evaluating the
operations performance of supply networks under static environmental conditions and by neglecting practical aspects at a shop floor level. In addition, the implementation of physical IAVs in real manufacturing settings is rarely reported in the literature with the actual benefits not being supported by indicative business cases, yet. Second, to tackle RQ2, we used a commercial simulation software package and we also developed a bespoke software application along with a 3D validation and verification emulation tool which can be applied to evaluate an IAV’s operations in any industrial setting. The two simulation models (i.e. commercial and bespoke) along with the emulation tool developed in this research can be useful for the effective design of specific supply chain operations in diversified manufacturing sectors. Extensive validation on these software platforms is the subject of our on-going research. Third, focussed on our attempt to answer RQ2, we applied a depth-sensor as a test bed to an actual warehouse to assess its possible utilisation for guiding an IAV system. Fourth, a theoretical and empirical evidence-based methodological framework is proposed that suggests the integrated evaluation of IAVs in supply chain operations through conceptualisation analysis and simulation modelling, progressing towards the emulation and physical application of test beds in a customised working environment. The proposed methodological process assists in enabling digital supply network transformations (Srai, 2017). RQ3 is intertwined with RQ2 and the applicability of the proposed methodological process is demonstrated through the developed conceptual design, simulation and emulation tools, and the test bed experimentation.

7.1 Theory implications
Our study findings confirm that commercial off-the-self simulation software packages provide limited modelling capabilities towards creating realistic models of complex manufacturing and distribution systems whereas the development of bespoke simulation tools is time-consuming, expensive and requires compelling modelling skills and programming capabilities (Bechtsis, Tsolakis, Vlachos and Iakovou, 2017). Generally, simulation modelling enables researchers to focus on the optimisation of supply chain operations without having to concern about detailed hardware and other operational aspects like maintenance and operating space (Zeng et al., 2016). However, especially for distribution operations, a major challenge associates to the congruence of simulation models and the corresponding real-world systems (Ottemöller and Friedrich, 2017). In this regard, emulation environments could replicate and optimise real-world processes, and capture unpredictable risks in order to proactively assess the impact of the external and internal manufacturing and distribution system environments to provide insights for increased efficiency (Weyer et al., 2016).

7.2 Practice implications
A significant development of this research refers to a practical “toolbox” approach combining simulation and emulation techniques to support the proactive analysis of IAVs in supply chain echelon-specific operations. In addition to our theoretical implications in the operations management field, we confirm that the real-world application of a physical IAV system enables consideration of the full spectrum of temporal and spatial environmental dynamics at echelon-specific operations (Van Brummelen et al., 2018). Intelligent vehicles can secure a level of situation awareness in even unstructured facilities, thus resulting in a corresponding dynamic response behaviour to perform certain operations and tasks. IAVs are being embraced by agricultural stakeholders (Reina et al., 2017); hence, the provided methodological framework could be applied for the preliminary assessment of alternative intelligent systems in precision farming operations in terms of sustainability impact at economic (e.g. optimal resources’ utilisation and increased yield), environmental (e.g. improved energy consumption) and social (e.g. enhanced safety) levels. From an
7.3 Limitations and future research avenues

In conducting this study, some limitations are evident which, however, provide interesting grounds for expanding our research horizons. First, the provided analysis framework was developed using literature evidence and our experimental work and research experience, without consulting any industry experts. Second, this study was developed based on the application of a single physical device (i.e. Microsoft Kinect sensor) as a test bed and, thus, we should further proceed with the testing of a physical IAV in an industrial warehouse. Albeit the use of a single sensor as a test bed cannot provide a magnitude of data streams required in today’s digital progression dynamics, it provides valuable proof-of-concept information and demonstrates that our implementation is capable of navigating physical autonomous vehicles in realistic industry-like environments.

With respect to future scientific directions, we aim to demonstrate the applicability of the proposed methodological framework on real-world settings. The case of the pharmaceutical industry is paramount for understanding and designing automated operations of the respective end-to-end supply networks, with specific focus on supporting more participative healthcare through responsive digital manufacturing models and more patient-centric delivery models possibly enabled by IAVs (Harrington et al., 2016). Moreover, our framework could be applicable to the case of circular networks defined by renewable chemical feedstocks which are characterised by diverse and volatile physico-chemical quality specifications. Renewable feedstocks require precise and timely material handling operations to offer value-added intermediates or end-products while contemporarily addressing emerging supply chain management challenges and market dynamics (Tsolakis et al., 2016). We further envisage that IAVs are embraced appropriately at each industrial network echelon to promote collaborative supply chain management for fostering business excellence and sustainability (Attaran and Attaran, 2007), especially in the today’s e-commerce and business-to-customer models (Tsironis et al., 2017).

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References


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Electric sports cars and their impact on the component sourcing process

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Abstract

Purpose – The purpose of this paper is to explore how the sourcing process of the electric sports car sector is changing with respect to competitive advantage, required capabilities and emerging opportunism.

Design/methodology/approach – The case study data collection covered the period from January till August 2017, which implies a total period of eight months. The empirical analysis implies a sequence of 20 conducted interviews with senior managers, team leaders and operational employees from various organizational departments and functions within Company A, various suppliers and experts from the automobile industry as well as primary and secondary literature.

Findings – This work makes a contribution to the operations capability literature. It highlights the important role that sourcing will play to achieving strategic advantage in the electric sports car segment. Four key operational capabilities are emerging in the operating model. The first links to "capacity" and the ability of suppliers to be locally based so that they can deliver high-quality products and services in the minimum time (optimizing the "time-value" configuration). The second is the "design" of the supplier network. The third relates to "supplier management." Finally, the fourth capability relates to the ability of the firm to "integrate" and "align" their marketing and IT planning processes with their sourcing process.

Research limitations/implications – Throughout the adaption of a sourcing framework and its extension to consider operational capabilities, the authors have begun to answer the research question of how the sourcing process for the supply of new electric powertrain components is being transformed. These initial findings, the authors intend to expand with more advanced case study work with the firm that will involve empirical modeling of process efficiency and inventory management.

Practical implications – The work closes the gap regarding the need for practical application tools, designed for process managers, who are being confronted by turbulent, unpredictable and fast moving technological-driven market environments. Although the sourcing framework was developed to test the impact of the electric mobility trend, it can likewise be applied for the sourcing of components in other fast changing environments as well.

Social implications – The paper raises the issues of the social role of the smart city planners in providing city spaces to enable the servicing of electric vehicles and to assist their production by developing the skills, capacity and capabilities of local city populations which will be needed to sustain and scale up any locally based operating model of electric vehicle production and servicing.

Originality/value – Although much has been written about the technological challenges of electric vehicles and the rise of new entrants such as Tesla to challenge the dominance of the sports car manufacturer’s very little work to date have explored the business-to-business (B2B) dimensions. The focus has been largely with the business-to-consumers (B2C) market.

Keywords Outsourcing, Sourcing, Electric sports cars, Operational capability

Paper type Research paper

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1. Introduction

The motor vehicle of 2025 is expected to look and function quite different than it does today. It is suggested that cars will become a computer on wheels generating vast amounts of valuable data. The future motor vehicle firm will need to have a “smart city” infrastructure (whereby information and communication technologies are integrated into urban infrastructures (Wamba, 2017)) in place if it is to be able to process, analyze and strategically learn from the data it collects. Forecasts estimate a global market of 250m connected cars on the road within the next eight years (Gissler, 2015). Consulting firm McKinsey estimates that connected car data and the new business models that emerge could be worth $1.5tn a year by 2030 (Gao et al., 2016).

A connected car denotes: “a vehicle equipped with internet access, and usually also with a wireless local area network” (Swan, 2015, p. 3). There are a number of disruptive market and technological trends presumed to shape the future of cars, from a growing focus on service innovation to new patterns of ownership and the emergence of disruptive technologies (i.e. “big data” (BD) (Zhan et al., 2017) and the “internet of things” (IoT)) (Stawski, 2015).

Whilst the developments in IoT and big data have created several market opportunities for incumbents (Müller and Jensen, 2017), it is primarily the new entrants, such as Tesla which have seized the strategic initiative and built first mover advantage through their distinctive service innovation competences (Storey et al., 2016).

Although much has been written about the technological challenges of electric vehicles and the rise of new entrants such as Tesla to challenge the dominance of the sports car manufacturer’s very little work has explored the business-to-business (B2B) dimensions. The focus has been with the business-to-consumers (B2C) market.

The scope of this paper is therefore to enhance the existing literature and fill this gap, by building, testing and advancing a theoretical framework with case study data. The work will focus upon the strategic alignment of the sourcing process with organizational strategy; in order to capitalize on the opportunities being created by rapid technological change. This framework is theoretically underpinned by transaction cost economics and the resource-based view (RBV). We combine these two theories and extend them to highlight the strategic assets and transaction efficiency that can be contributed by the sourcing process, to firm competitive advantage. The electric sports car provides a context for the authors to advance operational capabilities theory. We aim to solve a theoretical puzzle: can the sports car firm build sufficient operational capability through outsourcing, to deal with strategic turbulence being caused, by the need of the firm to adjust its organizational strategy to the electric mobility trend?

In terms of the electric powertrain components, the trend toward electric vehicles has led to the need for a completely new set of car components. For which the resource setting and potential sourcing strategy needs to be evaluated and defined for the first time. The paper will focus on the three components: “e-machine,” the “pulse converter” and the “battery.” As these are the most important components in terms of economic and operational value to the electric vehicle powertrain.

This paper is organized as follows. In the next section, we consider the main bodies of sourcing theory and propose an adapted version of the Mcivor framework. The methods for testing and advancing this framework are then outlined in Section 3. Case study results will be presented in Section 4 and finally in Section 5 the conclusions and implications for further research are presented.

2. Sourcing theory

By viewing the firm as a bundle of resources and capabilities that are employed in specific ways to create competitive advantage for an organization (Barney, 1991), the RBV is crucial to understanding the discipline of outsourcing. Hence, superior relative performance of a specific organization explains why certain activities are internalized or outsourced.
The study of outsourcing is rooted in the drive for greater efficiencies and cost reductions. For most organizations, outsourcing is seen as a powerful tool to reduce costs and improve performance. There are two influential theories in the study of outsourcing; this is “RBV” and “transaction costs economics” (TCE) (Mcivor, 2009, pp. 45-46).

Most of the literature is either focused on TCE or the RBV approach in explaining outsourcing decision (Vivek et al., 2008; Coates and McDermott, 2002; Grover and Malhotra, 2003; Hayes et al., 2005; Holcomb and Hitt, 2007; Jiang et al., 2007; Vastag, 2000; Williams et al., 2002). Hamel and Prahalad (1994) have evolved RBV to the core competence concept, with the distinction between core and non-core business that has become very influential in outsourcing practice.

Consequently, organizations may access complementary capabilities from third-party firms where no advantage can be gained from performing these activities internally (Mcivor, 2009, p. 47). Giving activities which do not constitute a core competence of the organization to other firms, and who can provide these at lower costs is the basis for the “make” or “buy” decision which is also defined as transaction costs.

The TCE approach is based on the assumption, that the transaction is the basic unit of analysis (Williamson, 1981, pp. 549-556). Its primary purpose is to explain why certain industrial arrangements operate with different efficiency degrees (Yang et al., 2012, pp. 4462-4463).

Transactions are thereby defined as actions, in which goods or services are transferred across a technologically separate interface (Williamson, 1981, p. 552). Transaction costs are in this term defined as costs which occur due to misunderstandings and conflicts, which lead to delays, damages or malfunctions (Williamson, 1981, p. 552). After having assessed the internal and external transaction costs, the efficient boundaries of the firm can be defined.

Based on this assessment, the procurement decision between the two alternatives of make (produce the product internally) and buy (purchase it from an autonomous supplier are made (Williamson, 2008, p. 5)). According to Williamson (1975), only those products and services should be produced internally, for which the internal transaction costs are less than the transaction costs of purchasing these at an open market. The strict focus on these two options only implies that mixed models like joint ventures (JV) or franchising are not considered (Williamson, 1981, pp 549, 556).

Further research has revealed (refer to Figure 1), that the factors of transaction attributes and environmental conditions and the factors of industrial arrangement and governance mechanisms are determining both transaction costs and “make or buy” effectiveness (Rindfleisch and Heide, 1997; Yang et al., 2012, p. 4465).

From these transaction attributes, statistical results from Yang et al. (2012, pp. 4472-4473) reveal that the environmental risk is the factor with the highest direct influence on outsourcing performance. Furthermore, they indicate that hybrid mechanism such as legal contract and

![Figure 1. TCE framework](Source: Adapted from Yang et al. (2012, p. 4464))
informational adaption are having a strong mediating effect, but this needs to be combined with relational adaption for making outsourcing effective (Yang et al., 2012 pp. 4472-4473).

Whereas further empirical studies have revealed a positive correlation between high asset specificity and hierarchical governance which implies internal production (Mcivor, 2009, pp. 46-47, Williamson, 2008), the effect of uncertainty is a further controversy discussed in the literature. Furthermore, Walker and Weber (1987) found that uncertainty can increase the use of hierarchical governance, Harrigan (1986) claims that opposite effect of uncertainty upon the level of hierarchical governance.

Once applying the TCE approach, managers need to consider a wide range of transaction costs. In both the analysis of the external as internal transactions and relative costs, important cost sources may be missed out. An example of these costs are the administrative costs in finding an appropriate supplier for the outsourced transactions. Further it needs to be ensured, that the transactions outsourced are operationalized in the desired quality and time. This aspect is often underestimated and can lead to serious delays which result in high costs for the outsourcing organization. Although TCE offers a good decision tool to define whether it is economically reasonable to make or buy products or services in the short run, it lacks the implication of this decision for the strategy and competitive advantage of an organization in the long run.

Another critique of the TCE comes from Conner (1991), who criticizes the understanding of the firm existence upon minimizing the opportunistic potential for asset-specific investments. So far, the TCE and RBV were treated as independent approaches for the outsourcing decision. Whereas the TCE concentrates on governance skills and provides sound understanding for analyzing market vs hierarchical mechanisms in outsourcing decisions, the RBV explains why firms differ in performance and focuses on the existent inter-organizational collaborations and ways to enhance complementary resources to create competitive advantage (Barney, 1991).

The analysis of the two approaches has showed that both offer a solid understanding and basis for an organization’s outsourcing decision. Yet none of the two approaches alone can and should be used in an outsourcing decision case at an organization. Although the two approaches seem to be completely different, there is a complementary nature between both theoretical standpoint, which is based on the characteristic of being difficult to trade or imitate that applies for both distinctive capabilities and specific assets (Peteraf, 1993). In some cases, the recommendations given from each approach can even be complementary.

An example for such a case would be when an organization obtains the resources needed to develop a difficult-to-imitate capability and the opportunism potential is high, the activity should be internalized (Mcivor, 2009, p. 48). Based on the fact, that neither theoretical perspective can completely explain the make-or-buy decision; both perspectives are required in order to obtain a holistic decision basis (Combs and Ketchen, 1999; Mcivor, 2009, p. 48). In Table I, the contradictory and complementary approaches of the two theories are illustrated.

Table I shows, that in some cases, the two approaches give complementary recommendations. For those cases, in which there are contradictory prescriptions, a

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<th>Superior Resource position</th>
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<td>RBV—Perform Internally</td>
<td>RBV and TCE</td>
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<td>TCE—Outsource</td>
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<td>Complementary</td>
<td>Contradictory</td>
<td></td>
</tr>
<tr>
<td>RBV and TCE—Outsource</td>
<td>RBV—Outsource</td>
<td>TCE—Perform internally</td>
</tr>
<tr>
<td>Lower</td>
<td>Potential for opportunism</td>
<td></td>
</tr>
</tbody>
</table>

**Source:** Adapted from, Mcivor, (2009, p. 61)
further analysis of the specific situation is required. In extending the TCE and RBV approaches theorists have started to focus on how capabilities can be built in the operating model to achieve transactional efficiencies through the resource assets. If resource assets are the inputs into an operating model and transaction efficiencies a performance output, there is gap to understanding the “mediating” operational capabilities needed to convert the resource assets into transactional advantage.

2.1 Operational capabilities

We define an operations model as the content, structure and interaction of an operation’s resources, processes, people and capabilities, configured in order to create customer value. In presenting this definition of an operations model, we refer to the lack of definitional clarity surrounding “business models” more generally and their various contexts (Zott et al., 2011).

A business model is a complex, multi-dimensional concept, which has been defined differently by previous studies (Zott et al., 2011). Generally speaking, it defines the rationale and logic that a firm identifies, creates, delivers and captures value; and illustrates the architecture of the product, service and information flows, the sources of revenue and benefits for suppliers and customers, and the method by which a firm builds and uses its resources to offer its customers better value than its competitors and make money in doing so (Massa and Tucci, 2013; Baden-Fuller and Morgan, 2010).

Meanwhile, an operations model is a key part of a business model, as it defines the way a business model works and how the firm implements its strategy, and in particular, how the firm configures its people, processes and technology to create and deliver value to its different stakeholders. Operational capability is the ability to align critical processes, resources and technologies according to the overall guiding vision and customer focused value propositions coupled with the ability to deliver these processes effectively and efficiently (Nada and Ali, 2014, p. 505).

Building on the work of (Porter, 1985), we view the operating model as a source of value creation within the supply chain and a key source of capability. Whilst the capacity of the operating model relates to the resource inputs, capabilities are achieved when you organize your operations (i.e. plant, suppliers, storage, and transport) better than your rivals or you differentiate, in a way unique enough for your operation to survive. For instance, a local designed network could be a capability if it is possesses the agility to respond more efficiently, than global value chains to small scale demand in the narrow market scope of a city.

Employees could be a capability if they possess high levels of creative and design ability. Whilst your suppliers could be a capability if you have strong relationships with them and they can supply you with low lead times (i.e. lean and JIT practices). A summary of representative literature on operational capabilities is provided in Appendix 1. This table illustrates that operating capabilities will enable your operation to meet its performance focus (i.e. quality and responsiveness) and it connects your inputs (strategic resources and assets) to the outputs (transactional efficiencies).

From the periscope of the RBV, an effective sourcing process for a sports car firm, would be one in which it possessed the operational capability to effectively manage its external technological shocks, and use to them to enhance its competitive standing.

2.2 Theoretical framework

Building on these underpinning theoretical antecedents an outsourcing decision framework was developed. The framework is theoretically underpinned by a synthesis of a corpus of literature on TCE, RBV and operational capabilities. The framework is based on three key characteristics which we have adapted from McIvor (2009). This is illustrated in Figure 2.

In order to identify the recommended sourcing solution, each potential outsourcing option is checked upon the three key characteristics of its contribution to the organization: competitive
advantage, its relative capability position and the opportunism associated with the outsourcing analysis. Based on the individual results, specific sourcing options are recommended.

In cases of potential outsourcing decisions, our framework model offers organizations a comprehensive tool, which combines the advantages of the two main theories of TCE and RBV. A further advantage of our sourcing framework is the fact that it also includes inter-organizational collaborations. In the literature, this approach is often referred to as the relational view, which implies the concept of: “how firms can gain and sustain competitive advantage by means of combining resources in unique ways across organizational boundaries” (Dyer and Singh, 1998; Mcivor, 2009, p. 48).

The approach has evolved from the limitations of the TCE and as an extension to RBV can thereby be seen as an example of an attempt to combine both theories. As neither in the TCE, not the RBV approach this option is considered, it constrains both approaches in their individual applicability. In the case of the combined framework model, this crucial option is implied which expands its versatility and opens a greater range of alternatives.

According to Hamel et al. (1989, p. 134) strategic alliances and JV aim to exchange knowledge and can be used to strengthen the partners against outside rivals. They are usually established when the participating partners feel it is beneficial to combine their resources and capabilities to gain access to new markets or in order to develop new technologies. The difference of a JV and a strategic alliance is that the latter stops short of forming a separate organization. Based on the fact that both partners usually build up new skills and diffuse the new acquired knowledge throughout their own organizations, the alliance strengthens both partners, although it simultaneously weakens each of them against the other. Therefore, the alliance can be also viewed as a new way of competition (Hamel et al., 1989, p. 134).

Although our framework model comprises a wide range of potential sourcing alternatives and offers a structured and theoretical-based guideline for potential outsourcing decisions, the model implies also some limitations, which need to be considered when using it as a decision tool. Due to the fact, that both TCE and RBV theories are based on economic rationale, the influence of the political context is little considered in the outsourcing decision. Based on the contradictory prescriptions in some cases, these should be especially analyzed with caution.

Likewise, the organizational strategy and the defined sourcing decisions based on the (Mcivor, 2009, p. 55) framework needs to be regularly revised. This is due to a central premise of his framework—“the outsourcing strategy needs to be linked with corporate strategy.”

In addition, all three key characteristics may change over time, for which reason a revised analysis would lead to a different sourcing prescription. In spite of these limitations it is a well-tested, internally consistent and rigorous framework which has been successfully applied across a number of studies (Yang et al., 2012).

![Figure 2. Theoretical framework for outsourcing evaluation](image-url)
3. Research method

The data collection method relied primary upon extensive qualitative data acquisition in order to obtain further information upon the trends and their externalities. Based on the following points, the sports car manufacturer Company A offers a qualified organizational setting for an analysis of the trend of alternative driving technologies.

Being a luxury sports car manufacturer, the targeted market segment of the organization includes wealthy customers, which are willing to spend more money on innovative products and technologies. This fact puts the Company A in a considerable comfortable starting position. Apart from this, the trend has already altered the organizational structure and certain business units and can be recognized in the everyday business. This implies that first changes and experiences have already been collected and are therefore available for a qualitative data analysis. For instance, for the visible changes is the decision to set up the new manufacturing line for the new fully electrified Company A sports car, Mission X.

As the manufacturing of a fully electrified car is incomparable to the manufacturing of conventional cars, the management of Company A decided to invest several hundred million Euros in the establishment of the new manufacturing line in mainland Europe.

These issues imply that the changes rooted and triggered of by the trend toward alternative driving technologies are already faced and experienced by the organization, its business units and the employees. Therefore, it can be said, that the ecosystem of Company A is at the current stage at a standpoint, where it has to transform itself and its brand reputation from the traditional sports car manufacturer of fuel engines toward a new and modern mobility provider for exclusive demands. At this unfrozen first stage of change, the organization is relatively open to strategic new organizations and settings (Eisenhardt, 1989; Lewin, 1951).

The conducted case study data collection covered the period from January-August 2017, which implies a total period of eight months. The empirical analysis implies a sequence of 20 conducted interviews with senior managers, team leaders and operational employees from various organizational departments and functions within Company A, various suppliers and experts from the automobile industry as well as primary and secondary literature. These were analyzed using the qualitative coding procedure outline by (Molleda and Moreno, 2008).

All the primary evidence including the answers and comments to each thematic characteristic were grouped by company according to the level of agreement/disagreement of identified response patterns. Excel spreadsheets were then used as response matrices to identify patterns of consensus and disagreement, and then to determine similar patterns between the different maker facilities (Molleda and Moreno, 2008, p. 117). As the goal of this study is to detect cross-maker we focused on the main items of consensus in every organization to compare them all together (Roberts, 2000; Poindexter and Mccombs, 2000).

The interviews were conducted during various time slots within the mentioned period both at the organization side in Northern Europe. Before the interviews were conducted, the interviewee was explained about the purpose of the study to identify suitable sourcing strategies based on the alternative driving technologies.

Furthermore, the interviewees were assured, the anonymity of the collected data. The interviews were semi structured. This means, that the interview followed a list of predefined topics and questions. All the interviews were held in a separate room in a one-to-one communication form. The interview content was transcribed, but not recorded. The decision to hold the interview in the described setting was based on the intention to hold the interview in a neutral surrounding in which the interviewee was feeling comfortable. This implies that the interview partners were not distracted by everyday business and the interview surrounding was set in a familiar setting.

Consequently, the interviewee was willing to share more and honest information. By the influence of third persons in the interview surrounding, the data generated could get biased.
The decision not to record the interviews was taken based on the same assumptions. In the absence of a recorder, interviewees were sharing a greater amount and more in detail information upon their personal opinions.

The initial interviews were covering a broader range of topics. Later interviews were gradually reshaped by the findings of the first interviews. This enabled the critical reflection of stated opinions and assumptions. Besides the data generation from the conducted interviews further access to a wide range of internal documents and information were given.

The usage of a qualitative approach has advantages and disadvantages. Due to the timeliness of the trend, economical available data upon this issue is rare. Furthermore, it is yet unclear, how and to what extent, the trend will affect the industry. Therefore, a quantitative analysis of data was offering limited options. The data generated are resulting from qualitative data analysis from a range of industry experts.

The limitations and disadvantages of the qualitative approach is the bias of the interviewee. In order to minimize this bias, a number of measures were conducted. First the interview sample group was extended from organization internal interviewees to industry wide experts. This ensured that the conducted findings were not seen through the lens of the organization, but were similarly recognized within the industry. Second and in order to avoid problems of hierarchical bias, interviews were conducted at different hierarchical levels within the organization as well as within different organizational functions and departments.

The selection of the sample group further implied members, with different tenure at the organization. Third, all interviewees were asked to name other potential interview partners which had similar or different standpoints on the trend after the interview. By doing so, it was ensured that contrasting perspective was respected. The interview schedule is attached in the appendices of the paper.

We aimed to advance our knowledge of the sourcing constructs outlined in the classification stage, through their thematic extension with primary data (Eisenhardt, 1989). Through the thematic interplay of data with theory we could now confirm, modify or reject parts or the whole framework categorization.

4. Initial findings at Company A
4.1 Contribution to competitive analysis
The results of the case study suggest that the emobility trend is significantly impacting on the procurement department at Company A. In addition, it is impacting unequally on the capabilities of their different suppliers. Whereas the combustion powertrain procurement has experienced yet only gradual changes resulting from the trend, the electric procurement department is affected to a much large extent. Concerning the combustion engine powertrain issues, our analysis revealed, that there is an ongoing trend toward an increasing concept responsibility (KV) quote and a bundling of components.

The increasing KV quote trend implies that the competence, knowledge and responsibility of the engineering of components have shifted from the OEM to the suppliers, which has released internal capacities within the engineering department. Likewise, the bundling of components decreases administrative capabilities within the purchasing department. Resulting from the firm undertaking “knowledge sourcing”[1], the freeing-up of capacities is a crucial process in order to improve the innovation potential within a department and to allow the employees to gain competences in further areas. Hence, the freeing-up of capacities at the OEM requires a transfer and installation of these at the supplier side.

This trend can be explained by the RBV. Although the resources of an organization are limited, they can be reconfigured to a certain extent. In order to reconfigure these resources, they need to be released from their current position before being reconfigured. In terms of the powertrain components for the new electric cars, these are sourced by the electric procurement department. The main parts for the electric powertrain are the battery, the
pulse converter and the e-machine. The decision to assign the electric powertrain components to the electric purchasing department was based on the technological proximity between the existing electric product portfolio and the new electric powertrain components.

Although there exist similarities between the components, the sourcing situation for the new 21 powertrain components varies to a large extent to the sourcing of the existent electric components portfolio. But based on the fact, that the configuration and composition of these three parts impacts on the power, speed and performance characteristics of Company A’s future electric car.

Resulting from the qualitative analysis, the e-machine, the pulse converter and the battery are the central parts of the powertrain for an electric vehicle. All three components contribute to a large degree to the future characteristics of the electric car and thereby constitute a high contribution to the future competitive advantage of Company A.

As the technology for each component is still in its engineering beginnings, the opportunism potential for each component is expected to be high. Therefore, the strategic relevance for each of the mentioned three components is very high. In terms of the e-machine and the pulse converter, the contribution to the future core competences of the organization is also very high. Based on the business strategy to convert the product portfolio gradually upon 22 electric vehicles, the possession of core competences within the e-machine and pulse converter field will be a crucial competitive advantage factor for A.

4.2 Relative capability analysis

Although the competences for each product category of the electric powertrain have to be acquired from scratch, the evolvement speed in knowledge acquisition for each component is different. Based on the shorter technological proximity of the e-machine and the pulse converter to the traditional electric purchasing portfolio, the knowledge acquisition speed of these components is faster than the one upon the battery, which is still in its beginnings.

Based on the fact, that the engineering and manufacturing of the traditional cars did not require in-depth chemical knowledge, the competence upon this field is still in its beginnings. Therefore, the technological proximity between the competences and capabilities required to engineer and manufacture batteries and the existent competences, at Company A, is still very large. Basically, there is a capability gap at Company A in its ability not only to manufacture the batteries but also they are heavily reliant on knowledge sourcing to their suppliers. For instance, the research and development of battery technology.

The firm is strongly increasing its capacities within the field of the electric car; the focus is currently at setting up human and technological capacities within the field of the machine and the pulse converter. Consequently, the engineering and partial manufacturing of e-machines and pulse converters is defined to become a future core competence of Company A. Hence, the sourcing strategy needs to support this potential whilst proving the optimum sourcing option for the organization to achieve its future core competence. In the case of the battery, the manufacturing would require the setting up of a specific battery factory which would tie up too much capital. That would be required at the current stage to adjust the manufacturing lines and sourcing process to build the new electric cars.

By having defined its mission in providing the customer an exclusive and dynamic mobility experience, Company A’s core competences are still bound to the engineering and manufacturing of sports cars. Nevertheless, the battery represents an important component for the electric car, as it contributes to the power characteristics of the future electric car. Therefore, the strategic relevance of the battery is still high.

The e-machine as well as the pulse converter were assigned by our interviewees into the “knowledge sourcing” category. The firm have slightly more knowledge capability with the pulse converter technology than they do with the e-machine. The speed of external technological change is such that there is an “implementation gap.” This is because there is
slow “process diffusion.” This is the diffusion of the required knowledge, which would need to be implemented quickly, so the sourcing process could be reconfigured to optimize the fast changing technologies. These would need to be implemented much more quickly, to add value to their component design and manufacture. Although the e-machine and pulse converter technology is relatively new for A, it obtains already basic competences within related technological areas, for which the technological proximity between the capabilities can be defined as medium.

4.3 Potential for opportunism
The potential for opportunism was identified by Company A to be most likely achieved through the establishment of strategic alliances, combined with the option of a CVC[2] investment. This could be integrated into the knowledge sourcing portfolio of Company A. This sourcing strategy suggestion is also complementary to the sourcing strategy of Tesla, which is committing itself into a strategic partnership with some of its crucial suppliers in order to source knowledge.

For the e-machine and pulse converter, the potential suppliers have no automotive experience and the market for such components still needs to establish itself. In order to ensure further knowledge sourcing upon the e-machine and pulse converter, Company A should establish strategic alliances with the technological most advanced partners in order to acquire the crucial core competencies and capabilities that will ensure the organizations competitive advantage in the long run.

There are slightly more opportunities for pulse converters than the e-machine component. Although “A” has not yet committed itself into such a strategic partnership, the innovation potential resulting from the collaboration work with its suppliers and the speed of acquiring further competencies within the operating field is yet immense and underlines the potential of such collaborations.

Considering the recent established strategic partnership between Volvo and Siemens (Handelsblatt, 2017), Company A could evaluate and define which strategic partnership to implement in order to ensure its future knowledge sourcing access. In terms of the battery, the situation is different. Although the strategic relevance of the battery is also very high, the contribution to the defined future core competences of Company A of this component is low.

A negative example of an organization trying to overcome this “OEM-supplier” gap are Nissan and Renault, which decided to manufacture the battery themselves, but failed due to the strategic advantage their battery suppliers had, a gap which could not be closed within time. However, there are examples such as OEM Daimler, who are currently setting up a battery assembly factory, which suggests that not all firms have given up in trying to make their own battery technology.

Though as with Company A, Daimler faces a large capability gaps toward the cell production technology and is therefore concentrating on the assembly of the battery components only, trying to obtain further knowledge in this field via small incremental adjustments. Unlike Daimler and Company A, the OEM Tesla contains a different technological background, for which the capability gap between Tesla and its strategic alliance with Panasonic is lower.

Consequently, for Company A the recommended sourcing strategy is to implement a sourcing platform for the battery components. Within such a platform, they can gradually and slowly obtain further knowledge upon the component, while the responsibility of the engineering and configuration of the battery remains at the supplier.

Further, “A” can define the framework conditions for the components, which the various suppliers then can use in order to engineer and adjust their components. In doing so, Company A needs to ensure a competitive and cooperative climate within the platform. This will nurture further innovations, which are based on the network effect supporting the value of the platform will be more complementary than competitive (Gawer and Cusumano, 2014).
4.4 Advancement of the framework

The key findings of the case study are presented in Table II. The e-machine, the pulse converter and the battery are the central parts of the powertrain for an electric vehicle. All three components contribute to a large degree to the future characteristics of the electric car and thereby constitute a high contribution to the future competitive advantage of Company A.

As the technology for each component is still in its engineering beginnings, the opportunism potential for each component is potentially be high. However, in terms of the e-machine and the pulse converter, the contribution to the future core competences of the organization is also very high. It is apparent that the possession of core competences within the e-machine and pulse converter field will be a crucial competitive advantage factor for A. The firm therefore classifies the e-machine and pulse converter as “knowledge sourcing.”

They accept that a combination of the speed of external technological change, together with gradual internal adaption and integration of the required knowledge (needed by the firm) into their sourcing processes (to optimize their efficiency), implies that they are not yet in a strategic position to acquire the needed resources within time.

<table>
<thead>
<tr>
<th>Component</th>
<th>Sourcing process</th>
<th>Contribution to competitive advantage</th>
<th>Relative capability position</th>
<th>Opportunism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery</td>
<td>Outsourcing physical production</td>
<td>High but the firm reliant on its suppliers who have more advanced technological know-how and capability to manufacture High contribution to competitive advantage (in particular cell production)</td>
<td>Engineering shifted from the OEM to the supplier Manufacturing would require the setting up of a specific battery factory which would tie too much capital that is required at the current stage to adjust the manufacturing lines to build the new electric cars. Low capability position</td>
<td>Collaborative sourcing (but not partnerships) with battery suppliers There is low opportunism associated with the batteries smallest component (i.e. cell production) The investments for such a cell production would capitalize too much investment for Company A The potential for future cost reductions due to economies of scale and process improvements are smaller than the potentials implied in other components</td>
</tr>
<tr>
<td>Pulse converter</td>
<td>Knowledge sourcing</td>
<td>Bundling of components Engineering and partial manufacturing Contribution to competitive advantage is high</td>
<td>Human and technological capacity and capability is being built within the organization Slightly more developed than the e-machine Medium operational capabilities and resource assets to deal with knowledge evolution</td>
<td>Establish strategic alliances with the technological most advanced partners More opportunities for strategic alliances relative to the other two components</td>
</tr>
<tr>
<td>e-machine</td>
<td>Knowledge sourcing</td>
<td>Bundling of components Engineering and partial manufacturing High contribution to competitive advantage</td>
<td>Human and technological capacity and capability is being built within the organization Medium operational capabilities</td>
<td>Establish strategic alliances with the technological most advanced partners</td>
</tr>
</tbody>
</table>

Table II. Advancement of the framework
For the e-machine and pulse converter, the potential suppliers have no automotive experience and the market for such components still needs to establish itself. In order to speed up their acquisition and diffusion from their policy of “knowledge sourcing,” Company A should establish strategic alliances with their technologically most advanced partners. This is needed if they are to acquire the crucial core competencies and capabilities that will ensure the organizations competitive advantage in the long run.

Although it has not yet committed itself into such a strategic partnership, the innovation potential resulting from the collaboration work with its suppliers and the speed of acquiring further competencies within the operating field is immense and underlines the potential of such collaborations.

Considering the recent established strategic partnership between Volvo and Siemens as well as current discussions upon further strategic alliances between OEMs and these component suppliers (Handelsblatt, 2017), Company A should evaluate and define which strategic partnership to implement in order to ensure its future knowledge sourcing access.

In terms of the battery, the situation is different. Although the strategic relevance of the battery is also very high, the contribution to the defined future core competences of Company A of this component is low. This judgement of Company A was based on the technological proximity between their partners and the low potential for opportunism within the cell production.

The low opportunism associated with the batteries smallest component, the cell production, results from two major points. First, the investments for such a cell production would capitalize too much cash for Company A. Further, the profitability of such an investment would not support the organizations business strategy. Second, the raw material cost would currently comprise above two-thirds of the total costs of the cell. This implies that the potential for future cost reductions due to economies of scale and process improvements are smaller than the potentials implied in other components.

Facing a large capability gap, the sourcing of knowledge cannot be conducted efficiently. So they rely on suppliers for both knowledge and physical component supply.

4.5 Theoretical contribution
This work makes a contribution to the operations capability literature. It highlights the important role that sourcing will play to achieving strategic advantage in the electric sports car segment. Four key operational capabilities are emerging in the operating model. The first links to “capacity” and the ability of suppliers to be locally based so that they can deliver high-quality products and services in the minimum time (optimizing the “time-value” configuration).

The second is the “design” of the supplier network. This needs to be configured to optimize all supply chain assets and needs to be agile enough to deal with non-tangible movements in knowledge and innovation advancement. Such movements can be unpredictable and difficult to forecast.

The third relates to “supplier management.” Suppliers will add capability through their ability to be innovative and creative and increasingly be strategically positioned as service innovators and service solution providers, rather than product manufacturers. Close supplier relationships, supplier development strategies and joint partnership working on building tacit knowledge, technological know-how and innovative capacity will be the key sources of future advantage. The skills and training of buyers in new technologies such as big data and smart city technologies will enable emerging opportunities in local city markets to be identified and realised.

Finally, the fourth capability relates to the ability of the firm to “integrate” and “align” their marketing and IT planning processes with their sourcing process. The sourcing process needs to implement marketing decision instantly in the emerging twentieth-first
century market for electric sports cars if the firm is to remain competitive. The market is evolving rapidly and the fluidity of the service-product environment toward customisation requires a hyper-efficient lean production focus.

5. Conclusion
Resulting from the trend toward electric cars, the automobile industry is expected to be fundamentally reshaped. Thereby the European OEMs, including the sports car manufacturer “A,” will need to rethink and adjust their business and sourcing strategy in order to keep their superior global brand and market leader competitive position.

They are facing an unprecedented market threat from new entrants not only from the USA, but also from state-backed firms emerging in China, India and other countries. Countries, which are investing public funds to subsidize commercial firm R and D, and are fiercely pushing their firms to be market leaders in the electric sports car sector. One crucial factor will therefore be the decision upon the new component and resources setting, in which the organization needs to define which of the parts of the value creation process should be kept internal and which parts should be outsourced.

Throughout our adaption of a sourcing framework and extension to consider operational capabilities, we have begun to answer the research question:

RQ1. How the sourcing process for the supply of new electric powertrain components is being transformed?

These initial findings, we intend to expand with more advanced case study work with our firm that will involve empirical modeling of process efficiency and inventory management.

5.1 Implications for practitioners
Our work closes the gap regarding the need for practical application tools, designed for process managers, who are being confronted by turbulent, unpredictable and fast moving technological-driven market environments. Although the sourcing framework was developed to test the impact of the electric mobility trend, it can likewise be applied for the sourcing of components in other fast changing environments as well. Therefore, it can be adopted for defining the appropriate sourcing strategy for “security” and “safety” device components. This is due to the fact that the sourcing framework is governed and directed by organizational strategy, which is a considerable solid factor that remains constant in fast changing environments.

Furthermore, the basement on the strategy assures that the sourcing strategy does not interfere with the business strategy, which could cause harmful consequences. Besides the model offers a good decision guideline for management, the decision criteria for categorizing the specific component in either area could be analyzed and defined more accurately by further research. This would minimize the effect of personal bias on the categorization as well as making the strategic sourcing decision between the organizations more comparable.

Similar to any other strategic tool, the recommendations generated by the strategic sourcing framework needs to be reviewed and verified on a regular basis. This needs to be done at least in simultaneous routine as the business strategy is revised, in order to assure their alignment.

5.2 Implications for future research
In addition to more detailed operational analysis at Company A we intend to explore the role that local enablement (by smart city planners) will play in the diffusion of electric sports vehicles. We intend to build our research program to explore ten smart cities around the world to determine the impact of local infrastructure spending and policy initiatives, on the speed of diffusion of electric sports cars and the evolution of local supplier networks.
The issues of small production scale and narrow geographic scope, together with audits of local capacity and capability will provide the theoretical and practical (policy) focus for our investigation. The aim will be to longitudinally investigate (up to five years) the impact of different city eco-systems, on the sourcing of electric vehicle components (B2B) and multi-stakeholder relationships (within the context of the smart city).

The supply chain network capability impact of “public/private” hybrid initiatives such as infrastructure provision and the electric vehicle is an interesting area to explore. Whether cities are prepared to develop local production spaces to service electric vehicles and help assist in developing the skills, capacity and capabilities needed to sustain and scale up local operating models are still areas to be explored and investigated.

We are entering a new era where cars could theoretically be made and distributed locally and serviced within a city space (by a city network configured on a “low time-high value” configuration) but this will require smart city planners to work closely with the electric sports car manufacturers. How this impacts on the sourcing process, capabilities and capacity is a question we will be considering answering in our future investigations of the factors influencing the sourcing process of electric vehicle components.

Notes
1. Knowledge sourcing is the process by which organizations and individuals who are in search of certain expertise can avail them by connecting with the right individuals in the organization or through the use of external suppliers (Williamson, 2008, p. 17).
2. This acronym refers to Corporate Venture Capital.

References


Further reading


Appendix 1

<table>
<thead>
<tr>
<th>Authors</th>
<th>Operational capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peng et al. (2008)</td>
<td>Routine-based approach to studying operational capabilities. Investigate manufacturing capabilities at the plant level where they are actually realized. Two main operational capabilities as the unit of analysis “innovation” and “improvement.” Operations decisions involve assessing specific processes and resources available to determine their potential contribution to the needed capabilities, and integrating individual routines into consistent bundles to achieve the desired performance. This research contributes to this end by conceptually linking routines to capabilities and performance, thus enhancing our understanding related to the specific ways in which capabilities can be built.</td>
</tr>
<tr>
<td>Srai and Nand (2013)</td>
<td>Operations strategy refers to how firms develop and combine resources and capabilities to achieve long-term competitive goals. Capabilities are the means by which resources in a firm are arranged to effect a desired end. “Cost,” “quality,” “flexibility” and “delivery” have been identified as the main operations based capabilities. While some researchers have proposed other capabilities such as innovation, operations management researchers generally accept cost, quality, flexibility and delivery as the main operations related capabilities. The cost capability refers to how competitive a firm is with respect to the cost of producing and providing its products or services to its customers, and is generally measured as the unit cost of product/service offered. The second capability of quality refers to the extent to which the products/services that are provided meet the expectation of the customers. This is usually measured in terms of customer satisfaction levels. The delivery capability refers to the firm’s ability to meet the promised provision of product or service within a timely manner. It is usually measured in terms of deviation from expected delivery time. Finally, flexibility capability requires a firm to have the capacity to meet the contingent requirements of customers. This is usually measured as a composite of requisite variety with sufficient volume.</td>
</tr>
<tr>
<td>Kortmann et al. (2014)</td>
<td>Two ambidextrous operational capabilities, i.e., mass customization capability and innovative ambidexterity fully mediate the relationship between strategic flexibility and operational efficiency in India and the USA.</td>
</tr>
<tr>
<td>Coltman and Devinney (2013)</td>
<td>Research allocation choices managers make between 6 distinct operational capabilities (customer engagement, cross functional coordination, creative solutions, operations improvement, IT infrastructure and professional delivery) They show how these capabilities interact service context moves from a basis of commoditization to one of customization.</td>
</tr>
<tr>
<td>Xia et al. (2016)</td>
<td>They develop a software capabilities system to realize various functionalities. These include team coordination, higher visibility, co-located development and efficiency improvement in communication.</td>
</tr>
<tr>
<td>Gralla et al. (2016)</td>
<td>This work explores problem solving transport and humanitarian capabilities for dealing with urgent and ill-defined operations management problems.</td>
</tr>
<tr>
<td>Davies and Brady (2016)</td>
<td>The authors distinguish between project capabilities at the operational and dynamic capabilities at the strategic levels, arguing that firms depend on identifiable dynamic capabilities (e.g. portfolio management techniques) to know when and how to maintain current project capabilities and when to modify or replace them depending on the conditions encountered. Furthermore, the relationship between dynamic and project capabilities is found to be reciprocal, recursive and mutually reinforcing. In the proposed reciprocal relationship, the emergence of new or declining project capabilities provides indications for the strategic priorities, behaviors and future deployment of an organization’s dynamic capabilities.</td>
</tr>
</tbody>
</table>

Table AI
Summary table of operational capabilities literatures
Appendix 2. Interview guide

(1) The trend toward electric mobility is expected to have a transformational impact on the automobile industry. What do you think about this trend?

(2) Which advantages and disadvantages do you see concerning this trend? Do you see the advantages or disadvantages predominating?

(3) How does the trend affect your daily business? Did you experience any major changes?

(4) Which challenges do you see related to the trend toward electric vehicles for the total industry?

(5) Which challenges are you confronted with in your daily business resulting from the trend toward electric vehicles?

(6) Did the trend affect the composition of your business partners? If yes, please give examples.

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Unlocking innovation in the sport industry through additive manufacturing

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Abstract

Purpose – Fast-changing customer demands and rising requirements in product performance constantly challenge sports equipment manufacturers to come up with new and improved products to stay competitive. Additive manufacturing (AM), also referred to as 3D printing, can enhance the development of new products by providing an efficient approach of rapid prototyping. The purpose of this paper is to analyse the current adoption of AM technologies in the innovation process of the sports industry, i.e. level of awareness; how it is implemented; and its impact on the innovation process.

Design/methodology/approach – This work followed a qualitative research approach. After conducting a research of the current literature, this paper presents findings that include case studies from different companies, as well as a semi-structured interview with an outdoor sports equipment manufacturer. Companies from all over the world and of different sizes from under 100 employees to over 70,000 employees were considered in this research.

Findings – Literature research shows that AM brings many possibilities to enhance the innovation process, and case studies indicated several obstacles that hinder the technology from fully unfolding. AM is still at the early stage of entering the sports equipment industry and its potential benefits have not been fully exploited yet. The findings generated from the research of real-life practices show that AM provides several benefits when it comes to the innovation process, such as a faster development process, an optimised output, as well as the possibility to create new designs. However, companies are not yet able to enhance the innovation process in a way that leads to new products and new markets with AM. Limitations, including a small range of processable material and an inefficient mass production, still restrain the technology and lead to unused capability. Nevertheless, future prospects indicate the growing importance of AM in the innovation process and show that its advancement paves the way to new and innovative products.

Research limitations/implications – Limitations exist in the qualitative approach of this study, which does not include the quantitative verification of the results.

Originality/value – Very few studies have been conducted to investigate how firms can harvest AM to increase their innovation capabilities. How firms can use AM to shorten product development time is an emerging topic in business and operations but has not been studied widely. This paper aims to address this gap.

Keywords Additive manufacturing, 3D printing, Innovation matrix

Paper type Research paper

1. Introduction

1.1 Background

As part of a predicted fourth industrial revolution “Industry 4.0”, new technologies, able to produce individual products with a batch size of one as efficiently as mass production, are foreseen to replace conventional production processes (Lasi et al., 2014). One of these new technologies is additive manufacturing (AM), more commonly known as “3D printing”. The technology allows the manufacturing of one off parts in a faster and less complicated manner than conventional manufacturing processes, and represents a valuable key factor in the implementation of industry 4.0. Therefore, AM technologies gain more and more
attention and are currently being implemented in several processes in industries such as aerospace, automotive, health and others (Schiller, 2015). Now, the sports equipment industry also starts to implement this new technology (Salles and Gyi, 2012). With a strong focus on the perception of the customer, the benefits of one off parts and mass customisation, enabled by AM, can be crucial in this industry. Every human is anatomically hardwired differently, and every person therefore has different preferences in fit and form. In sports, the equipment used by athletes often significantly impact their performance: a racket that has a better grip, a suit that provides a better aerodynamic or a cleat that allows better traction. Furthermore, equipment is also a significant factor when it comes to injuries, as wrong fitting equipment can easily lead to accidents. In the fast-moving sports market, companies are constantly challenged to come up with new products that outdo the ones of the competitors and provide a good fit and performance. However, many products in the sports equipment industry have reached maturity, and can hardly be improved by conventional methods. Here, AM as a new technology can bring new possibilities into the innovation process of the sports equipment industry and enhance it to a new level.

1.2 Research objective and research question
This work therefore investigates the use of AM technologies in the innovation process of the sport sector and aims to show the consequences of this usage. Specifically, three research questions will be addressed:

RQ1. How aware is the sport industry of the potential of AM technologies?

RQ2. How is AM implemented in the innovation process?

RQ3. What impact has this implementation on the innovation process?

For this, the paper will first introduce the current literature about this topic, and afterwards develop a framework, based on the literature. The findings, which include results from seven case studies, and the interview with a sports equipment manufacturer to critically evaluate the developed framework, are then presented. Subsequently, the discussion comprises reasons for the current use of AM in the innovation process of sports equipment, as well as recommendations for the industry and future prospects. Furthermore, an analysis of the current awareness of AM processes in this industry is conducted. This paper concludes with research limitations and suggestions for further research.

2. Literature review
The term “innovation” can be defined as developing a new or improved product or process (Damanpour, 1996; Baregheh et al., 2009; Tan et al., 2015, 2017; Tan and Zhan, 2017; Chung and Tan, 2017). Since new products tend to have an increased chance of being flawed, usually prototypes are developed to undergo testing and eradicate those flaws before considerable investment is made (Pham and Gault, 1998). Especially in the sports industry, a flawless product in terms of form, fit and functionality is very important to improve the performance of the athlete on the one hand, and to avoid pain and injuries on the other hand. In the following, an overview over the innovation process in the sports industry is given, and the implementation and impact of AM in this process is explained.

2.1 Innovation in the sports industry
The general innovation process can be divided into two different approaches, the Technological Push and the Demand Pull. In the Technological Push approach, the source for innovation is represented by the producer, for example in the form of the research and development department. Science and research play an important role in this approach and an invention has to precede an innovation. This means that scientific breakthroughs
lead to new technological applications, which, in turn, lead to innovations (Hippel, 2007). The Demand Pull innovation, on the other hand, is driven by the consumer. This means the profitability of the innovation in terms of fulfilling the consumers’ needs and desires is the main driver of the innovation process (Gerke, 2016). Here, external factors “pull” the innovations into the market. The innovation process in the sports industry is influenced by a combination of those two approaches, with the main sources for innovations being the consumers and firm-internal sources (Tietz et al., 2004; Hyysalo, 2009).

The two distinctions of Technology Push and Demand Pull can be linked to the differentiation of process and product innovation, whereas the technological push represents the process innovation and the demand pull the product innovation. Utterback and Abernathy (1975) argued that the proportion of product and process innovation is depending on the maturity of the related industry in which these occur. Industries evolve similarly over time and thereby pass through three different stages or patterns, called “Fluid Pattern”, “Transitional Pattern” and “Specific Pattern”. As shown in Figure 1, with increasing maturity, the amount of product innovations decreases and process innovation increases (Utterback and Abernathy, 1975; Desbordes, 2001).

The determination of the current stage of the sports equipment industry, however, is not that easy. Since this industry encompasses a broad variety of segments, products exist in different forms and complexities and range from clothes over rackets to parts of a race car in the motor sports segment. The fact that not every type of equipment has evolved at the same time and with the same speed makes it clear that the sport industry with its various goods cannot be assigned to a specific state (Desbordes, 2002). However, it is obvious that many objects of the sports equipment industry have reached their innovative potential. This means, for example, a shoe can hardly be the target of new innovations, at least not by using conventional processes. At this point, process innovations, that lead to advances in technology, are enabling new opportunities for the innovation process (Collins J., 2015). The AM technology represents a new way of producing parts and can be the key to new innovations. The usage of this technology in the innovation process is described in the following.

2.2 Impact of additive manufacturing on the sport equipment innovation

As mentioned before, AM is already implemented in different industries and processes. Figure 2 shows an overview of the utilisation of AM in several industries. As illustrated,
the sports industry is far behind other industries, such as jewellery or aerospace, and the implementation of AM is still in its infancy. Nevertheless, the sport industry with its high technological nature, frequent product renewals and high involvement of the customer in the innovation process (Desbordes, 2002) provides several opportunities for the use of AM, which are more and more realised by companies (Gausemeier et al., 2011).

The sport sector is characterised by rapidly evolving customer demands and preferences. The fast-changing market leads to a high competition in making new designs and technologies available as fast as possible (Manoharan et al., 2013). Thus, time to market is critical for companies to be competitive and AM, as an enabler of agile manufacturing can be crucial in this competition (Gunasekaran et al., 2017). Using AM technologies for the prototyping process can have a significant impact on the duration of the entire cycle of product development, commercialisation and product launch (Manoharan et al., 2013). According to Waterman and Dickens (1994), AM can shorten the time to market by as much as 90 per cent and the tooling lead time by 35 per cent compared to conventional manufacturing, since no moulds, other toolings, or computerised numerical control programs are necessary in this technology (Morrow et al., 2007; Fireman, 2017). Additionally, with the designs being created on the computer, AM enables the opportunity to make design updates within hours instead of months, since adjustments on the digital computer-aided design (CAD) file can be made and implemented faster (Evans and Spada, 2013). This time reduction can furthermore shorten the gap between small companies and big players, since even smaller companies can alternate designs faster and provide customers with products quickly (Kappius, 2013).

Next to the benefits of a faster product development, AM provides unlimited freedom of design. By circumventing the necessity of the design for manufacturing (Mohr and Khan, 2015), a constraint that limits the design for products on those who are efficient to manufacture conventionally, products can be redesigned with a focus on other important aspects, for example enhanced functionality or material savings (Mohr and Khan, 2015). This enhances the product development process by giving opportunities for new design innovations (Huang et al., 2012). Since this can also lead to a design alternation of the product itself, AM can reduce the material consumption by up to 40 per cent by reducing both the weight of the product and the amount of waste produced (Achillas et al., 2015).
In doing so, the usage of lattice structures simultaneously increases the strength of a part, leading to an optimal strength to weight ratio (Atzeni and Salmi, 2012). The geometric freedom that allows these lattice structures also leads to the creation of new shapes. Being able to create complex interiors, and to process in non-linear direction, AM overcomes obstacles inherent in conventional processes such as milling or lathing (Jain and Kuthe, 2013; Evans and Spada, 2013). Additional benefits of this geometric freedom are the good dimensional accuracy of AM processes (Manoharan et al., 2013), as well as the use of multiple materials simultaneously (Reinhart and Teufelhart, 2011). All these factors combined can lead to the fabrication of creative new products, and therefore also provide access to new markets and therefore target a broader range of customers (Niaki and Nonino, 2017; Diegel et al., 2010; Dimitrov et al., 2012).

Another important aspect of the innovation process is the cost of developing a new product. Although traditional manufacturing is still more economical when considering mass production, AM is less costly when it comes to producing single pieces, occurring in the prototyping phase of the innovation process (Gibson et al., 2010; Achillas et al., 2015). In a study, Waterman and Dickens (1994) found that new development costs can be reduced by 60–90 per cent using AM compared to traditional prototyping. Furthermore, AM processes are less prone to errors in the production, and therefore produce less obsolete products (Jain and Kuthe, 2013). Studies by Waterman and Dickens (1994), Kim and Oh (2008) and Chowdury et al. (2012) showed that due to an accurate 3D model prior to the production, as well as the good dimensional accuracy offered by the machines, AM technologies provide less wastages and errors, leading to a saving of money.

Finally, there is the aspect of convenience. Since AM machines consume less space than most of the traditional manufacturing machines, they usually can be placed near the test site. In fact, the production becomes location independent and can be implemented where it is most efficient. This eliminates a time-consuming and costly transportation and enables a faster adjustment to necessary changes (Manoharan et al., 2013; Mawale et al., 2016). This eases the collaboration with the consumer, which is, as mentioned before, one of the main sources for product innovation in this industry (Niaki and Nonino, 2017). Therefore, consumers are integrated early in the innovation process of sport equipment (Desbordes, 2002) to form so called “prosumers”, people actively not only involved in the creation of a product, but also being its main customers, and help to enhance the innovation process by guiding the product’s development towards people’s needs (Toffler, 1980; Mohr and Khan, 2015). In fact, 10–38 per cent of users of consumer products have an impact on the development and modification of products (Franke and Shah, 2003; Lüthje et al., 2005). This shows how important the collaboration with consumers in the innovation process is, and therefore how big the impact of AM is in simplifying this collaboration.

All these factors of using AM can have a positive impact on the innovation process. Nevertheless, as AM is still in its infancy as a technology, it faces certain limits and challenges. One of the main downsides of the technology is the limitation of usable material. Although certain AM technologies have a wide range of materials in theory (any material in powder form) (Waterman and Dickens, 1994), this is not the case in practice due to the complex thermal properties of polymers and a lack of control of current laser systems (Goodridge and Ziegelmeier, 2017). Furthermore, laser-based processes require a high level of maintenance and care and their machines are still very expensive (Jain and Kuthe, 2013). This can compensate the savings due to AM technologies mentioned before. Many companies also see themselves confronted with the challenge to handle the high complexity of the CAD tools needed to develop the design transmitted to the printer. Here, experts or further trainings are needed that can increase the cost of the development process further (Gausemeier et al., 2011). Another financial aspect is the payback time of prototypes made with plastic. Niaki and Nonino (2017) discovered that companies using plastic for
prototyping perceive a longer payback time than those using metal. This is due to the
difference in the selling price, as the ones made of plastic are sold for less than the same
product made out of metal.

Keeping the mentioned limitations in mind, the impact of AM is very dependent on the
type of technique that is used. It is therefore important to consider each process’
characteristics when implementing AM in the innovation process. There have been several
studies evaluating the different AM technologies regarding their capabilities in different
categories, including Manoharan et al. (2013) or Waterman and Dickens (1994) which can be
used to critically assess the different AM techniques.

Figure 3 visualises the impact of AM on the innovation process with both advantages
and disadvantages. The attributes that are increased through manufacturing are shown on
the top, the ones decreasing at the bottom of the diagram. As discussed in the previous
literature review, there are good opportunities for companies to implement the technology in
their process, with only the cost aspect impossible to be assigned to exclusively one side.
The following chapter will develop a framework of AM in the innovation process based on
the reviewed literature.

2.3 The theoretical place of additive manufacturing in the innovation process of sports
equipment

When it comes to determine the place of AM in the overall innovation process of the sports
industry, an innovation matrix is a helpful tool to do so. Based on a research by Nagji and
Tuff (2017), innovation can be divided into three levels of ambition: core innovation,
adjacent innovation and transformational innovation. The core innovation level includes
only incremental changes to already existing products, in which company draws on already
existing assets. The adjacent innovation is a mixture between the core and transformational
innovation, and describes the advancement of something the company is familiar with into
new space, e.g. new customers or technologies. For this level, the company needs insight in
new technology, demand trends and other market variables, for extending existing
capabilities to new use. The highest level, the transformational innovation, includes the
creation of new offers or even businesses to serve new customers and markets. To achieve
these “breakthrough” or “disruptive” innovations, companies need to use unfamiliar assets, e.g. new technologies (Nagji and Tuff, 2017).

Figure 4 shows a matrix based on the ambition matrix of Nagji and Tuff (2017). The x-axis represents the novelty of technology and the y-axis represents the novelty of the customer or market, respectively. Considering the literature, it can be said that AM technologies have a high potential of enhancing the innovation process of the sports equipment industry. The fact that this new technology, and its process of developing and easily iterating prototypes enables the production of new shapes, leads to a location in the “New” column under technology. As the freedom of design that comes with AM can lead to new products and even markets, as mentioned by Niaki and Nonino (2017), Diegel et al. (2010) and Dimitrov et al. (2012), the position of AM in the innovation process can be located in the radical innovation area (white X). This would make the technology the key aspect in overcoming the stagnation in innovation currently inherent in the sports equipment industry.

3. Methodology

The aim of this research is to investigate the company’s awareness of AM, its implementation and its impact on sports equipment innovation. In order to do so, this work followed a qualitative research approach that includes case studies from different companies, as well as a semi-structured interview with an outdoor manufacturer. The objective of this qualitative research is to obtain a detailed understanding and an in-depth view of the investigated topic, by answering questions concerning the “How” and “Why” (Eisenhardt, 1989; Hennink et al., 2011).

Case studies were found to build an ideal base for this research, as they can give good insights in the practical usage of AM. In view of the fact that AM is an emerging technology with very little literature about its usage in the sports industry, this case study represents a theory generation research (Ketokivi and Choi, 2014). By choosing this kind of research, biases caused by relying on existing theory can be circumvented (Martin and Eisenhardt, 2010).
For this purpose, information was gained from several sources over the period of three months. Websites of different companies, including their own research and development blogs, as well as industry reports and AM magazines, have been studied. Furthermore, newspaper articles and articles of companies that either did an interview or a case study with the sports equipment manufacturer themselves contributed to the information used for the case studies. To verify this information from the case studies, a telephone interview with a sport equipment manufacturer was conducted (see Appendix for the interview questions). Low cooperativeness from other companies to participate limited the number of interviews to one. Among the rejections for interviews, only one company explained its denial with the lack of possibilities of AM for their company.

Information was sought from different companies, as the information gained from multiple sources is considered more conclusive, which overall results in a more resilient study (Herriott and Firestone, 1983). Targeted companies underlay the condition of having their business area in the sports equipment industry. This can range from clothing equipment over protection material to external equipment like golf clubs or rackets. Right at the beginning, however, the motor sports industry was excluded. Since its nature is far more technical based in comparison to the aforementioned segments, it is not easily comparable to the other sectors of the industry and its investigation could weaken the results of this research. Other than that the characteristics of the targeted companies did not underlie any further conditions. Following a theoretical replication approach (Yin, 1994), a heterogeneous sample with companies from all over the world and of different sizes from under 100 employees to over 70,000 employees enables an even bigger diversity. With regard to the intended diversity, the cases include protection equipment, external equipment from the category “bats, rackets, and other instruments”, outdoor equipment such as surfing and skiing, and clothing equipment such as shoes, with the latter being the most common sector for the use of AM and therefore discussed in more detail than the others. After seven case studies, the data collection was completed, since similarities in the gained information occurred multiple times. This suggests that saturation needed for this approach is reached and the investigated topics have been processed (Glaser and Strauss, 1999).

Getting information from an interview and from this form of case studies that relies on information presented by the company, always underlie a bias (Kvale, 1994). It needs to be kept in mind that the companies usually want to justify their decision of implementing AM in the innovation process by only showing the positive aspects of the technology and downplay possible disadvantages or obstacles. Therefore, the information needs to be handled with care.

By combining case studies and an interview as described in this chapter, a comprehensive insight about the awareness of AM in the real-life business can be gained and different views about its implementation can be shown. This is needed for the verification of the developed framework and to answer the research questions of awareness, implication and impact of AM on sports equipment innovation.

4. Findings
4.1 Case studies
The first group of investigated companies are using AM technologies to enhance the innovation process of footwear. The first company, the American sports company Nike, started implementing the technology in 2013 to prototype a plate for a cleat. The benefits in using AM enable Nike to prototype a fully functional plate in a fraction of the usual time that is needed by continuous collaboration with the athlete (Nike, 2013). They continued the utilisation of AM technologies over the years and were able to prototype 30 different versions of the plate for its latest product, the Zoom Superfly Flyknit, reducing sampling time from weeks to days. The possibility to reduce weight, test and quickly iterate
products, enable superior final products. This substantiates the implementation of AM in the innovation process of the company (Nike, 2016).

Nike's competitor, the German sportswear manufacturer Adidas, implemented AM to reduce the time required to create a prototype to one to two days. Without AM, a prototype shoe consumed the workforce of 12 technicians and took from four to six weeks to complete (Maxey, 2013). Using AM to create a running shoe midsole, enabled Adidas to reduce weight and increase the flexibility of the product, without reducing its stability (Materialise, 2017). With the aim to use AM in mass production, Adidas is collaborating with the technology firm Carbon to implement a new AM process that can fulfil these requirements (Iglesias, 2017; Collins T., 2015). This collaboration enabled Adidas to produce prototypes the same way the final (mass) product would be produced. Therefore, the prototyping process becomes obsolete and Adidas can perform the testing on the actual end product, which means a shortening of the entire production cycle (Carbon, 2017; Adidas, 2017). In the long run, Adidas plans on producing customised shoes immediately and in store, after a digital measurement of the customers' feet through foot scan technologies, to provide the ultimate personalised experience (Materialise, 2017).

The third company using AM in footwear is the American company New Balance. To create a 3D printed plate for a running shoe, New Balance generates biomechanical data of the athlete to develop a 3D model, entailing a close and continuous collaboration with the athlete (EOS, 2017; New Balance, 2013). Benefits for the company include a 5 per cent weight reduction (EOS, 2017), unmatched geometry by conventional methods, leading to a highly flexible but durable part (New Balance, 2016). However, the production is rather labour intensive. The sole needs several hours to print, and after completion every sole needs to be removed from the powder, cleaned and processed separately, and then sent to the assembly and finishing department (Grunewald, 2016). Nevertheless, New Balance sees further benefits in using the technology, including the possibility to produce on demand, to make updates without continuous investments, as well as to adjust the process to individual sizes (New Balance, 2016; EOS, 2017).

AM is also used in the innovation process of exterior sport equipment. The American Golf equipment manufacturer Cobra Puma Golf started using the technology in the early 1990s. AM increases the efficiency in the prototyping process in terms of time and money, as conventional methods are time intensive and constant iterations cause high investments. Furthermore, the conventional process usually allows only simple designs, compared to the new possibilities that can be created with AM. However, the outcome of the 3D printing process is only a prototype and since its polymer is weak and brittle, it cannot be used for actual impact testing. Therefore, AM is only used to verify the design in a CAD programme and to perform non-destructive measurements and test, such as aerodynamic tests, on the golf club (Kennedy, 2017).

The American winter sports equipment manufacturer Burton Snowboards uses AM to develop a new form of binding for snowboards, which allows the snowboarder to mount the snowboard by stepping in the binding instead of strapping it around their shoes. This has always been an insoluble challenge for manufacturers. With the use of AM for the prototyping process, Burton was able to overcome hurdles by circumventing design constraints, and by continuously and immediately test and iterate the product until a functional product was developed (Scott, 2016; Bradstreet, 2016).

The Austrian company Red Bull teamed up with the Canadian 3D printing bureau Proto3000, to 3D print an entire surfboard (Rakic, 2017). The aim was to create an exact duplicate of an already existing board. Since human error that occurs with the conventional manufacturing of surfboards, makes it hard to shape a board consistently and therefore to produce several boards that are exactly the same, AM is supposed to circumvent this obstacle. The prototyping process took about a month, including the printing of the board in ten different pieces over the time of 100 hours, until an acceptable prototype was created (Scott, 2017; proto3000, 2017). Apart from the weight of the 3D printed board, which was
almost three times heavier than the original, the replication was successful in terms of shape, angles and other nuances (Rakic, 2017). To adjust the weight, proto3000 is working on a dissolvable core that serves as a frame or ribbing of the board. After wrapping the fibrous material around it and sealing it, the core will be dissolved away, leading to a seamless wrap and a board, that is as light as the original (Proto3000, 2017). This represents a combination of the new AM technology and the traditional concept of a fibreglass wrapped board, combining complex design possibilities with reduced weight (Rakic, 2017).

Finally, the Austrian body protection company Zweikampf implemented AM to develop a three-part shin guard system that eliminates issues resulting from bad fitting of mass produced shin guards. The shin guard is designed in a y formed honeycomb structure, which absorbs and diffuses the impact by distributing the force throughout the structure, leading to a tough and durable product (Grunewald, 2017). Next to the complex design, AM enabled the company to reduce weight and thickness and simultaneously increase the strength of the guard. Furthermore, every shin guard is tested inhouse and external regarding its performance (Millsaps, 2016). Similar to Adidas, this company represents an example for the merging of prototyping and final product production.

These case studies represent the implementation of AM technologies in the practical, real-life context. Table I shows an overview of these different case studies and their use of AM in the innovation process. The level of innovation indicates how innovative or new the product manufactured with AM is. Since every company apart from Burton did not invent any new products with the implementation of AM, but only improved existing products, the level of innovation is predominantly low.

4.2 Interview

The interviewed company asked for anonymity and is therefore referred to as “company A”. Only selected parts of the interview will be quoted for clarification and illustration of the resulting data.

Company A is a manufacturer of outdoor sports equipment, including ski, trekking and hiking equipment, with their main products being sticks. With less than 50 people working

<table>
<thead>
<tr>
<th>Company</th>
<th>Sector</th>
<th>Product</th>
<th>Reasons for implementation</th>
<th>Level of innovation</th>
<th>Customer involvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nike</td>
<td>Footwear</td>
<td>Spikeplate for cleats</td>
<td>Time savings, continuous iteration, weight reduction, possibility of new shapes</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Midsole for running shoe</td>
<td>Reduce man hours needed, weight; increase flexibility, consistent mechanical properties, high resolution and surface finish, shorten development cycle</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Adidas</td>
<td>Footwear</td>
<td>Plate and sole for running shoe</td>
<td>Reduce weight and turnout time; unmatched geometry; increase flexibility and durability; economical product iterations</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>New Balance</td>
<td>Footwear</td>
<td>Golfclub</td>
<td>Reduce prototyping time and cost; more iterations possible; more design possibilities</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Cobra Puma Golf</td>
<td>Golfclubs</td>
<td>Golfclub</td>
<td>Reduce prototyping time, weight and material; continuous iterating and testing; circumvent design constraints</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Burton</td>
<td>Snowboards</td>
<td>Snowboard binding</td>
<td>Eliminate human errors; produce accurate and complex designs</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Red Bull and</td>
<td>Surfboards</td>
<td>Surfboard</td>
<td>Savings in time and money; customisation of products; increased durability; reduced weight and thickness</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Proto3000</td>
<td>Protection</td>
<td>Shin Guards</td>
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Table I. Companies overview
inside the research and development department, and approximately 250 employees in total, the company represents a rather small enterprise. On a yearly basis between two and five new product developments are generated, which, however, are not limited to just one product. If, for example, a new handle is developed, it is likely to be used on different models and products. This rate of innovation is reflected in the general approach towards new technologies, where the company is located somewhere in the “first follower” role:

I would say we are in the front third. Probably not all the way at the front, because it is known, that the first [companies] invest rather more money or maybe have to pay dearly. But we are in the front third, we are always making an effort to apply or implement new technologies.

Therefore, the awareness of AM in the company is high. After joking about implementing AM a few years ago, now the company uses the technology for about three years for prototyping purposes. The company sees the benefits of AM in the rapid production of prototypes, as well as savings in costs, compared to conventional methods such as casting. Furthermore, the possibility to illustrate designs to employees from other departments with an actual tangible product, rather than showing a digital file on a computer, eases the imagination of the final concept, making communications easier. Another benefit compared to conventional method lies in the opportunity to let the production of bigger or multiple parts run over the weekend and therefore use time that is normally idle as well.

Next to the benefits, the company recognised several disadvantages and challenges that come with the use of the AM technology. For one, physical testing on the prototypes often requires an alternation of the product, e.g. a greater wall thickness, since the material used for AM does not represent the attributes of the material used for actual production. For another, since the prototypes look like a final product, it can lead conclusion that the product will be available immediately. However, since it is just a prototype, still time for the real production needs to be considered:

[…] it looks pretty fast like the product would be ready and already available, but this is only the prototype. Back in the days, a prototype looked kind of like a hand carved model and nowadays it looks pretty fast finished with the design and all. But that is simply not the case, because then actually still the injection moulding needs to be done, where up to two month of tool completion needs to be taken into account.

The information generated from this interview demonstrates that also a small company is able to implement and use AM in the innovation process. By rapidly and cheaply producing prototypes and easing the presentation of ideas, the technology enhances the innovation process. However, physical testing and misinterpretation in terms of availability of the final product still pose challenges for the company’s usage of AM.

5. Discussion

5.1 Reasons for the implementation of AM in the innovation process

After studying the recent literature about the innovation process in sports equipment and the role of AM in this industry, as well as generating real-life data from several case studies from different companies and from an interview, the similarities between theory and practice became obvious. Here, three main reasons for the use of AM in the innovation process emerge.

The argument by Manoharan et al. (2013) and Waterman and Dickens (1994) that AM increases the prototyping speed and therefore accelerates the entire development process is the first main reason why almost every company from the case studies, and also Company A from the interview implemented this technology. The possibility to a faster testing and iterating of the product, and therefore a faster elimination of flaws, enables a better final product than conventional manufacturing does. Even though the case of Red Bull and
Proto3000 indicated that some products cannot exploit the benefit of speed provided by AM, the interview showed, the use of the idle time, e.g. the weekend, can compensate the longer printing time for certain products.

Second, the convenience factor was dominant in the literature, case studies and the interview. The enhanced collaboration with stakeholders, i.e. athletes or other departments, has a significant impact on the quality and the performance of the final product. The compact build of most printers and the resulting flexibility of production location enable an efficient work with athletes by prototype, test and iterate location independently. In the sport industry, this collaboration is particularly important, as the athlete's performance, as well as their health, are subject to the performance of the product. This became clear in the Burton case study, where the numerous testing and iterating of the product led to a binding superior to earlier attempts. Also in Adidas future vision, where the production of shoes will take place right at the store and therefore with close involvement of the customer, this convenience plays an important role.

Third, there is the possibility to create designs and shapes that were not feasible before. As mentioned before by Mohr and Khan (2015), Huang et al. (2012) and Evans and Spada (2013), the freedom in design led to more flexible and durable parts in the production of shoe soles and plates, made the exact duplication of a surfboard possible, and improved the quality in protection equipment.

All the benefits of AM lead to the facilitation of the innovation process and therefore to the ease of product development. Being able to prototype hundreds of different iterations in a rapid manner led to the improvement of long established products, such as cleats, as well as to the development of newer products, such as new bindings for the snowboard industry.

An overview over the impacts of AM on the innovation process that compares the findings from the literature to the findings from the case studies is shown in Table II. However, with regards to the framework developed in Section 2.3, the case studies and the interview showed that the benefit of freedom of design mentioned in the literature can only be verified to some extent. Figure 5 shows the innovation matrix with integration of the cases and the interview. Each black circle represents a company from the case studies and the green circle represents the interviewed company A, all of which are located in the technological breakthrough area. The new technology is mostly used to slightly improve already existing products, such as the sole for cleats, or the shin guards, by using new forms of designs, such as lattice structure. Nevertheless, so far only existing customers and markets can be satisfied with these developments. With the production of a new binding,
Burton indicated how the technology could help in the development process and lead to a new product. As this still does not represent a significant new development, the mentioned possibilities for creative new products and therefore new markets could not have been confirmed by the case studies nor the interview. Considering this, the overall role of AM in the innovation process therefore must be moved from the radical innovation to the edge of the technological breakthrough in the adjacent area (white X).

A further factor from the literature that cannot be verified completely is the savings of cost when using AM, since only one of the cases (Cobra Puma Golf) and the interviewed company mentioned costs as a reason for the implementation. Further interviews would be helpful to see, if the cost aspect plays an important role in the implementation.

5.2 Current awareness of AM, recommendations for the industry

Figure 5 in Section 5.1 shows that AM is currently not leading to radical innovations and new markets. This is likely to be due to the early stage of the technology. Considering the fact that AM is still evolving and has room for improvements, the potential to open new markets does exist. For this, two main advancements are necessary. The first one includes the range of process able material. As described in the literature and in the interview, the nowadays useable material for AM processes can introduce certain challenges to the prototyping process. With more and more different materials becoming available to use for AM, the range of properties and product characteristics manifolds, leading to more application possibilities. The second and more important advancement is the possibility of meeting the demand of a production line. This means that even if AM leads to the invention of a completely new product, it cannot open new markets. For one, AM cannot be used efficiently for mass production yet. For another, conventional mass manufacturing underlies the design of manufacturing. As this has most likely been circumvented by AM in the innovation process, the new created product is unlikely to be prototyped with AM and then mass produced with conventional processes, due to a limitation in the production capabilities of the latter.

Showing again an alternated matrix from the framework, Figure 6 illustrates the possible future role of AM in the innovation process, given that the two mentioned factors will develop and improve over time. It shows that AM moves into the Radical Innovation field as
described in the literature, and really becomes a Transformational Innovation, generating new customers and opening new markets.

Next to the reasons for the implementation of AM, the investigation showed that the awareness of the new technology in the sports equipment innovation process is still very low. Figure 2 by Gausemeier et al. (2011) illustrates that the sports industry is significantly lacking behind in implementing AM technologies. Considering the number of companies that have been contacted for this work and did not reply, as well as the fact that 18 companies denied help because of not using this technology or not being familiar with it, it is likely to say this industry is indeed not very aware of the potentials of AM.

This unawareness, however, seems neither to be due to too high investment cost, nor to be in any relation to the size of a company. Small companies such as the interviewed company, as well as Burton (approx. 400 employees worldwide and a revenue of approx. $40m), and especially Zweikampf as part of Bernstein Innovation only having ten employees, also the smallest companies managed to implement AM technologies in their innovation process. Compared to these firms, the big, established companies such as Nike, New Balance and Adidas can draw on much more resources, and still did not achieve more significant process improvements. The fact that size and revenue are not in relation to the possibility of implementing AM supports the argument made by Kappius (2013) that small companies could equal disadvantages and become more competitive to the bigger companies.

Finally, it is not possible to say AM technologies are definitely enhancing the innovation process of every company. Appropriate material that represents the final product’s material as accurate as possible, and the dimensions of the prototype must be considered by companies before the decision of implementing AM is made.

6. Conclusion
The purpose of this research project was to investigate the industry’s awareness of AM, its implementation and its impact on the innovation process of the sports equipment industry. The results of this research show that the use of AM technologies in the innovation process...
of sports equipment can have a significant impact on both innovation speed and output. By using AM for the creation of prototypes, the possibilities of fast iteration and testing, combined with the creation of shapes that are not possible with conventional manufacturing, lead to optimised final prototypes in a shorter timeframe than with traditional prototyping processes. The fact that the prototyping process can take place where it is most efficient enhances the collaboration with the consumers, or “prosumers”, which is key in the sport industry. This enables the production of equipment that provides a superior performance. Although the literature states that AM leads to entirely new products and therefore can open new markets, this could not be confirmed by the information generated from real-life companies. The sports industry’s current awareness of AM technologies is still very low and not even close to the level of industries such as the aerospace industry or the jewellery industry. In addition, the technology itself is still evolving, meaning that there is still room for improvement. Especially the low range of processable material and the slow speed for mass production withhold the technology from making the major changes in the innovation process of sports equipment that can lead to new products, customers and markets.

6.1 Implications for theory
This work contributes to the existing literature in the fields innovation and AM, and with the latter to the theory of agile manufacturing. By showing how AM is used in a real-life context, the results represent a counter view to the existing literature and put the many theoretical benefits of the technology into perspective. Therefore, a broader picture is generated. Furthermore, the work is relevant for the literature in the fields of Industry 4.0 and Internet of Things, by showing a digital and connected way of the innovation process.

6.2 Implications for practice
This paper shows that AM technology can be implemented by companies of all sizes. Furthermore, it gives good examples on how AM can be used in the innovation process and what the outcome of this usage is. Companies that have not implemented AM or are completely unfamiliar with this technology can use this paper as a guideline and aid in their decision process of implementing the new technology in their innovation process or not.

6.3 Limitations
Limitations exist in the qualitative approach of this study. Especially in this case, with only one source for primary data, there was no possibility to verify the generated information. Although several companies were contacted as potential interview partners, the unwillingness for cooperation made it impossible to avoid this limitation. Additionally, every company underlies a certain bias of justifying the investment in AM for the innovation process, and therefore is likely to understate downsides of these technologies. Independent observers could circumvent this bias and put focus on the downsides as well.

As mentioned before, the sport industry and its equipment are very customer focussed and build around the perception of the consumer. Therefore, the generated theory in this paper is very context specific and represents a theory in use (Voss et al., 2016). Further research is therefore needed to quantitively review and verify the findings generated in this study and to expand the findings on other industries. Furthermore, only western companies were investigated, which leaves China, as one of the biggest player in the industry, to the subject of further research. Finally, since this work only focussed on the innovation process, it is important to see how AM can be implemented in the manufacturing of end products, to determine the progress that has been made and to see, how realistic Adidas’ vision of mass customisation is.
References


Appendix. Semi-structured interview guideline

Background

(1) What is the main business area of your company?

(2) How many workers are employed in the development department?

(3) How much money is annually invested in the innovation process?

(4) How many new products are developed (e.g. per year)

AM focus

(1) How would you assess the attitude of the company towards new technologies on a scale from 1 (early adopter) to 10 (forced adopter)?

(2) How high is the level of awareness for AM technologies in your company from 1 (not heard from it) to 10 (implemented in the company)?

(3) Since when are you using this technology?

(4) What technologies specifically are used? How many machines are currently in use?

(5) Why? What was the trigger for the implementation and what benefits are you gaining from the use of AM technologies?

(6) Have you noticed any disadvantages and challenges with this technology?
(7) What is going to happen in the future for your company in this area?
(8) What needs to be changed/improved on current AM technologies?
(9) Can you name an example development you made with using AM technologies?

After a short introduction about the topic, information about the background of the company was gained. The main part started with a broader opening question, followed by the key questions. At the end, again a broader closing question was asked to finish the questioning (Hennink et al., 2011).

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IT capabilities, firm performance and the mediating role of ISRM
A case study from a developing country

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Abstract
Purpose – The purpose of this paper is to develop and test a research model that looks at the direct impact of information technology (IT) capabilities on firm performance and the mediating effects of the information security management system (ISMS) on this relationship.
Design/methodology/approach – The study uses a hypothetico-deductive approach based on quantitative data collected from 136 surveyed professionals in the field of IS, IT and the related security environment.
Findings – The results confirm the direct impact of IT capabilities on firm performance and the mediating effects of ISMS on this relationship.
Originality/value – The study draws on the resource-based view theory to develop a model that assesses the direct impact of IT capabilities on firm performance and the mediating effects of ISMS on this relationship in Cameroon, a developing country in Africa.

Keywords IT capability, IS success model, ISRM, Maturity level, Firm performance

Paper type Research paper

Introduction
In the current IT-dominated age, information has become the primary asset of any ambitious organization, and the quality of management decision is completely dependent on information. Information capabilities span a wide array of domains: enhancing business operations; facilitating management decision making; and deploying business strategies (Silva et al., 2014). Moreover, IT capacities bring performance to business (Lee et al., 2007; Yeh et al., 2012). Yet, companies that have integrated relevant IT capabilities may experience other serious challenges to their performance, especially when it comes to value creation. Computer attacks are known to be among the causes of these challenges, as maintaining and safeguarding the confidentiality, integrity and availability of information is a tough assignment for firms which are eager to protect their strategic value (ISO/IEC, 2013; Silva et al., 2014).

According to Knowdys Consulting Group, cybercrime has a very negative impact on the economic development of Sub-Saharan African enterprises. For example, in 2014, cybercrime costs between $12,000 and $13,000 per day to businesses based in West Africa (Knowdys Consulting Group, 2014). In fact, the literature confirms that SMEs in Africa face numerous obstacles to their development, notably as regards information security, because there is a shortage of skilled human resources, IT resources and support (Dubelaar et al., 2005). Moreover, the today’s global connectedness and the quickly evolving nature of ITs have made technology-driven security solutions inadequate to meet information security challenges (Hall et al., 2011). In this context, an organization can be cyber-attacked even when its IT capabilities are good. Examples of common cyber-attacks include login usurpation of non-IT employees by means of social engineering, which harms the organization and undermines its performance, and targeting and attacking a dismissed...
employee whose login information was not withdrawn from the list of authorized users. Therefore, protecting IT information has become a key economic challenge for organizations seeking to ensure a permanent security of both their information and the related technology (Weishäupl et al., 2015). Additionally, even though firms have been investing increasingly in information security and in their strategic role in today’s business success, an effective implementation of information security strategy remains one of their top challenges (Ernst & Young, 2011). It should be recalled that while information security is crucial to the survival of any serious organization, it can only be guaranteed by the information security risk management (ISRM) (ISO/IEC, 2013), whose importance is always remarkable when IT capabilities naturally expose the organization to information security risks or IT risks (Carcary, 2013; Ernst & Young, 2011).

Thus, in this study, we investigate the impact of integrating an information security system into enterprise performance. Is an information security system embedded into the IT structure of an organization enough to trigger its performance? The literature on IS indicates that the relationship between information technology (IT) capabilities and organizational performance appears to be a widely studied topic and related findings are being used by decision makers (Huang et al., 2009). Despite the importance of IT capabilities within an organization nowadays, it is difficult to link them with the anticipated benefits for an organization (Wade and Hulland, 2004). The resource-based theory (RBT) was developed to sustain that a company with resources has a competitive advantage that can be maintained for a long term to enhance performance. This is a key theoretical perspective that explains the relationship between IT capabilities and firm performance (Addas and Pinsoneault, 2007; Bharadwaj, 2000; Wade and Hulland, 2004). According to RBT, resources are static while our environment is dynamic. Taking into consideration that a company must always fit one’s surroundings, RBT alone cannot explain the impact of IT capabilities on firm performance (Huang et al., 2009).

Some scholars suggest that a positive link between information system investments and firm performance may be explained by several other factors that aim at identifying the indirect benefits of ITs (Akter et al., 2016; Huang et al., 2009; Wamba et al., 2017). Hence, IT capabilities cannot fully explain the performance of an organization. In particular, different mediator constructs are being used in the link between IT capacities and firm performance, such as total quality management, the ability to use resources and process-oriented dynamic capabilities (Anand et al., 2013; Huang et al., 2009; Mooney et al., 1995; Wamba et al., 2017). We have not identified any study about the mediation effect of information security in relation to IT capabilities and firm performance conducted in a developing country in Africa, this confirms the originality of this study. On the presumption that IT capabilities cannot only have a direct impact on firm performance, our study aims to examine the following research question:

**RQ1.** Does ISRM mediate the relation between IT capabilities and firm performance?

To address this research question, this study draws on the literature on IT capabilities, RBT and dynamic capability (DC) to build a research model, hypotheses and a research design. Other sections deal with data analysis, the presentation of findings, the discussion for the study and implications for research and practice.

**Background**

**RBT and IT capabilities**

Numerous authors (Pratono, 2016; Niehaves et al., 2014; Rahimi et al., 2016; Brocke et al., 2014) approve the primary statement of contingency theory which supposes that the organizational structure of an enterprise is determined by the scientific, economic and technological characteristics of its environment. Thus, Tan et al. (2016), in the context of
supply chain management, corroborated that information and knowledge are both critical resources which are determinant of enterprises that intend to gain essential value from their relationship with business partners. To address the technology characteristic in this study, two complementary theories are used: RBT and IT capability.

Within the IS discipline, IT business value is one of the most discussed topics, and RBT appears as an in-depth perspective for its analysis. RBT considers the firm as a complex set of assets, humans, knowledge and processes. RBT was developed to argue that a company endowed with resources is able to have a sustainable competitive advantage for the firm’s performance (Bharadwaj, 2000; Wade and Hulland, 2004). This advantage can be maintained because any company is able to protect itself against skills and technology transfer or imitation. RBT categorizes IT resources in six major domains (Wade and Hulland, 2004), namely assets, core competencies, marketing resources, IT infrastructure, managerial IT skills and IT capabilities (Huang et al., 2009). On the other hand, Bharadwaj (2000) suggested and validated six dimensions for measuring firm IT capabilities: IT/business partnerships, external IT linkages, business IT strategic thinking, IT business process integration, IT management and IT infrastructure. Her study revealed the reliability of each dimension and this was validated by a psychometric test on a sample of IS executives. Therefore, using RBT to assess the impact of IT capabilities on firm performance makes sense.

**IT capabilities and firm performance**

The positive link between IT capability and firm performance has been tested in several contexts, especially in developing countries, as it is the case in this study, with a wide range of results (Behera et al., 2015; Lee et al., 2007; Daulatkar and Sangle, 2015; Wong and Wong, 2011). Thus, it is now accepted that IT capabilities are now considered as a competitive advantage enabler within an organization because of their high operational and strategic potential. Many study argue that IT technological resources and IT managerial resources have a significant positive effect on firm performance (Addas and Pinsonneault, 2007; Akter et al., 2016; Anand, 2013; Bharadwaj, 2000; Lee et al., 2007; Yeh et al., 2012; Chuang and Lin, 2015; Mithas et al., 2011; Awashti and Sangle, 2012; Daulatkar and Sangle, 2015; Liang et al., 2010; Wamba et al., 2017). For example, IT capabilities have a significant positive effect on financial performance (Anand et al., 2013; Bharadwaj, 2000; Santhanam and Hartono, 2003), marketing performance (Anand et al., 2013; Mithas et al., 2004), administrative performance (Anand et al., 2013; Mithas et al., 2004) and efficiency performance (Liang et al., 2010). According to Kim et al. (2012), IT management, IT personnel and IT infrastructure are dimensions of IT capability in the sociomaterialistic perspective. Characterized IT capability is, in terms of “unidirectional and unrelated conceptualization,” a major highlight of sociomaterialistic-based modeling and completes the IT capabilities identified.

Based on some studies, only acquired IT resources seem to ensure good firm performance, but Wade and Hulland (2004) sustained that IT resources are necessary but not sufficient for good firm performance. Moreover, regarding the RBT and IT capabilities, it appears that resources are static while our environment is dynamic. The fact that a company should always fit its surroundings has raised the need for dynamic capability (DC) theory, according to which resources should be developed and integrated within a company. Teece et al. (1997), pioneers of this theory, defined the DC as the ability to integrate, build and reconfigure internal and external skills to adapt to rapid environmental changes. It is well agreed that the RBT facilitates the choice of resources while DC enables development and renewal of these resources (Eisnerhardt and Martin, 2000; Teece et al., 1997). As such, the DC theory fills the gap dynamically with a process orientation between resources and the environment; Teece et al. (1997) said that this issue is closely tied to the firm’s business processes, market positions and expansion paths. In the IT domain, ISRM is one of the
activities that are being used to develop, renew and improve IT technology resources and IT management resources (ISO/IEC, 2011). Regarding the ISO/IEC 27005:2011 standard, ISRM is process based and can be used further as an input for operating firm business processes, market positions and expansion paths. Because ISRM is process based as a standard and as a tool (ISO/IEC, 2011, 2013), the DC theory permits its utilization for studying the effect of IT capabilities.

Research model and research hypotheses

Drawing on the literature on IT capabilities, this study proposes the research model shown in Figure 1 using RBT and DC. This study proposes IT capabilities as three second-order constructs: IT management capability, IT personnel capability and IT infrastructure capability, based on the sociomaterialistic theory (Kim et al., 2012; Wamba et al., 2017), as well as five first-order constructs: planning and design, planning for IT standards and controls, tangibility, flexibility and capability (Bharadwaj et al., 1999). This study also argues that IT capabilities impact firm performance in two ways: directly and indirectly with the mediation of ISRM.

In relation to RBT, IT management capability, IT personnel capability and IT infrastructure capability are the three key components of firm IT capabilities. Former studies argue that IT capabilities have a positive significant effect on firm performance. For example, Anand et al. (2013) exploited 100 case studies documented between 2002 and 2012, and concluded that firm IT capabilities (IT management capability, IT personnel expertise and IT infrastructure flexibility) have a significant positive effect on performance improvement at the organizational level (financial performance, marketing performance and administrative performance).

Other authors have studied the mediating effect of processes on the relationship between IT capabilities and firm performance. For example, Lin (2007), Anand et al. (2013) and Wamba et al. (2017) found that process-oriented DC mediates the relation between IT capabilities and firm performance. Likewise, Huang et al. (2009) designed a method to validate the positive mediating effect of IT innovation on the link between IT capabilities and firm performance. Regarding the process-oriented DC and cyber criminality (in constant evolution), ISRM is a good candidate to act as a mediator construct between IT capabilities and firm performance. In this case, ISRM should be considered as a process drawing on the ISO/IEC 27005:2011 standards which identify six activities: context establishment, risk planning and design, planning for IT standards and controls, flexibility, capability and tangibility. ISRM aims to mitigate the security risk of cyber crime.

![Figure 1. Research model](image-url)
assessment, risk treatment, risk acceptance, risk communication and risk monitoring and review. These six activities were assessed to determine the maturity level of ISRM.

Based on these observations, our study suggests to test not only the direct effect of IT capabilities and firm performance but also the mediating effect of ISRM on the relationship between IT capabilities and firm performance. Therefore, our research hypotheses are:

**H1.** IT capabilities have a significant positive effect on firm performance.

**H2.** IT capabilities are positively connected to ISRM.

**H3.** ISRM is positively connected to firm performance.

### Research method

To verify our different hypotheses, we used a hypothetico-deductive approach using quantitative data collected during a survey. Such an approach has proven its efficiency and reliability in the field of social sciences, through the structural equation modeling (SEM) method and the partial least square (PLS) method. The PLS-SEM method has been successfully used to analyze our models and theories when developing our research model.

Our sample comprised IT professionals and managers from selected enterprises. Our survey, with 41 questions, was structured into two parts: 35 questions using a seven-point Likert scale to measure IT capabilities and firm performance, and 6 questions using a five-point Likert scale were formulated and administered to measure the ISRM maturity level. Out of the 485 online questionnaires that were sent to potential respondents, a total of 136 were found with zero missing value by online survey. This number was appropriate for our study according to Cohen (1992) and Hair *et al.* (2014). The demographic profile of respondents is given in Table I. Also, no difference was found between early respondents and late respondents.

Data analysis was being carried out using SmartPLS software, and comprised three steps. First, we realized quality analysis of our different constructs using outer loadings (Hair *et al.*, 2017), discriminant validity (Henseler *et al.*, 2015), composite reliability (Nunnally and Bernstein, 1994), AVE (Hair *et al.*, 2017), Cronbach’s $\alpha$ (Hair *et al.*, 2017) and Fornell–Larcker criteria (Fornell and Larcker, 1981; Hair *et al.*, 2013, 2017). Second, we tested the significance of each relation so as to confirm the different formulated hypotheses. Thus, we applied the SmartPLS bootstrapping method with 5,000 bootstrap samples, as

<table>
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**Table I.** Demographic profile of respondents
recommended by Hair et al. (2017). The significance indicator is the Student $t$-statistic and $p$-value (Hair et al., 2017). Finally, we will analyze mediation effect of ISRM in order to address the nature of indirect relationships between IT capabilities and firm performance (Baron and Kenny, 1986; Nitzl et al., 2016; Preacher and Hayes, 2008; Sobel, 1982).

Results (confirmatory factor analysis using PLS-SEM)

In order to assess the high-order IT capabilities model, this study applies PLS-SEM in order to estimate the hierarchical models by removing the uncertainty of inadmissible solutions by means of its flexible assumptions (Hair et al., 2014, 2017). We apply PLS-SEM with a view to obtain very reliable results using a few data samples. Wamba et al. (2017) used the PLS path modeling to estimate a third-order reflective big-data analytics capabilities model. In the reflective model, the manifest variables are affected by the latent variables, contrary to the normative model. Reflective constructs are generally viewed as giving rise to its indicators.

Measurement model

In order to assess our research high-order model, we used the SmartPLS v3.2.6 (Hair et al., 2014) software, which enables an estimate of parameters in the inner and outer models. We applied PLS-SEM using the PLS algorithm and bootstrapping with 5,000 subsamples (Fassott et al., 2016; Hair et al., 2013, 2017; Henseler et al., 2016). Prior to assessing the structural model, descriptive statistics on the constructs were described (see Table II) and the measurement model was evaluated in terms of indicator reliability, internal consistency reliability, convergent validity and discriminant validity (Hair et al., 2013).

In the first place, we confirmed the indicator reliability as all the items were significantly loaded on their elected constructs. The confirmatory factor analysis showed that all the item loadings were greater than the threshold of 0.7 (Fornell and Larcker, 1981), except IIT1 (0.637) and IIT2 (0.698) for IT capabilities constructs. These values are also acceptable because they are greater than 0.4 (Hair et al., 2013). Second, the internal consistency reliability was also validated using the Cronbach’s $\alpha$ and composite reliability, which exceeded the threshold of 0.7 for all the constructs (Nunnally and Bernstein, 1994). Third, the convergent validity was established by the average variance extracted (AVE) of each construct, which exceeded 0.5 (Hair et al., 2017). The high AVE of our constructs indicated that the observed items explained more variance than the error terms. Finally, we confirmed the discriminant validity of each construct, which suggested that the measurement model (using the Fornell-Larcker criterion) was good for this study. We found that the square root of the AVE’s first-order construct was higher than its correlation with other first-order constructs (Table III). This means that any first-order construct is different from another in our research model.

Structural model

The structural model established a significant effect of IT capabilities and ISRM on firm performance with path coefficients of 0.433 ($p < 0.001$) and 0.358 ($p < 0.001$), respectively, explaining 47.7 percent of the variance (see Figure 2). IT capabilities enhanced ISRM with a path coefficient of 0.522 ($p < 0.001$), explaining 27.2 percent of the variance. Therefore, all three hypotheses ($H1$–$H3$) were supported as the path coefficients were significant at $p < 0.001$ (Hair et al., 2017). The $F^2$ concerning $H1$ (0.261) and $H3$ (0.179) indicated a moderate effect size, while $H2$ (0.374) indicated a strong effect size. The $R^2$ values (0.477 for firm performance and 0.272 for ISRM) indicated a good model’s predictive accuracy, which was confirmed by a good predictive relevance of effects on both firm performance ($Q^2 = 0.325$) and ISRM ($Q^2 = 0.185$) (Hair et al., 2013).
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<td>AVE = 1)</td>
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Table II. Constructs characteristics

Notes: α, cronbach’s α; CR, construct reliability; AVE, average variance extracted
Mediating effect
Our research model, answering one of our research questions, showed a possible mediating effect of ISRM on the relationship between IT capabilities and firm performance. Mediation analysis based on the Preacher and Hayes method (Hair et al., 2013, 2017) assessed the significance of the direct effect on the relationship between IT capabilities and firm performance without including the mediator variable ISRM. This effect was significant, with a path coefficient of 0.433 ($p < 0.01$). Thus, we proceeded by validating the significant indirect effect on the relationship between IT capabilities and firm performance including the mediator variable with a path coefficient of 0.187 ($p < 0.01$). Finally, we calculated the variance accounted for VAF in order to determine the size of the direct effect in relation to the total effect. Results showed a partial mediation of ISRM in the relationship between IT capabilities and firm performance with a VAF of 30.1 percent. In addition, the Sobel (1982) test showed that ISRM mediated the relationship between IT capabilities and firm performance with a z-statistic of 4.08.

<table>
<thead>
<tr>
<th>Capability</th>
<th>Flexibility</th>
<th>ISRM</th>
<th>Planning for IT standards and controls</th>
<th>Administrative performance</th>
<th>Market performance</th>
<th>Tangibility</th>
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<tr>
<td>1.000</td>
<td>0.731</td>
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<td>Flexibility</td>
<td>0.731</td>
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<td>0.731</td>
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<td>0.663</td>
<td>0.884</td>
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<td>Tangibility</td>
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<td>0.673</td>
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Table III. Inter-correlations of first-order constructs
Discussion
This study aims to examine the direct impact of IT capabilities on firm performance and the mediated effect of ISRM on the relation between IT capabilities and firm performance. The results reveal that all the causal links theorized by our model are strongly supported and that the high-order IT capabilities construct has a stronger effect on both ISRM and firm performance. More precisely, IT capabilities and ISRM explained 47.7 percent of the variance of firm performance, 30.1 percent of which is explained by the mediator ISRM. The positive effect of this mediator was confirmed using VAF (30.1 percent), ranging from 20 to 80 percent and indicating a partial mediation (Hair et al., 2017). This suggests that by improving both IT capabilities and ISRM, firm performance is also enhanced. Among three dimensions of IT capabilities, IT management capability ($\beta = 0.934$) was comparatively more important than IT personnel capability ($\beta = 0.885$) and IT infrastructure capability ($\beta = 0.880$). This suggested the importance of IT management when establishing a firm. Nevertheless, should this difference be thinner, it would suggest giving equal importance to these constructs when building IT capabilities. The results also show a significant positive association of each second-order construct with their first-order constructs.

Implications for research
This study has some research implications regarding IT capabilities. One of them is that this research work features among the first to evaluate the mediating role of information security with ISRM in the relationship between IT capabilities and firm performance, and therefore, to set out the important role of IT capabilities in the performance of a firm/organization. Despite the rich background literature on IT capabilities, firm performance and the relationship between these, studies on information security constructs and on their impact on firm performance, especially those using PLS-SEM, remain insufficient. Our study tested the mediating effect of ISRM on the relationship between IT capabilities and firm performance using data collected from Cameroonian firms. The effects of IT capabilities and ISRM are rarely been studied in the literature. Finally, we have been able to adopt a high-order IT capability construct in our research model, and this enabled us to go deeper into its impact on firm performance.

Implications for practice
The findings of this study provide several guidance outlets to managers who are engaged in the implementation or improvement of IT capabilities in a firm. As the three components of IT capability strongly impact firm performance, managers need to set IT management using IT planning, design, standard and control, before embarking on an effective tangibility of IT personnel as well on the flexibility and capability of IT infrastructure. In addition, an adequate implementation of IT capabilities will positively impact ISRM while guaranteeing corporate information security. The mediating role of ISRM is clearly commensurate with our highly dynamic environment. Furthermore, an ISRM system within firm is well indicated for sustaining the competitive advantage deriving from the use of IT capabilities.

The main recommendations are concerned with the impact of ISMS on firm performance which is the originality of this study. The findings showed the need to focus on the continuous improvement of the maturity level of the information security risk management process, which is expected to produce an enhanced quality of ISMS. Therefore, IT-related stakeholders such as chief information officers are expected to master the ISMS process and particularly the risk management according to the ISO 27005 standard. At this level, the following recommendations are therefore formulated:

- Create key positions for the internal implementation and management of ISMS; they include an information security manager, an information security risks manager and an ISMS auditor.
• The information security manager should hold a certification in information security management and or the ISO 27001 Lead Implementer certification, and be able to measure the security return on investment, drawing on relevant security information for the firm’s performance.

• The information security risks manager should hold an ISO 27005 Risk Manager certification and have an expertise in the use of risks management tools such as MEHARI (Méthode Harmonisée d’Analyse des Risques).

• The auditor of ISMS should hold a certification in information security audit and/or the ISO 27001 Lead Auditor certification.

• On a regular basis, organize further training sessions for managers to update their knowledge and adapt to the daily security demand of their working environment.

• Enable the IS department to formalize the ISMS process and constantly maintain a security dashboard, to accurately measure the performance of their activity and the achievement of objectives.

• Develop a communication plan to facilitate the acceptance and implementation of security measures.

At the level of the information security manager, the incumbent should be given a greater mission such as counseling, support, security-related information management, training and supervision. Moreover, he/she should be empowered to intervene directly in all or part of the company’s IS system. Therefore, the information security manager is expected to:

• have a full grasp of the various activities of the company’s departments;
• master change management;
• manage the information security risk;
• develop solutions for information security problems;
• implement or monitor the implementation of these solutions;
• implement the business continuity plan;
• establish and manage an information security dashboard; and
• calculate the information security return on invest.

Limitations and future directions
Our conceptual model was based on a theory and then tested with reliable survey instruments and data. Yet, some limitations to this study exist. First, the fact that this study was carried out in the specific domain of IT capability in a developing country constitutes a limitation. Only a replication of our conceptual model using other parameters can enable any generalization of the topic. Second, our findings were based on PLS-SEM, with 136 questionnaires administered and collected. Such findings should be retested using not only a greater number of collected data (more questionnaires) and a multi-group analysis but also using qualitative data analysis to confirm generalizations of the findings. Third, we adopted perceptual measures rather than objectives measures, which can better highlight the effects of IT capabilities on firm performance and the mediating role of ISRM. Fourth, while the RBV has emerged as one of the most used theories in various fields of research, some scholars argued that it is not “a useful perspective for strategic management research” (p. 22) given that it “is not currently a theoretical framework” (Priem and Butler, 2001).
Future studies should consider using more robust perspectives including the dynamic capabilities (Teece, 2012; Teece and Pisano, 1994). Fifth, in this study, we only look at the difference between early respondents and late respondents to account for common method bias. Future studies should explore new techniques, including the method–method pair technique (Sharma et al., 2009). Finally, we could not consider the organizational culture and the top management commitment to adopt IT capabilities and information security, which could be used as moderating variables to extend knowledge for organization benefits.

Conclusion
In this study, by taking support from RBT and IT capability theories, we have developed a theoretical model that looks at the direct impact of IT capabilities (that is taking in third order with sub-constructs IT management, IT infrastructure and IT personnel) on firm performance and the mediating effects of the ISMS on this relationship. Like many other authors, such as Huang et al. (2009), we confirm that there is a positive relationship between IT capabilities and the performance of a firm. However, it is not enough to explain the whole firm performance. In fact, intermediation of ISMS is relevant to completely predict the firm performance. Our study also highlights the importance of the context (e.g. Africa) for theory testing. The results of this study provide strategies to enhance the use of IT capabilities with the objective of better firm performance. Also, managers are informed that ISMS is a critical resource to enhance firm performance. Finally, this study points to a better use of ISMS and RBT model in future research on firm performance.

References


### Appendix

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<tr>
<th>RM</th>
<th>Process establishment is mature (basic criteria, scope and boundaries, organization for information security risk management)</th>
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<th>Slightly disagree</th>
<th>Undecided</th>
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**Table AI.**

**Table AII.**

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### Mediating role of ISRM

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<td><strong>INQ1</strong> ISMS information outputs are useful in our daily jobs</td>
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<td><strong>SEQ2</strong> ISMS has up to date equipment</td>
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<td><strong>SEQ3</strong> ISMS is well integrated</td>
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<td><strong>SEQ4</strong> ISMS employees have the knowledge to do their job well</td>
</tr>
<tr>
<td><strong>SEQ5</strong> Employees of ISMS understand the specific needs of its users</td>
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<td><strong>SEQ1</strong> Network architectures are appropriate</td>
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<td><strong>SEQ2</strong> Data architectures are appropriate</td>
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<td>Table AVII.</td>
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<td></td>
<td>Mediating role of ISRM</td>
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<tr>
<td>PAD1</td>
<td>ISMS helps us to identify alternative supply sources</td>
</tr>
<tr>
<td>PAD2</td>
<td>ISMS locates substitute products/services</td>
</tr>
<tr>
<td>PAD3</td>
<td>ISMS minimizes uncertainty in ordering lead time</td>
</tr>
<tr>
<td>PAD4</td>
<td>ISMS helps us to make products/services information available to customers</td>
</tr>
<tr>
<td>PAD5</td>
<td>ISMS helps us to add value to existing products/services</td>
</tr>
<tr>
<td>PAD6</td>
<td>ISMS helps us to ensure high efficiency in internal meetings and discussions</td>
</tr>
<tr>
<td>PAD7</td>
<td>ISMS helps us to ensure high efficiency in decision-making process and high quality of final decision</td>
</tr>
<tr>
<td>PAD8</td>
<td>ISMS helps us to ensure good co-ordination among organization's functional areas</td>
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<td>PAD9</td>
<td>ISMS helps us to maximize company’s strategic planning efficiency</td>
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Table AIX. Administrative performance
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<th>Constructs</th>
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<td></td>
<td>PAD9</td>
<td>4.897</td>
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</table>

Table AX.
Descriptive characteristics of sub-constructs

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Jean Robert Kala Kamdjoug can be contacted at: jrkala@gmail.com

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Internet of Things adoption for reconfiguring decision-making processes in asset management

Paul Brous, Marijn Janssen and Paulien Herder
Technology, Policy and Management, Technische Universiteit Delft, Delft, The Netherlands

Abstract

Purpose – Managers are increasingly looking to adopt the Internet of Things (IoT) to include the vast amount of big data generated in their decision-making processes. The use of IoT might yield many benefits for organizations engaged in civil infrastructure management, but these benefits might be difficult to realize as organizations are not equipped to handle and interpret this data. The purpose of this paper is to understand how IoT adoption affects decision-making processes.

Design/methodology/approach – In this paper the changes in the business processes for managing civil infrastructure assets brought about by IoT adoption are analyzed by investigating two case studies within the water management domain. Propositions for effective IoT adoption in decision-making processes are derived.

Findings – The results show that decision processes in civil infrastructure asset management have been transformed to deal with the real-time nature of the data. The authors found the need to make organizational and business process changes, development of new capabilities, data provenance and governance and the need for standardization. IoT can have a transformative effect on business processes.

Research limitations/implications – Because of the chosen research approach, the research results may lack generalizability. Therefore, researchers are encouraged to test the propositions further.

Practical implications – The paper shows that data provenance is necessary to be able to understand the value and the quality of the data often generated by various organizations. Managers need to adapt new capabilities to be able to interpret the data.

Originality/value – This paper fulfills an identified need to understand how IoT adoption affects decision-making processes in asset management in order to be able to achieve expected benefits and mitigate risk.

Keywords Asset management, Internet of Things, IoT, Business process, Adoption

Paper type Case study

1. Introduction

1.1 Motivation

The Internet of Things (IoT) can be used to collect more and more data which can be used by decision-makers to acquire the necessary insights in a timely fashion. IoT and data analytics will transform complete supply chain processes (Kumar et al., 2016) and has the potential to revolutionize management (Fosso Wamba et al., 2015). But developing and managing this data to an acceptable level whereby the right information can be provided to the right people at the right time is a complex undertaking.

Modern economies are supported by large infrastructures of transport systems, water and waste disposal networks, and energy and telecommunications networks. As such, the proper management and maintenance of the assets making up the infrastructure is vital to prosperity. IoT has the potential to improve the management of these assets by providing insight into the utilization of the infrastructure and the quality of the assets for...
maintenance and replacement strategies. Asset management as a type of business process is highly dependent on large amounts of data from which relevant information can be created and is used for decision-making during the life-cycle of assets. Infrastructure assets are stationary systems (or networks) that serve society where the system as a whole is intended to be maintained indefinitely to a specified level of service by the continuing replacement and refurbishment of its components (Herder et al., 2008). Asset management is generally understood to be the set of activities of a business objective associated with: identifying what assets are needed; identifying funding requirements; acquiring assets; providing logistic and maintenance support systems for assets; and disposing or renewing assets so as to effectively and efficiently meet the desired objective (Hastings, 2010; Woodhouse, 1997).

1.2 Research problem, objective and approach

The term, IoT refers to a network of physical objects that are able to communicate their data over the internet (Hounsell et al., 2009; Ramos et al., 2008). IoT enables asset managers to access remote sensor data and to monitor and control the physical world from a distance, allowing many physical objects to act in unison, through means of ambient intelligence (Ramos et al., 2008). IoT can benefit asset management organizations by providing enough quality data to generate the information required to help asset managers make the right decisions at the right time (Brous and Janssen, 2015b). For example, IoT can be used to collect data to determine the position and length of traffic jams, and to redirect traffic or offer alternative multi-modal forms of transport by using location sensors and analyzing traffic flow. But IoT adoption can also impact the asset management organization in unexpected ways. Automating processes often necessarily leads to changes to organizational structures and cultures as tasks performed by people become automated, whilst other tasks and responsibilities which previously did not exist become apparent (Brous and Janssen, 2015a).

Technology and organization influence each other in many ways, and analytical efforts to treat these as distinct conceptual units are increasingly being called into question (Boos et al., 2013). As such, it is important to understand how IoT adoption affects decision-making in asset management business processes in order to be able to achieve expected benefits and mitigate known and unknown risk. This research fills that gap by analyzing the changes in the business processes of maintaining civil infrastructure assets brought about by IoT adoption. The research objective is to understand how IoT adoption affects decision-making processes in asset management. As there is limited knowledge in this field and deep insight into the field is needed, case study research is used. Case study is a qualitative research method particularly suited to researching contemporary phenomena that cannot be separated from the environment they are embedded in (compared to laboratory experiments, for example) and that have not been scientifically studied to a large extent so far (Benbasat et al., 1987). The case studies comprise two organizations that have similar goals to reduce confounding effects in the study. Two case studies of IoT adoption within the asset management domain are presented in this paper. The cases have been made anonymous in the interests of privacy. The first case, a water measurement network, is managed by a central government organization. We refer to this case as case “X” in this paper. The second case study, a pump management decision support system, is managed by a water board. We refer to this case as case “Y” in this paper.

This paper reads as follows: Section 2 presents the literature background; Section 3 describes the research methods in detail; and Section 4 describes the case studies background and compares the cases. The case studies are discussed in Section 5 showing how business processes need to be changed driven by IoT. Finally, conclusions are drawn in Section 6.
2. Background

According to Kabir et al. (2014), decision-makers are increasingly being faced with competing investment demands whilst needing to distribute limited resources so that the infrastructure systems can be maintained in the best possible condition. Kabir et al. (2014) show that infrastructure management decisions are often based on multiple and conflicting criteria/data that are subject to different levels and types of uncertainty, and traditionally, these decisions incorporate engineering judgment and expert opinion. However, in a data-driven world, many stakeholders are gaining increased access to information about the asset and are often capable of arguing for opposing courses of action in the face of unsubstantiated decisions. In this research we identify three main decision-making processes of asset management, namely:

1. decision-making for performance management (Archetti et al., 2015);
2. decision-making for managing how infrastructure services are perceived (Hentschel et al., 2016); and
3. decision-making for improving infrastructure services (Koo et al., 2015).

2.1 Decision-making for performance management

Decision-making processes with regards to maintaining current service levels are generally focused on preventing malfunction or asset failure or to quickly assess damage to infrastructure after an event such that maintenance procedures could be directed to the areas that need immediate attention (Aono et al., 2016). As such, performance measurement is required for corrective, preventive and predictive maintenance as well as other supportive activities (Parida et al., 2015). According to Phares et al. (2004), routine inspections are the traditional method of gathering information regarding the performance of the infrastructure. Routine inspections are regularly scheduled inspections to determine the physical and functional condition of infrastructure assets. Generally, a series of condition ratings that describe the general condition of the asset are considered for performance measurement. According to Phares et al. (2004), these condition ratings, consider both the severity of deterioration and the extent to which it is distributed throughout each of the components. The more often these inspections take place, the higher the granularity. Often, traditional inspections are performed subjectively. In other words, inspectors visually inspect the asset and makes an expert judgment based on what they see and their past experience.

2.2 Decision-making for managing how infrastructure services are perceived

According to Parida et al. (2015), maintenance is often integrated into a production process involving human factors. As such, although difficult to measure (Simões et al., 2011), perception management of infrastructure services is an important aspect to the asset management decision-making process as the effectiveness of the different facets of the performance system is often dependent on the competency, training, and motivation of people interacting with the infrastructure and the asset management systems (Ljungberg, 1998). For example, when planning maintenance on a busy section of highway it is important to take into account how the maintenance will affect the public and how the public will perceive the need for the maintenance. Decisions such as when to perform the maintenance (at night or during the day), or how best to inform the public, for example to provide alternative routes, are important aspects of infrastructure decision-making which require large amounts of data. For example, IoT data can provide insight into such aspects as the busiest times of day or night, or popular destinations (for determining alternative routes). Therefore, the relationship between the organization and the customer may be
critical due to the influence that service quality has on user satisfaction level and the fact that people are involved in decisions related to maintenance and execution of tasks (Ardalan et al., 1992).

2.3 Decision-making for improving infrastructure services
Traditional thinking about the strategic decision-making process rests on the belief that actors enter a decision-making process with a known set of objectives, gather information about these objectives and select an optimal alternative to achieve these objectives (Eisenhardt and Zbaracki, 1992). However, Eisenhardt and Zbaracki (1992) also suggest that whilst people may be rational, power tends to win battles of choice. For example, according to Smith (2014), competing interests mean that managers increasingly embed poorly managed tensions into their organization’s strategy which require ongoing responses rather than one-time resolutions. Despite this, Marquez and Gupta (2006) believe that having a strategic perspective to asset management is a key factor for success. For example, detections of damage or failure of critical public infrastructure may have significant societal and economic impacts (Tien et al., 2016).

2.4 Effects of IoT adoption on asset management decision-making processes
Infrastructure systems consist of many different types of assets that could have long life cycles. For example a bridge lasts for at least 30 years, however, regular maintenance might be needed. Civil infrastructure assets need to be maintained to ensure their optimal value over their entire (long) life cycles (Hassanain et al., 2003). As early as 2001 there were already many software tools for asset management (Hassanain et al., 2003; Vanier, 2001), and since then many data formats, data sources and pools of unstructured data have become available over the years. At a high level, Hassanain et al. (2003) suggest that asset management tooling should at minimum provide the following functionality:

- identification of assets;
- identification of performance requirements;
- assessment of asset performance;
- plan maintenance;
- manage maintenance operations;
- life-cycle costing analysis;
- life-cycle analysis and long-term service-life prediction; and
- central repository for asset information.

It is expected that IoT adoption will change performance measurement of infrastructure services, like applying statistical learning (Archetti et al., 2015). Second, IoT adoption is expected to change the perception of infrastructure services, like perceiving sudden changes in temperature by which a fire could be detected (Hentschel et al., 2016), or the deterioration of the quality of assets over time (Brous et al., 2017). Finally, IoT adoption is expected to change business processes, for example through self-organizing resource planning (Zhang et al., 2015). In the next sections, we discuss these effects of IoT on asset management.

2.5 IoT adoption expected to change performance management of infrastructure services
IoT services are knowledge intensive and require collection of appropriate data contents, data analysis and reporting (Backman and Helaakoski, 2016). As such, statistical learning and network science is expected to play a critical role in converting data resources into actionable
knowledge (Archetti et al., 2015). Due to increasing pressure on budgets and personnel as well as increased utilization of civil infrastructure, public asset management organizations increasingly need to intelligently manage their infrastructure with fewer resources (Rathore et al., 2016). By managing and analyzing various IoT data, it should be possible to create new services to achieve an efficient and sustainable civil infrastructure (Backman and Helaakoski, 2016; Hashi et al., 2015). IoT may bring an improved understanding of complex processes which is expected to help improve the efficiency of transport management and infrastructure services, and help with effective reporting (Kothari et al., 2015). IoT infrastructure could potentially be used to reduce costs in terms of time and money (Aono et al., 2016), as traditional methods of inspecting infrastructure, such as highway structures and bridges, for damage are often reactive in nature and require significant amounts of time and use of costly equipment. By specifying events (Hashi et al., 2015; Tao et al., 2014), it should be possible to obtain a set of data before and after an event to be used for analysis and evaluations, taking the effect of the event into consideration.

2.6 IoT adoption expected to change perception of infrastructure services
Rathore et al. (2016) believe that smart management of traffic systems with the provision of real-time information to the citizen based on the current traffic situation should enhance decision-making. Jonoski et al. (2013) believe that an important potential of IoT adoption may lay in developing applications for the broadest user base of individual citizens, not only as recipients of information, but also as suppliers of data. As such, Jonoski et al. (2010) suggest that a possible approach toward meeting this challenge may be the development and deployment of information systems that integrate the operations of data collection, data and model integration, and information dissemination such that organizations can work together with the users of their information for mutual benefits. In this way, IoT is expected to be able to provide users with information on costs, time, environmental impact and perceived quality of services (Archetti et al., 2015).

2.7 IoT adoption expected to change business processes of infrastructure services
In order to keep civil infrastructure such as bridges safe and functioning, regular inspections to determine the condition of the asset are a necessity (Ahlborn et al., 2010; Neisse et al., 2016). For example, traditional inspections of bridges are usually visual assessments by trained personnel where all the asset’s component conditions are observed once every three to six years, and are summarized into one report (Phares et al., 2004). After the inspection is done, asset managers must decide what maintenance interventions are needed based on these inspection reports. However, inspection reports of bridges can be biased by subjective judgments of the experts or by lack of information (Kallen and van Noortwijk, 2005). IoT data may make it possible to remotely observe the condition of objects and thereby enhance the available information on the current condition of public infrastructure (Ahlborn et al., 2010) and their environments.

2.8 Summary of effects of IoT adoption on the asset management decision-making process
The expectation is that IoT will be used for key decision-making in operational activities. It is expected that IoT will be used in a variety of ways related both to the real-time measurement and analysis of data as to trend analysis of historical data over time (Brous and Janssen, 2015b). Expected benefits of IoT adoption for business processes include:

- self-organizing resource planning (Zhang et al., 2015);
- creation of new services to achieve a sustainable civil infrastructure (Backman and Helaakoski, 2016);
improving the efficiency of infrastructure services (Kothari et al., 2015) and thus reducing costs in terms of time and money (Aono et al., 2016); automation of processes (Hentschel et al., 2016); timelier provision of information (Rathore et al., 2016) allowing for more accurate inspections and analysis (Ahlborn et al., 2010); greater frequency of inspections (Neisse et al., 2016); and reduce or remove the need for physical, on-sight inspections (Ahlborn et al., 2010).

But adopting IoT also has consequences for asset management business processes. Expected consequences for asset management business processes include:

- requires understanding of the conditions and factors for effective and sustainable adoption of new data sources (Brous and Janssen, 2015b);
- requires statistical learning and network science to convert data resources into actionable knowledge (Archetti et al., 2015);
- requires the development and deployment of information systems that integrate the operations of data collection, data and model integration and information dissemination (Jonoski et al., 2010); and
- requires defining events in terms of sensing (e.g. sound, light, etc.) for localized events. For example, when is a loud noise an accident or simply a car back-firing? (Hentschel et al., 2016).

3. Research approach

There is a void in literature in improving business processes by using the potential of big data (Fosso Wamba and Mishra, 2017). The objective of this research is to understand how IoT adoption affects decision-making processes in asset management. To this end, a background of relevant literature was developed in order to place the research in context, gain insight into the asset management decision-making process and identify expected changes to the decision-making process that IoT adoption may bring. The case study method was employed to examine how IoT adoption in real life settings have affected asset management decision-making processes. Case study research was chosen as the main research method because it allows the examination of the effects of IoT adoption in a real-world context (Eisenhardt, 1989; Yin, 2003). The case studies were explorative in method and descriptive in nature.

According to Eisenhardt (1989), a broad definition of the research question is important in building theory from case studies. This research assumes that asset management organizations need data to achieve their business goals, but that the traditional approach of providing disparate systems for each information requirement is no longer adequate. IoT has much potential for improving decision-making about assets, however, the impact of IoT adoption on asset management business processes has not yet been investigated systematically and remains largely anecdotal. This leads us to our main research question which asks:

**RQ1.** How IoT adoption affects decision-making processes of asset management?

Following Ketokivi and Choi (2014), induction type reasoning was used in order to look for both similarities and differences across the cases and proceed toward theoretical generalizations. As with other multiple case study research (Otto, 2011; Pagell and Wu, 2009), the data analysis in this research contained both within and across case analysis
Within case analysis helps us to examine the impact of IoT on asset management decision-making processes in a single context, while the across case analysis triangulates the constructs of interest between the cases. Within case analysis is a process of data reduction and data management (Miles and Huberman, 1994), and in this research had five main components. First, we tried to make sense of the social fabric of these asset management organizations and how IoT adoption affects the company's business culture. Second, we cross-referenced the organization's asset management activities in relationship to required skills and how these skills may change with adoption of IoT. Third, we identified how organizational structures and policies are affected by IoT adoption. Fourth, we identified how decision-making business processes are affected by IoT adoption. Finally we considered how IoT adoption introduces decision-making changes regarding the technology choices of an asset management organization. With regards to cross-case analysis, data reduction was primarily done through categorization. Table III below is partly a result of this process. The end result of the within case analysis was an inventory of effects of IoT on asset management decision-making processes.

3.1 Case selection

Whilst single cases are recommended where the case represents a critical test of existing theory, or where the case is a unique event, or where the case serves a revelatory purpose, a limited number of case studies is considered to be more successful with regards to theory formulation and testing (Yin, 2003). Using more than one case study provides us with the opportunity to build the theory irrespective of an organization, which improves the argument for generalization. The evidence from multiple cases is often considered more compelling and the research more robust (Herriott and Firestone, 1983). We followed a similar approach to that employed in studies conducted by Pagell and Wu (2009) and Wilhelm et al. (2016) and selected two different organizations by applying a number of criteria. Two organizations tasked with maintaining infrastructure were selected. Case X operates at the national level, whilst case Y operates at the regional level. This enables us to compare differences between the levels to determine possibilities for generalization. Any use of multiple-case designs should follow replication logic to guarantee external validity. For this reason, we defined the following criteria which were used to select the different cases:

1. The case must be a complex functioning unit.
2. The primary processes supported by the case must be focused on the management of civil infrastructure.
3. Asset management processes must be supported by the asset management data infrastructure, evidenced by the existence and monitoring of key performance indicators.
4. People operating within the case must be willing to cooperate in the research and must be willing to provide access to the information required for the research.
5. The case environment should be “data-rich.” This means that the organization should produce, manage and maintain at least 5 large data sets as well as a more than twenty small to medium data sets.
6. The asset management data infrastructure must include at least one use case of IoT adoption.

The research studies the impact of IoT adoption on business processes in asset management data infrastructures. The cases of IoT adoption to be investigated were selected based on the criticality of their use and their importance to the organization. To avoid confounding effects, the study was limited to the examination of cases of IoT adoption in asset management according to specific criteria as specified above.
3.2 Data collection
It is not only generalization that presents challenges when adopting the case study methodology; the reliability aspect should also be taken into consideration (Yin, 2003). Reliability refers to the demonstration that the operation of a study, such as the data collection procedures, can be repeated with the same results (Yin, 2003). Yin (2003) recommends employing a well thought out research protocol to ensure reliability. According to Yin (2003), a case study protocol is a formal document which describes the set of procedures involved in the collection of data for a case study. The protocol used in this research follows the advice from Yin (2003) and included the problem statement, a delineation of the unit of analysis, the steps (including the altering of the steps) to be taken, the procedures for contacting key informants and making field work arrangements, reminders for implementing and enforcing the rules for protecting (the privacy of) human subjects, a detailed line of questions, and a preliminary outline for the final case study report. The protocol used in the case studies includes a variety of data collection instruments including documentation, individual interviews and group discussions as suggested by Choi et al. (2016). The use of multiple research instruments is encouraged to ensure construct validity through triangulation, taking different angles toward the studied object (Runeson and Höst, 2008), which provide a stronger substantiation of our propositions (Eisenhardt, 1989). At the start of the research, in June 2015, group discussions were held with staff directly involved in the exploratory use cases or who were tasked with managing and maintain the systems. Between October 2015 and June 2017, individual interviews were held with personnel in the organizations under study. Internal documentation was selected which dealt with issues faced by the adopting projects. All interviews were documented in writing. The documents were then analyzed and transferred into an integrated case document (one for each case). The first versions of this document were then sent to the interview participants for feedback and clarification of open points. Once all the additional information feedback had been incorporated, the final version was reviewed and discussed with the main contacts at the organizations under study. Table I gives an overview of the sources used in the case studies.

4. Case studies background
The exploratory cases were chosen as being representative of organizations at the national, and regional levels, respectively, in compliance with the principles outlined in Section 2. The cases are described in the following order, first, case X and then case Y. At the end of the section, a comparison of the cases is provided.

4.1 Case X
The first case, the automatic measurement of water data, case X, is managed by a central government organization. Case X is a facility that is responsible for the acquisition, storage and distribution of data for water resources. Case X provides a complete technical infrastructure for the gathering and distribution of water data and delivers the data to various stakeholders within and outside the organization such as, hydro-meteorological centers, municipal port companies, flood early warning services and other private parties.

Case X was created from the merging of three previously existing monitoring networks and also includes data from third parties, including water data from foreign countries and other public organizations such as the shipping and transport industry, logistics, harbor management, meteorology, regional and local water management, and international water management. Case X has approximately 640 data collection points using a nationwide system of sensors. The data are then processed and stored in the data center and is made available to a variety of systems and users. Case X collects data regarding water levels, wind speed, wave heights, water temperature, astronomical tides, water currents, salt content, etc. These data are aggregated and calculated within models to accurately predict water levels and water quality.
Based on these models, decisions are made to close storm surge barriers, close swimming areas, send out messages to shipping, etc. As such, we can classify case X services as being collaborative aware services (Gigli and Koo, 2011), as case X services are used to make decisions, and based on those decisions, to perform an action. Case X services have “terminal-to-terminal” communication, as well as “terminal-to-person” communication.

4.2 Case Y
Case Y is a decision support system for water management. Traditional water level measurement is performed using a level scale in fresh waterways such as ducts and locks. This is placed during construction of the asset and indicates the depth related to the soil (usually) a plurality of centimeters. Case Y automates this process with IoT measurements. The main pumping stations regulate the water levels in the region. Case Y manages approximately > 3,500 km of polder ditches, > 130 automated polder pumping stations, > 20 automated inlets, > 100 automated weirs, > 100 remote level loggers, > 80 smaller pumping stations, > 200 smaller pumping stations, > 3,000 fixed weirs and > 2,000 fixed inlets. Case Y involves the regulation of the water level in streams, lakes, ditches, moats and canals. This is vital for industrial development, agricultural businesses, environmental management and recreation. The height at which the water level of an area is set depends on the use and function of that area. For example, although water levels in wildlife areas often fluctuates, farmers tend to prefer a relatively low water level to prevent their land from becoming too wet.

In the process screen of case Y, IoT measurements are displayed from telemetry, supplemented by estimations from the system itself. These include inland water levels, meteorological information and volumetric flow rate. The system reads precipitation from rainwater measuring stations every 15 min and water levels on the reservoirs which is measured at the polder mills. In addition, the system receives weather forecasts every 15 min via FTP. These are three files with 1 h, 3 h and 24 h forecasts of precipitation, wind
and evaporation. The relevant level manager indicates which target level should be used and whether a precipitation protocol is active. The system in case Y then calculates the desired deployment of each reservoir mill for the next 24 h and makes a “request” for the use of pumping stations for the required time. As such, we can classify the services in case Y as being collaborative aware services (Gigli and Koo, 2011), as the services are used to make decisions, and based on those decisions, to perform an action. The services have “terminal-to-terminal” communication, as well as “terminal-to-person” communication.

4.3 Comparison of the case studies
Both cases are involved in water management in the public sector, and the number of measuring stations is similar. Significant differences are in the levels and how the systems are governed. Case X is a national system, which means that the sensors are spread over a wide geographical region and the asset management processes can affect large numbers of people. Case Y, on the other hand, is regional and has a mix of publicly and privately owned sensors. As such, the risk of poor system maintenance may be higher, but the geographical region is much smaller and there are far fewer people affected, significantly reducing the impact of risks involved. Table II demonstrates how IoT adoption affects asset management business processes and specifically how these effects are manifested in the cases.

As seen in Table II, all effects as expected in the literature were found in both cases. As such, we may infer that IoT adoption impacts the asset management process in a variety of ways, which will be discussed in the next section.

5. Discussion: changes to decision-making processes in asset management
The literature background and case studies provided valuable insight into which asset management decision-making processes are affected by IoT adoption, but more research should be conducted into specifically how IoT adoption affects these processes. Business processes for decision-making are executed by people working in organizations having a social culture and supported by technology. In this research we found that all these aspects of business processes needed to be reconfigured to benefit from IoT. Table III groups the aspects of business processes needing to be reconfigured in order to benefit from IoT.

Building theory from cases is a strategy resulting in proposition derived from empirical evidence (Eisenhardt, 1989). In this section these changes are discussed in further detail from organizational through to technical, respectively, in the order described in the list above. For each of the areas a generic and testable proposition is derived which is deeply grounded in empirical evidence. The propositions are consistent with both cases:

P1. IoT adoption requires organizational changes to process and make use of the data.

Organizational changes brought by IoT adoption may be identified in the way that ubiquitous sensing enabled by Wireless Sensor Network technologies cuts across many areas of modern day living (Gubbi et al., 2013). Gubbi et al. (2013) believe that IoT provides the ability to measure, infer and understand environmental indicators, and the proliferation of these devices in a communicating–actuating network creates the IoT wherein sensors and actuators blend seamlessly with the environment around us, and the information is shared across platforms in order to develop a common operating picture. For example, in case X, sensors installed in buoys in countrywide network of sensors monitor the water levels in rivers and in the sea. The system automatically sends reports to storm surge barriers and to their managers if water levels exceed the defined thresholds. Data analytics are needed to analyze the data generated by IoT devices. New people were hired and a separate department is introduced to deal with the IoT data and make decisions. Early predictions of rising water levels can be made and the storm surge barriers can be automatically closed to prevent major flooding. Utilities and independent power providers can reduce operating
Internet of Things adoption

<table>
<thead>
<tr>
<th>Expected effects of IoT on asset management business processes</th>
<th>Case</th>
<th>Effects of IoT adoption on the cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>IoT data expected to change performance measurement of infrastructure service</td>
<td>Case X</td>
<td>Adoption of IoT has introduced more detailed and accurate predictive analysis for management of water levels and water quality of major waterways. Case X collects, aggregates and models data to accurately predict water levels and water quality. Based on these models, decisions are made to close storm surge barriers, close swimming areas, send out messages to shipping, etc.</td>
</tr>
<tr>
<td>IoT data expected to change perception of infrastructure service</td>
<td>Case Y</td>
<td>Adoption of IoT has introduced more detailed and accurate predictive analysis for management of water levels in regional waterways. Case Y calculates the desired deployment of each reservoir mill for the next 24 hours and schedules use of pumping stations for the current time</td>
</tr>
<tr>
<td>IoT data expected to change improvement processes of infrastructure service</td>
<td>Case X</td>
<td>IoT adoption has allowed asset managers access to greater levels of up-to-date information regarding the state of waterways and has greatly increased efficiency in the collection of this data, making the decision-making less subjective. For example, the information about the state of objects from case X contains real-time information about pump rotation times, lift heights, valve positions, operating time and spray times</td>
</tr>
<tr>
<td>IoT data expected to change perception of infrastructure service</td>
<td>Case Y</td>
<td>IoT adoption has allowed asset managers access to greater levels of up-to-date information regarding the state of the regional waterways and has greatly increased efficiency in the collection of this data, making the decision-making less subjective. For example, this means greater insight into which preventive measures should be taken regarding water pollution if severe rainfall is expected</td>
</tr>
</tbody>
</table>

Table II. Comparison of how IoT is used in the cases and the effect of IoT on the asset management process

Expenditure and cut costs associated with maintenance and manpower through real-time fault monitoring capabilities provided by IoT solution, improving the day-to-day grid effectiveness and capacity planning with detailed reporting and intelligence:

P2. IoT adoption requires people to adopt new skills.
People related changes by IoT adoption may be seen in the way people themselves have to adapt to new technologies. New capabilities, skill sets and new ways of thinking are required to be able to leverage the full benefits of IoT and adopt a data-drive decision-making process. It has become clear that combining information from devices and other systems using expansive analysis, may provide new insights for managers of public infrastructure. For example, it is possible to embed wireless sensors within concrete foundation piles to ensure the quality and integrity of a structure. These sensors can provide load and event monitoring for the projects construction both during and after its completion. This data, combined with data from load monitoring sensors designed to measure weights of freight traffic, may provide managers of physical infrastructure with new insights as to the maintenance requirements of the infrastructure. The managers need to have understanding of what the data means to use them for decision-making. For this they were educated to develop new skills:

P3. IoT adoption requires data provenance and governance.

Quality of decision-making processes in asset management are directly linked to the quality of the data and being generated within the business processes. As such, with regards to organizational related changes brought about by IoT adoption, the importance of data provenance and data quality for IoT infrastructures and the persisting requirement for manual intervention suggests the need for instituting strong data governance procedures as data quality issues are often do not arise from existing business rules or the technology itself, but from a lack of sound data governance (Thompson et al., 2015). Data governance is the exercise of authority, control, and shared decision-making over the management of data assets. It provides organizations with the ability to ensure that data and information are managed appropriately, aligns the data infrastructures with business requirements, ensures a common understanding of the data, and ensures compliancy to laws and regulations (Brous et al., 2016).
resolution of data quality issues, data governance may also assist IoT adoption in other ways as data governance provides both direct and indirect benefits. Direct benefits of data governance for business processes can be linked to efficiency improvements (Hripcsak et al., 2014), reductions in privacy violations (Tallon, 2013), and increased data security (Panian, 2010):

**P4.** IoT adoption requires changes in business processes to collect and use data from multiple sources.

Business process related changes can be found in aligning complex data structures. As such, other changes are often related to changes in the asset management business process. For example, traditional processes are often performed by people. When business processes become automated, people assume new or different roles and people-made decisions are often elevated to more strategical levels. This also often means changes in the organization as people are asked to perform other tasks in changing social and cultural environments and often in changing organizational structures. However, automating business processes is challenging, as aligning semantics or ontology between different IoT eco-systems is a complex task and interoperability and convergence with regards to visibility of processed data at the level of applications remains an issue (Mihailovic, 2016). This barrier has hampered IoT data sharing. According to Cao et al. (2016), sharing of IoT data will only reach its full potential if data can be collected by multiple sources such as if people are able to share their data related to different events by leveraging the sensing capabilities of their smartphones (Cao et al., 2016). The business processes should ensure that data from multiple sources will be integrated and can be used in decision-making processes. Some of the data collected may contain sensitive information such as the location data of the owners when using smart phone data. Compliancy to privacy and security regulations is therefore imperative and this need to be embedded in the business processes:

**P5.** IoT adoption requires standardization of technology.

Technical changes brought by IoT adoption may be seen in the introduction of new technologies which creates large amounts of data. The technical changes are therefore not only in the introduction of new hardware, but also with regards to new protocols for data transport and security, new ways to store data and new ways to analyze the data and turn it into useable information. These technologies need to be standardized to avoid fragmentation and lack of interoperability. The confluence of sensor-driven data, cloud computing and mobility is driving a need within asset management in which assets themselves become active participants in the various stages of their own lifecycles. This covers a range of technologies, such as data capture, barcode printing and RFID, but it also involves advanced analytics and machine-learning techniques that bring greater flexibility and dynamism to the multitude of data points that IoT architectures engender. Many asset management organizations are exploring IoT technology as an asset management tool, simply because the complexity and size of their infrastructure forces a new way of gathering data and monitoring systems (Hua et al., 2014; Lee, 2014).

**6. Conclusions**

Following Eisenhardt (1989) theory was built, developing five propositions for effective IoT adoption in decision-making processes. We found the need to make organizational and business process changes, development of new capabilities, data provenance and governance and the need for standardization. This research has shown that in seeking to adapt to changing circumstances, asset managers develop rules that anticipate the consequences of certain responses.

Currently, organizations are experimenting with new data sources and there is a general expectation that IoT will provide significant added value to asset management decision-making. Organizations can effectively and sustainably adopt these new data sources in their decision-making if the data that are measured can monitor the important factors of the
asset itself. The propositions have practical implications for organizations and show that IoT adoption can result in far-reaching changes. Adoption of IoT allows for more detailed and accurate predictive analysis, increasing trust in the asset management process and allowing for greater predictability in risk-based decision-making. This has allowed decision-making to become partially automated due to the greater certainty as to when and which action needs to be taken. Business processes for decision-making need to be reconfigured to allow IoT generated data to be included and to ensure data provenance so decision-makers can interpret the limitations and potential of the data and ensuring security and privacy is accounted for. Furthermore, the people in the business processes need to learn new skills to be able to understand and interpret the data. Decision-makers need to become more at home with data and data analytics. The culture needs to be changed to move from physical to data-based inspection of assets. Asset management organizations need to change their cultures to adopt IoT so that is ingrained throughout organization rather than being lost in departmental silos. Adoption of IoT requires an IT infrastructure that can facilitate the new data sources and requires a good understanding of the data collected and its quality aspects. Adoption of IoT needs appropriate management of the data to ensure compliancy to laws and regulations. Sound data governance is required to ensure that IoT can provide trusted data for decision-making. The results show that decision processes have been changed to deal with the real-time nature of the data, and managers need to adapt and develop new skills and capabilities to be able to interpret the data.

References


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Quality dominant logic in big data analytics and firm performance

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Abstract

Purpose – Big data analytics (BDA) gets all the attention these days, but as important—and perhaps even more important—is big data analytics quality (BDAQ). Although many companies realize a full return from BDA, others clearly struggle. It appears that quality dynamics and their holistic impact on firm performance are unresolved in data economy. The purpose of this paper is to draw on the resource-based view and information systems quality to develop a BDAQ model and measure its impact on firm performance.

Design/methodology/approach – The study uses an online survey to collect data from 150 panel members in France from a leading market research firm. The participants in the study were business analysts and IT managers with analytics experience.

Findings – The study confirms that perceived technology, talent and information quality are significant determinants of BDAQ. It also identifies that alignment between analytics quality and firm strategy moderates the relationship between BDAQ and firm performance.

Practical implications – The findings inform practitioners that BDAQ is a hierarchical, multi-dimensional and context-specific model.

Originality/value – The study advances theoretical understanding of the relationship between BDAQ and firm performance under the influence of firm strategy alignment.

Keywords – Firm performance, Big data analytics, Quality dominant logic, Big data analytics quality, Resource based view

Paper type – Research paper

1. Introduction

Big data analytics (BDA) is as a “holistic process to manage, process and analyze 5 Vs (i.e. volume, variety, velocity, veracity and value) in order to create actionable insights for sustained competitive advantages” (Fosso Wamba et al., 2015). BDA has become a common path to competitive advantage for many companies in the digital economy. In recent years, the ground-breaking analytics systems of companies such as American airlines (electronic reservations), United Parcel Service (usage patterns), Amazon (recommendation systems), or Netflix (consumer choice modeling) have made them more efficient and competitive. The data economy creates thousands of exabytes of new data through various digital platforms, including mobile devices, the Internet of Things and social media. According to Davenport (2013, pp. 66-67), “Big data also came to be distinguished from small data because it was not generated purely by a firm’s internal transaction systems. It was externally sourced as well, coming from the internet, sensors of various types, public data initiatives such as the human genome project, and captures of audio and video recordings.” BDA can help firms to manage risks, reduce costs, improve supply chain visibility (Lavalle et al., 2011; McAfee and Brynjolfsson, 2012; Verbraken et al., 2012), co-create business value between firms and customers (Xie et al., 2016), foster process and product innovation (Fosso Wamba, 2017; Yuanzhu et al., 2017), improve firm decision making...
process (Fosso Wamba et al., 2012; Fosso Wamba, Ngai, Riggins and Akter, 2017; Tan et al., 2017), improve firm overall performance (Wu et al., 2016) and gain competitive advantage by enabling improved supply chain innovation capabilities (Tan et al., 2015).

Although numerous organizations are embracing analytics, few have achieved the optimum level of firm performance (Davenport and Harris, 2007). As BDA evolves into an information ecosystem, quality dimensions are critical in generating new insights for businesses (Sun and Jeyaraj, 2013). However, there are increasing challenges related to the assessment of big data analytics quality (BDAQ) on firm performance (Kiron et al., 2014a, b) and inter-firm performance (Hazen et al., 2016). For example, Ransbotham et al. (2016) report that adoption of analytics is growing at a rapid pace but many still struggle to produce quality insights to maintain their edge.

Quality is at the center of business literature, with cross-disciplinary applications and dramatic implications for business value (Nelson et al., 2005). According to Srinivasan and Kurey (2014, p. 23) “In most industries, quality has never mattered more. New technologies have empowered customers to seek out and compare an endless array of products from around the globe.” Similarly, quality has been considered a critical business notion in the emerging data economy, during the requirement analysis process, and in the deployment of technology and talent resources combined with information, capitalizing its value (Kiron et al., 2014a, b).

For example, emphasizing the importance of technology quality, Davenport (2013, p. 67) states, “As analytics entered the 2.0 phase, the need for powerful new tools—and the opportunity to profit by providing them—quickly became apparent.” Indeed, quality analytics with robust insights can help decision makers serve customer needs better, increase sales and revenue, create new resources (e.g. services, products) and access to markets that were previously unexploited (Columbus, 2014). As attention to BDAQ grows, so does confusion about the role of quality dynamics and strategy alignment in achieving an edge in the market (Agarwal and Dhar, 2014; Goes, 2014; Sharma et al., 2014).

In this paper, quality is considered to be BDA’s distinctive competence or excellence in supporting business needs, by, for example, calculating the best price, managing risks, uncovering quality problems, detecting profitable and loyal customers, etc. (Davenport and Harris, 2007). Since the contexts of past quality theories differ, they may not be comprehensive enough to capture quality dimensions of BDA. Using the resource-based view (RBV) (Barney, 1991; Grant, 1991, 2002) and the IT quality theory in information systems (IS) (Nelson et al., 2005; Wixom and Todd, 2005), we propose that perceived technology quality (TECQ), information quality (INFQ) and talent quality (TALQ) influence overall BDAQ, which has a significant impact on firm performance. Thus, we deepen and extend quality dominant logic in BDA by including a key dimension—TALQ—which forms a critical dimension of analytics assessment along with TECQ and INFQ. We refer to this as the BDAQ model (see Figure 1). Illuminating the role of talent quality, Davenport and Patil (2012, p. 12) state, “More than anything, what data scientists do is make discoveries while swimming in data. It’s their preferred method of navigating the world around them. At ease in the digital realm, they are able to bring structure to large quantities of formless data and make analysis possible.” Taking the RBV perspective, this study argues that superior firm performance is driven by the excellence of quality dimensions, which are indeed inimitable, valuable, rare and non-substitutable organizational competences (Barney et al., 2001). Using IS success and IT quality theories, our study presents the argument that quality in BDA is multi-dimensional, hierarchical and context specific.

This study develops these research questions:

RQ1. What are the building blocks of BDAQ?

RQ2. How is it shaped and strengthened to influence firm performance?
By answering these questions, we make both theoretical and practical advances by investigating the relationships between perceptions of TECQ, INFQ and TALQ in the BDA domain, and explore their combined influence on firm performance under the impact of firm strategy alignment. The paper provides theoretical arguments that support the development of the conceptual model and hypotheses. We present our methodology, analysis and findings conclude with the limitations and theoretical and practical contributions of the study, and suggest guidelines for future research.

2. Theory

2.1 The resource-based view (RBV)

The paper draws on RBV to develop the multi-dimensional BDAQ model. RBV is rooted in Wernerfelt’s (1984) proposition to analyze a firm via its resources rather than its products, which, he considers, provides a better lens on potential strategic options. According to RBV, a firm’s competency depends on quality to manage its critical resources (human and other) effectively and realize competitive advantage, which can be translated into improved firm performance (FPER) (Grant, 2002; Newbert, 2007). RBV emphasizes achieving superior firm performance by establishing valuable, rare, inimitable and non-substitutable (RIN) resources of superior quality (Barney et al., 2001). In RBV, the value (V) dimension of research allows firms to create additional potential profit. The RIN components allow organizations to realize additional value from the competition. Subsequently, Barney and Clark (2007) add “organization,” which emphasizes appropriate management systems to fully exploit the value embedded in internal resources. In a similar spirit, Peteraf (1993) proposed four conditions leading to sustained competitive advantage: higher resources, “imperfect resource mobility, ex post limits to competition, and ex ante limits to competition.” He also argued that these four conditions must be “met for a firm to enjoy sustained above-normal returns” (Peteraf, 1993, p. 185). Extending this line of research, Newbert (2008)
established that “value and rareness are related to competitive advantage, that competitive advantage is related to performance, and that competitive advantage mediates the rareness-performance relationship.” While RBV has been proven to be a useful theory in many fields, including strategic management (Priem and Butler, 2001; Newbert, 2007), IS (Wade and Hulland, 2004; Newbert, 2008) and the emerging field of BDA (Gupta and George, 2016; Ji-fan Ren et al., 2017; Fosso Wamba, Gunasekaran, Akter, Ren, Dubey and Childe, 2017). For (Priem and Butler, 2001), elemental “RBV is not currently a theoretical structure.” They suggested enriching elemental RBV by incorporating new elements such as the temporal component of a firm, demand heterogeneity models, and answering “how” questions. In our study, we extend RBV by combining the IS success model and IT quality theories to develop an integrated BDAQ model and measure its impact on firm performance.

2.2 IS success and IT quality theories
RBV is consistent with IS success theory (DeLone and McLean, 1992; Delone, 2003) as both focus on the competences of internal management systems to influence firm performance. In a similar spirit, Wixom and Todd (2005) and Nelson et al. (2005) presented quality dominant logic in technology usage theory by putting forward two basic dimensions of IS (systems quality and information quality) to establish an IT artifact in the IS literature. They identified nine dimensions, five of which relate to systems quality (i.e. reliability, efficiency, flexibility, privacy, integration) and four to information quality (i.e. accuracy, completeness, currency, and format).

2.3 Theory-driven BDAQ dimensions
Quality is a holistic concept in BDA. For example, the quality of the technology platform in BDA determines the quality of transaction data, the availability of data in the warehouse, the selection and implementation of analytic software and the communication environment (Davenport, 2006). Similarly, as the technology platform evolves into an organization, it pays equal attention to information quality because “companies that learn to take advantage of big data will use real-time information from sensors, radio frequency identification and other identifying devices to understand their business environments at a more granular level, to create new products and services, and to respond to changes in usage patterns as they occur” (Sun and Jeyaraj, 2013). As well as strong infrastructure and robust information, the success of BDA depends on the talent of qualitative or quantitative analysts, widely referred to as data scientists. Talent quality plays a key role in BDA in terms of offering new products or shaping the business. For example, data scientists in LinkedIn have come up with game-changing analytics-driven services, such as “People You May Know,” “Jobs You May Be Interested In,” “Groups You May Like,” “Companies You May Want to Follow” and “Skills and Expertise” (Davenport, 2013). Prior studies have identified a number of dimensions and sub-dimensions of BDAQ that play key roles in influencing firm performance (Table I).

3. Research model and hypotheses
This study builds on prior studies to develop a research model that assesses BDAQ. The literature review identifies three principal dimensions of quality that reveal BDAQ: technology, information and talent (see Table I). Throughout our review and theoretical exploration, BDAQ was frequently identified as a higher-order and multi-dimensional construct with several sub-dimensions (see Table I). As such, we conducted two Delphi studies to explore the sub-dimensions of BDAQ under each primary dimension identified in the review. Round one of the Delphi study was conducted in November 2014 (n = 51) and round two in February 2015 (n = 43) with respondents who represented a balance of
analytics practitioners, consultants and academics. These early results offer strong support for the three primary antecedents and 13 underlying components to develop the research model (Figure 1).

3.1 Technology quality
We claim that technology quality, which we define as the user-perceived quality of the overall BDA platform, is one of the core antecedents of BDAQ. Technology quality has always received an enormous attention in IS literature as a means of providing information by measuring overall operations and communications (Delone, 2003). Petter et al. (2008, p. 238) cited technology quality as “the desirable characteristics of an information system. For example: ease of use, system efficiency, system reliability, and ease of learning, as well as system features of intuitiveness, sophistication, flexibility, and response times.” Illuminating the importance of technology quality in big data environments, Davenport (2013, p. 67) states, “Innovative technologies of many kinds had to be created, acquired, and mastered […] To complement them, new ‘agile’ analytical methods and machine learning techniques are being used to produce insights at a much faster rate.” Based on the extant literature and Delphi findings, our study identifies adaptability, integration, privacy, response time and system reliability as critical components of technology quality (see Table II). Overall, our study suggests that technology quality is a critical antecedent of BDAQ because technology provides information that is subsequently used for analytics-driven decision making. Indeed, many of the analytics failures in big data environments are related to the technology platform. Therefore, we propose the following hypothesis:

\[ H1. \] Technology quality has a significant positive influence on BDA quality.

3.2 Information quality
Organizations with robust technology and talent qualities aim to establish an information ecosystem to solve business problems and facilitate decision making (Wixom et al., 2013).
The extant literature and our Delphi findings identify four characteristics of information in BDA projects—accuracy, completeness, currency and format (see Table II). There can be slight variations among these dimensions across BDA environments; however, the degree of completeness, accuracy, format and currency of information significantly contributes to BDAQ. For instance, banks may produce a 360° view and more complete information for users by combining data from multiple platforms, such as online banking, physical visits to the bank, ATMs and customer complaints (Barton and Court, 2012a, b). Analytics-driven information quality has had increased exposure in the big data environment in recent years (Davenport et al., 2012; Schroeck et al., 2012; Petter et al., 2013). Nevertheless, there is a paucity of research that explores the role of information quality in BDA. Drawing on IT quality and BDA literature, we propose here that information quality is an important determinant of BDAQ (Wixom et al., 2013; Agarwal and Dhar, 2014; Goes, 2014; Sharma et al., 2014). Therefore, we propose the following hypothesis:

H2. Information quality has a significant positive influence on BDA quality.

3.3 Talent quality
The success of BDA largely depends on the talent quality of data scientists, that is, quantitative analysts who have both computational and analytical skills (Davenport, 2013, p. 67). Talent quality also indicates the ability of an analytics professional (e.g. someone with analytics skills or knowledge) to perform assigned tasks in the big data environment. According to Constantiou and Kallinikos (2015), in this context “know-how” and other categories of knowledge are qualities that can produce or sustain competitive advantage. According to Davenport and Patil (2012, p. 73), “Data scientists are the people who understand how to fish out answers to important business questions from today’s tsunami of unstructured information. As companies rush to capitalize on the potential of big data, the largest constraint many face is the scarcity of this special talent.”
Based on our Delphi studies and prior studies, our study identifies four distinct but equally important skill sets that are important for analysts: technology management knowledge (e.g. visualization tools, and management and deployment techniques); technical knowledge (e.g. database management); business knowledge (e.g. the ability to understand the differences between short- and long-term goals); and relational knowledge (e.g. cross-functional collaboration using information) (see Table II). With curiosity and the right amount technical training (e.g. Hadoop MapReduce, machine learning language, data visualization tools, database management-NoSQL, etc.), talent quality plays a key role during the discovery process in the BDA environment (Davenport and Patil, 2012; Davenport, 2013; Kiron et al., 2014a, b). Talent quality determines the quality of insights and overall BDAQ to gain competitive advantage (Barton and Court, 2012a, b). Therefore, we propose the following hypothesis:

**H3.** Talent quality has a significant positive influence on BDA quality.

### 3.4 BDAQ and firm performance

Quality insights from big data can impact firm performance by managing the supply chain better, making better apps, creating new products and retaining relationships with customers. For example, GE has transformed its operations and performance using real-time sensor data collection and analysis from industrial machines. Another example is provided by Xiaomi, a Chinese mobile maker, which has produced robust revenue in the last five years using analytics-driven service systems. The Bank of England has also created and adjusted policies at an extraordinary pace by embracing an all-out analytics culture (Ransbotham et al., 2016). Each of the quality dimensions specified in our conceptual model plays a critical role in producing analytics quality. For example, RBV suggests that the technology platform in analytics cannot explain variance in firm performance when it is not rare and not expensive to replicate (Ray et al., 2005). Similarly, since the adoption of analytics is growing, the asymmetric nature of information can create competitive advantage for various functional units (e.g. marketing, operations, HR, etc.), which again reflects the rarity and inimitability foundations of RBV. In a similar spirit, Ransbotham et al. (2015, p. 3) state, “Deriving business value from analytics depends in important ways on building strong [internal capabilities] that link insights with business outcomes”. We interpret “internal capabilities” as the quality of skilled talent that can innovate and create competitive advantages using techniques like data visualization, and predictive and prescriptive modeling. Therefore, we propose the following hypothesis:

**H4.** BDA quality has a significant positive impact on firm performance.

### 3.5 Analytic quality–firm strategy alignment

Strategy refers to a firm’s philosophy of how it can achieve higher performance in the markets within which it operates (Barney et al., 2001). Superior analytics qualities are believed to enhance performance when they are aligned with the firm’s strategy (Aslan et al., 2015). For example, one retailer failed to improve firm performance using big data insights because it required thorough restructuring of the supply chain, which was not supported by firm-level strategy. According to Ross et al. (2013), “[t]he biggest reason that investments in big data fail to pay off […] is that most companies don’t do a good job with the information they already have. They don’t know how to manage it, analyze it in ways that enhance their understanding, and then make changes in response to new insights.” Although firms invest hugely in improving analytics-driven insights, they are often disconnected from corporate strategy. For example, the emerging literature on BDA has found that alignment between analytics capability and firm strategy is a strong moderator of the relation between BDA capability and
firm performance (Akter, Wamba, Gunasekaran, Dubey and Childe, 2016). Therefore, we propose the hypothesis:

\[ H5. \] Alignment between analytics quality and firm strategy has a moderating influence on the relationship between BDAQ and FPER.

4. Method

4.1 Scale development

Our study either adapted or created measures on various scales that have been validated in past research. We customized scales according to the context of our BDA research to ensure that the scales are suitable for managers in big data firms.

In this paper, we have followed an approach used by (Akter, Wamba, Gunasekaran, Dubey and Childe, 2016; Akter, Fosso Wamba and D’Ambra, 2016; Fosso Wamba, Gunasekaran, Akter, Ren, Dubey and Childe, 2017) and considered BDAQ model as a higher-order, reflective-formative model. More specifically, the first-order dimensions are reflective (Mode A) and the higher-order dimensions are formative (Mode B) (Chin, 2010; Ringle et al., 2012; Akter et al., 2017). Table III presents dimensions, sub-dimensions, measurement items and their types. We measured information quality drawing on the constructs proposed by Wixom and Todd (2005) and Nelson et al. (2005). Similarly, system quality scale was adapted from Parasuraman et al. (2005) and Nelson et al. (2005) and talent quality scale from (Kim et al., 2012).

4.2 Control variables

Our study used several control variables to model the impacts of BDAQ on FPER. Specifically, we controlled for firm size and type to avoid any bias in our findings. The firm size was measured on the number of employees and firm type on the nature of primary industry; this ranged from transportation to IT. We controlled for firm size because larger organizations are correlated with better analytics performance than smaller ones. Similarly, we controlled for firm type to investigate the impact of any industry-specific analytics climate on performance. These variables were all measured using a categorical scale.

4.3 Sample

Using an online survey, we collected our data from a panel of respondents in France using a leading market research firm. The participants in the study were business analysts and IT managers with analytics experience in France. The market research firm selected a random sample of 500 members as our sampling frame. An invitation was sent to all members of the sampling frame to participate in the study. Out of the 337 panel members who agreed to participate in the study, 150 submitted questionnaires that were considered to have been correctly filled out and appropriate for further analysis. Thus, the survey gives us a response rate of 44.51 percent.

5. Data analysis

The study applied partial least squares (PLS), a variance-based structural equation modeling technique, to estimate the measurement and structural model (Chin, 2010). BDAQ is specified as a higher-order construct that contains three second-order formative constructs and 13 first-order reflective sub-constructs (see Table III). The study applies the repeated indicator approach to estimate the scores for the first-order, second-order and third-order BDAQ constructs following the guidelines of Wetzels et al. (2009) and Becker et al. (2012). The use of PLS has been suggested to estimate higher-order, reflective-formative constructs to ensure more theoretical parsimony and less model complexity (Law et al., 1998; Edwards, 2001; MacKenzie et al., 2005; Wetzels et al., 2009; Chin, 2010) and to test novel
<table>
<thead>
<tr>
<th>3rd-order constructs</th>
<th>2nd-order constructs</th>
<th>Type</th>
<th>1st-order constructs</th>
<th>Item</th>
<th>Item labels</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big data analytics quality (BADQ)</td>
<td>Information quality (Nelson et al., 2005; Wixom and Todd, 2005)</td>
<td>Reflective</td>
<td>Completeness</td>
<td>Reflective</td>
<td>COMP1</td>
<td>The big data analytics used: ___ provide a complete set of information</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>COMP2</td>
<td>___ produce comprehensive information</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>COMP3</td>
<td>___ provide all the information needed</td>
</tr>
<tr>
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<td></td>
<td>CURR1</td>
<td>___ provide the most recent information</td>
</tr>
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<td></td>
<td>CURR2</td>
<td>___ produce the most current information</td>
</tr>
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<td></td>
<td></td>
<td>CURR3</td>
<td>___ always provide up-to-date information</td>
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<td></td>
<td>Currency</td>
<td></td>
<td>FORM1</td>
<td>The information provided by the analytics is ___ well formatted</td>
</tr>
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<td>FORM2</td>
<td>___ produce comprehensive information</td>
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<td>FORM3</td>
<td>___ provide all the information needed</td>
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<td>CURR1</td>
<td>___ provide the most recent information</td>
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<td>CURR2</td>
<td>___ produce the most current information</td>
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<td>CURR3</td>
<td>___ always provide up-to-date information</td>
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<tr>
<td></td>
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<td></td>
<td>Format</td>
<td></td>
<td>FORM1</td>
<td>The information provided by the analytics is ___ well laid out</td>
</tr>
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<td>FORM2</td>
<td>___ produce comprehensive information</td>
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<td>FORM3</td>
<td>___ provide all the information needed</td>
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<td>CURR1</td>
<td>___ provide the most recent information</td>
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<td></td>
<td></td>
<td>CURR2</td>
<td>___ produce the most current information</td>
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<td></td>
<td></td>
<td>CURR3</td>
<td>___ always provide up-to-date information</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Accuracy</td>
<td></td>
<td>ACCU1</td>
<td>The big data analytics used: ___ provide correct information</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>ACCU2</td>
<td>___ provide few errors in the information</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ACCU3</td>
<td>___ provide accurate information</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Technology quality (Nelson et al., 2005; Parasuraman et al., 2005)</td>
<td>Reflective</td>
<td>System reliability</td>
<td>Reflective</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SYRE2</td>
<td>The analytics system performs reliably to provide the information</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SYRE3</td>
<td>The operation of the analytics system is dependable for the information</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>System adaptability</td>
<td></td>
<td>SYAD1</td>
<td>The analytics system can be adapted to meet a variety of needs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SYAD2</td>
<td>The analytics system can flexibly adjust to new demands or conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SYAD3</td>
<td>The analytics system is flexible in addressing needs as they arise</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>System integration</td>
<td></td>
<td>SYIN1</td>
<td>The analytics system effectively integrates data from different areas</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SYIN2</td>
<td>The analytics system pulls together information that used to come from different transactions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SYIN3</td>
<td>The analytics system effectively combines data from different areas</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>System response time</td>
<td></td>
<td>SYRE1</td>
<td>The analytics system does not take long time to process my requests</td>
</tr>
</tbody>
</table>

(continued)
<table>
<thead>
<tr>
<th>3rd-order constructs</th>
<th>2nd-order constructs</th>
<th>Type</th>
<th>1st-order constructs</th>
<th>Type</th>
<th>Item labels</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sytem Privacy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SYRE2</td>
<td>The analytics system provides information in a timely fashion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SYRE3</td>
<td>The analytics system processes my requests quickly</td>
</tr>
<tr>
<td>Talent quality</td>
<td>Reflective</td>
<td>Technical knowledge</td>
<td>Reflective</td>
<td>BATK1</td>
<td>Our analytics personnel are very capable in terms of programming skills (e.g. structured programming, web based application, CASE tools, etc)</td>
<td></td>
</tr>
<tr>
<td>(Kim et al., 2012)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BATK2</td>
<td>Our analytics personnel are very capable in terms of managing project life cycles</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>BATK3</td>
<td>Our analytics personnel are very capable in the areas of data management and maintenance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BATK4</td>
<td>Our analytics personnel are very capable in decision support systems (e.g. expert systems, artificial intelligence, data warehousing, mining, marts, etc)</td>
</tr>
<tr>
<td>Technology management knowledge</td>
<td></td>
<td></td>
<td></td>
<td>TMKO1</td>
<td>Our analytics personnel show superior understanding of technological trends</td>
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<td></td>
<td></td>
<td>TMKO2</td>
<td>Our analytics personnel show superior ability to learn new technologies</td>
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<td></td>
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<td></td>
<td></td>
<td>TMKO3</td>
<td>Our analytics personnel are very knowledgeable about the critical factors for the success of our organization</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>TMKO4</td>
<td>Our analytics personnel are very knowledgeable about the role of business analytics as a means, not an end</td>
</tr>
<tr>
<td>Business Knowledge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BKWO1</td>
<td>Our analytics personnel understand our organization’s policies and plans at a very high level</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>BKWO2</td>
<td>Our analytics personnel are very capable in interpreting business problems and developing appropriate solutions</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>BKWO3</td>
<td>Our analytics personnel are very knowledgeable about business functions.</td>
</tr>
</tbody>
</table>

(continued)
<table>
<thead>
<tr>
<th>3rd-order constructs</th>
<th>2nd-order constructs</th>
<th>Type</th>
<th>1st-order constructs</th>
<th>Type</th>
<th>Item labels</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relational Knowledge</td>
<td>BKWO4</td>
<td>Our analytics personnel are very knowledgeable about the business environment</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>RKWO1</td>
<td>Our analytics personnel are very capable in terms of managing projects.</td>
<td></td>
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</tr>
<tr>
<td>RKWO2</td>
<td>Our analytics personnel are very capable in terms of executing work in a collective environment</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>RKWO3</td>
<td>Our analytics personnel are very capable in terms of teaching others</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RKWO4</td>
<td>Our analytics personnel work closely with customers and maintain productive user/client relationships</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

| N/A | Analytics quality–firm strategy alignment (Akter, Wamba, Gunasekaran, Dubey and Childe, 2016; Setia and Patel, 2013, no. 21858) | AQFSA1 | The big data analytics plan aligns with the company’s mission, goals, objectives, and strategies |
| N/A | Firm performance (Tippins and Sohi, 2003) | AQFSA2 | The big data analytics plan contains quantified goals and objectives |
| | | AQFSA3 | The big data analytics plan contains detailed action plans/strategies that support company direction |
| | | AQFSA4 | We prioritize major big data analytics investments by the expected impact on business performance |

| N/A | Using big data analytics improved ____ during the last 3 years relative to competitors |
| FPER1 | ____ Customer retention |
| FPER2 | ____ Sales growth |
| FPER3 | ____ Profitability |
| FPER4 | ____ Return on investment |
propositions that suffer from a paucity of prior theory and are exploratory in nature (Hair et al., 2011). The study used the software package SmartPLS 3.0 (Ringle et al., 2015) to analyze the data using non-parametric bootstrapping with 1,000 replications (Efron and Tibshirani, 1993; Chin, 1998a, b; Tenenhaus et al., 2005) and the path weighting scheme for the inside approximation (Chin, 1998a, b; Tenenhaus et al., 2005; Wetzels et al., 2009).

6. Results

6.1 Measurement model

As a first step, our study estimates the reliability and validity of the first-order measurement model, which includes 13 sub-constructs of BDAQ as well as AQFSA and FPER (see Tables IV and V). The study ensured convergent validity as all item have loadings > 0.70, which indicates that respective items have higher convergence in measuring the constructs (Chin, 2010). It also ensured reliability of the measurement scale as all composite reliabilities were > 0.80 and average variance extracted (AVE) > 0.50 (Fornell and Larcker, 1981). Similarly, the study ensured discriminant validity as all cross-loadings were less than or equal to 0.40 and the square root of the AVEs in the diagonals of the correlation matrix exceeded the intercorrelations of the construct in the first-order model (Fornell and Larcker, 1981; Chin, 1998a, b, 2010).

Table VI shows our estimations of the interrelationships between the higher-order constructs, that is, second-order technology/talent/information quality constructs and the third-order BDAQ construct. Since we used the repeated indicator approach to estimate the higher-order constructs, the evaluation of the first-order constructs are based on loadings of items (see Table IV); however, the evaluation of higher-order constructs is based on path relationships (Becker et al., 2012) (see Table VI). For example, the results confirm that all the second-order constructs (i.e. TECQ, TALQ and INFQ) were manifested adequately in their corresponding first-order components. For instance, TECQ was reflected by systems reliability ($\beta = 0.82$), adaptability ($\beta = 0.80$), integration ($\beta = 0.85$), response time ($\beta = 0.80$) and privacy ($\beta = 0.72$), in which data integration reflects the highest variance (85 percent). Accordingly, variance of TALQ and INFQ was calculated to reflect their corresponding components (Table VI). Finally, we assessed the highest order, formative BDAQ constructs, which consist of TECQ (15 items), TALQ (16 items) and INFQ (12 items). We discuss these relationships in the next section, focusing on our proposed hypotheses.

6.2 Structural model

Our study assessed the validity of the structural model by estimating the relationship between technology quality, information quality, talent quality and the higher order BDAQ. In Table VII, the results provide a standardized $\beta$ of 0.395 (TECQ-BDAQ), 0.306 (INFQ-BDAQ), 0.416 (TALQ-BDAQ) and 0.788 (BDAQ-FPER) of the main model, respectively. All these path coefficients were significant at $p < 0.01$ (see Table VII), thus supporting $H1$–$H4$. Overall, the BDAQ model explains 53 percent of variance of firm performance, which is a large effect size in terms of $R^2$.

To test the moderating effect, we estimated the impact of BDAQ on FPER, the direct influence of AQFSA on FPER, and the interaction impact of BDAQ $\times$ AQFSA on FPER. The findings confirm the significant impact of a moderator, because the interaction effect (BDAQ $\times$ AQFSA) is significant ($\beta = 0.139, p < 0.01$) independently of the size of other path coefficients in the interaction model (Henseler and Fassott, 2010). The results also show that the size of the interaction effect is large ($f^2 = 0.406$), which supports $H5$ and confirms AQFSA as a significant moderator in the relationship between BDAQ and FPER. Finally, the study estimated the impact of two control variables (firm size and firm type), which were found to have an insignificant association with firm performance. (We discuss the
implications of all these findings in the discussion section that follows). The study conducted common method variance analysis using Harman’s single-factor test as we collected data from a single context (Podsakoff and Organ, 1986). The findings show 13 different factors (eigenvalues > 1) with 80 percent total variance. In addition the study

<table>
<thead>
<tr>
<th>Constructs</th>
<th>Items</th>
<th>Loadings</th>
<th>CR</th>
<th>AVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>System reliability (SYRE)</td>
<td>SYRE1</td>
<td>0.936</td>
<td>0.966</td>
<td>0.905</td>
</tr>
<tr>
<td></td>
<td>SYRE2</td>
<td>0.956</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SYRE3</td>
<td>0.962</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System adaptability (SYAD)</td>
<td>SYAD1</td>
<td>0.914</td>
<td>0.938</td>
<td>0.835</td>
</tr>
<tr>
<td></td>
<td>SYAD2</td>
<td>0.935</td>
<td></td>
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<tr>
<td></td>
<td>SYAD3</td>
<td>0.892</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System integration (SYIN)</td>
<td>SYIN1</td>
<td>0.941</td>
<td>0.964</td>
<td>0.899</td>
</tr>
<tr>
<td></td>
<td>SYIN2</td>
<td>0.963</td>
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<tr>
<td></td>
<td>SYIN3</td>
<td>0.940</td>
<td></td>
<td></td>
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<tr>
<td>System response time (SYRS)</td>
<td>SYRE1</td>
<td>0.891</td>
<td>0.932</td>
<td>0.820</td>
</tr>
<tr>
<td></td>
<td>SYRE2</td>
<td>0.937</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>SYRE3</td>
<td>0.888</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System privacy (SYPR)</td>
<td>SYPR1</td>
<td>0.933</td>
<td>0.964</td>
<td>0.900</td>
</tr>
<tr>
<td></td>
<td>SYPR2</td>
<td>0.954</td>
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<tr>
<td></td>
<td>SYPR3</td>
<td>0.958</td>
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<td>Technical knowledge (BATK)</td>
<td>BATK1</td>
<td>0.883</td>
<td>0.935</td>
<td>0.782</td>
</tr>
<tr>
<td></td>
<td>BATK2</td>
<td>0.902</td>
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<td>BATK3</td>
<td>0.913</td>
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<td>BATK4</td>
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</tr>
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<tr>
<td></td>
<td>TMKO2</td>
<td>0.935</td>
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<td></td>
<td>TMKO3</td>
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<td></td>
<td>TMKO4</td>
<td>0.874</td>
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<tr>
<td>Business knowledge (BKWO)</td>
<td>BKWO1</td>
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<td>0.946</td>
<td>0.814</td>
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<tr>
<td></td>
<td>BKWO2</td>
<td>0.899</td>
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<tr>
<td></td>
<td>BKWO3</td>
<td>0.922</td>
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<td></td>
<td>BKWO4</td>
<td>0.920</td>
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<td>Relational knowledge (RKWO)</td>
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<td>0.876</td>
<td>0.928</td>
<td>0.762</td>
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<tr>
<td></td>
<td>RKWO2</td>
<td>0.892</td>
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<tr>
<td></td>
<td>RKWO3</td>
<td>0.864</td>
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<td></td>
<td>RKWO4</td>
<td>0.859</td>
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<td>Completeness (COMP)</td>
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<td></td>
<td>ACCU 3</td>
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<td>0.963</td>
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<td>FORM 2</td>
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<td>FORM 3</td>
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<td>Currency (CURR)</td>
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<td>AQFSA4</td>
<td>0.827</td>
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<td>Firm performance</td>
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<td></td>
<td>FPER4</td>
<td>0.875</td>
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Table IV.
Assessment of first order, reflective model
### Table V.
Descriptive statistics, correlations, and AVEs

| Construct                              | Mean  | SD    | SYRE | SYAD | SYIN | SYRS | SYPR | BATK | TMKO | BKWO | RKWO | COMP | ACCU | FORM | CURR |
|----------------------------------------|-------|-------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| System reliability (SYRE)              | 4.742 | 1.019 | 0.915|      |      |      |      |      |      |      |      |      |      |      |      |      |
| System adaptability (SYAD)             | 4.984 | 1.105 | 0.430| 0.913|      |      |      |      |      |      |      |      |      |      |      |      |
| System integration (SYIN)              | 5.156 | 1.192 | 0.433| 0.419| 0.948|      |      |      |      |      |      |      |      |      |      |      |
| System response time (SYRS)            | 5.038 | 1.158 | 0.444| 0.476| 0.906|      |      |      |      |      |      |      |      |      |      |      |
| System privacy (SYPR)                  | 5.164 | 1.174 | 0.397| 0.379| 0.342| 0.948|      |      |      |      |      |      |      |      |      |      |
| Technical knowledge (BATK)             | 5.129 | 1.187 | 0.334| 0.300| 0.357| 0.433| 0.412| 0.884|      |      |      |      |      |      |      |      |
| Technology management knowledge (TMKO) | 5.146 | 1.143 | 0.318| 0.409| 0.510| 0.415| 0.427| 0.905|      |      |      |      |      |      |      |      |
| Business knowledge (BKWO)              | 5.073 | 1.095 | 0.394| 0.390| 0.407| 0.468| 0.370| 0.440| 0.902|      |      |      |      |      |      |      |
| Relational knowledge (RKWO)            | 5.158 | 1.051 | 0.329| 0.378| 0.367| 0.402| 0.464| 0.459| 0.436| 0.873|      |      |      |      |      |      |
| Completeness (COMP)                    | 5.004 | 1.102 | 0.377| 0.390| 0.431| 0.357| 0.368| 0.558| 0.448| 0.381| 0.891|      |      |      |      |      |
| Accuracy (ACCU)                        | 5.213 | 1.091 | 0.385| 0.421| 0.388| 0.492| 0.338| 0.348| 0.524| 0.510| 0.476| 0.901|      |      |      |      |
| Format (FORM)                          | 5.247 | 1.084 | 0.371| 0.352| 0.405| 0.372| 0.331| 0.366| 0.362| 0.435| 0.476| 0.436| 0.542| 0.947|      |      |
| Currency (CURR)                        | 5.113 | 0.979 | 0.365| 0.376| 0.347| 0.382| 0.312| 0.361| 0.362| 0.315| 0.441| 0.413| 0.416| 0.432| 0.926|      |

**Note:** Square root of AVE on the diagonal
conducted an unobserved heterogeneity test using REBUS-PLS, while investigating the nomological net (Esposito Vinzi et al., 2008). However, the results did not show any evidence of significant unobserved heterogeneity in data.

7. Discussion

7.1 Summary of findings
This study was undertaken to investigate the direct effects of BDAQ on FPER, as well as the moderating effects of AQFSA on the link between BDAQ and FPER. The findings show that all the hypothesized relationships in our conceptual model are supported. They also show that AQFSA is a significant partial mediator, which confirms that “without a strategy for advancing the use of analytics among decision makers, the desired results from data-driven insights will be elusive” (Ransbotham et al., 2016, p. 16). An investigation into the results on BDAQ antecedents illuminates both TECQ and TALQ as the two most significant predictors of BDAQ, followed by INFQ ($\beta = 0.30$). These findings are aligned with Ransbotham et al. (2015), who argue that firms will not be able to generate optimum revenues from investments in analytics technology unless they focus on improving the analytics talent bench. The findings also confirm the significant moderating impact of AQFSA on FPER ($\beta = 0.22$) with $R^2 = 0.65$. Overall, the nomological validity of the study was ensured as all the hypotheses were proven significant.

7.2 Theoretical contributions
This research offers some key theoretical contributions. First, we draw on the RBV and IT quality theories to present a nomological network that integrates technology quality,
information quality and talent quality with BDA quality and firm performance in a big data environment. Thus, our study contributes to the emerging literature on BDA by advancing the theoretical understanding of BDAQ and firm performance relationship (Wixom and Todd, 2005). In addition, this study extends prior research based on quality theories by exploring key predictors of BDAQ in the BDA environment. Specifically, our findings validate the fundamental roles of technology quality, information quality and talent quality in improving BDAQ in a BDA environment. For example, the importance of talent resources has been recognized as a pivotal factor to leverage the value of BDA information (Kiron et al., 2014a, b) for realizing competitive advantage (Lai et al., 2010). Indeed, Ransbotham et al. (2015) have acknowledged that firms that are currently innovating with BDA have “a strong talent base for developing analytics results.” That is probably why Mahoney and Pandian (1992) state that data scientists have the “sexiest job of the 21st century.” In future, different approaches and tools meant for facilitating the training of future business analytics professionals can be examined.

Second, the study validates the moderating influence of the alignment between analytics quality and firm strategy on the relationship between BDAQ and firm performance. In fact, firm strategy alignment has been recognized as an important concept in the IS and operations management literatures (Helfat and Peteraf, 2003; Setia and Patel, 2013), but very few studies have integrated the concept while studying the relationship between BDAQ and firm performance (Wixom and Todd, 2005) in the context of BDA. Yet our findings indicate a significant moderating influence of firm strategy alignment on the relationship between BDAQ and FPER. Therefore, this study extends analytics research in the IS and operations management literature.

Third, the study provides empirical evidence on the relationships between quality dynamics, as well as the moderating influence of the alignment between analytics quality and firm strategy, using a sample of 150 business analysts, business analytics, and IT professionals in France. It, therefore, contributes to overcoming the lack of empirical studies in the big data environment (Sammon and Adam, 2005; Fosso Wamba et al., 2015).

Fourth, our study extends prior research by examining the direct relationship between analytics resources and firm performance (Newbert, 2007; Kunc and Morecroft, 2010) and the mediating role of information quality in quality dynamics. For example, our results support the significance of INFQ as a strong mediator between both TECQ and BDAQ and TALQ and BDAQ, and thus confirming the fact that the “effect of IT on firm performance is mediated through a complex chain of intermediate variables” (Akter, Wamba and D’Ambra, 2017).

7.3 Practical contributions
There are several practical implications of this study, due to the operational and strategic potential of BDA across all industries. First, the proposed model can serve as a baseline model for performance assessment during the analysis and design of BDA applications for managers. Second, our study identifies a set of antecedents (i.e. talent, information, and technology quality) and components that may lead to high-level organizational efficiency and effectiveness using BDA. Third, the study proposes not only a combination of skills required for a data scientist, but also the conditions under which that may lead to superior firm performance. Fourth, our study provides a list of factors that may serve as a guide and control mechanism for managers during their investment decisions on BDA projects, and thus, foster the exploration and exploitation of BDA tools.

7.4 Limitations and future work
The present study has some limitations that should be acknowledged. First, it uses a cross-sectional research design to collect data. Future studies may use a case study or
a longitudinal study to better assess our proposed research model and capture its stability across time or settings. Second, data were collected only in one country. Future research could extend this study by collecting data from more countries with different cultural backgrounds to take into consideration cultural factors (e.g. language, developed vs developing countries). A third limitation is related to the use of a seven-point Likert scale to evaluate our items. This might lead to the so-called “acquiescence bias” or the “respondents’ tendency to respond to items positively without much regard for its true content” (Chin et al., 2008). A potential future research avenue would be to consider using the nine-point scale fast-form items with the two-anchor points ranging from −4 to +4 as suggested by Chin et al. (2008). Finally, it would be interesting to explore some other contextual dimensions that could influence the BDAQ construct.

8. Conclusions
Although the idea of analytics has gained momentum in recent years, it requires large-scale practice to enhance firm performance. Whereas the technology side of analytics needs to focus on reliability, adaptability, integration, response time and privacy, the information side must ensure complete, up-to-date, accurate and well-presented information for decision making. Similarly, talent quality can focus on developing technological, managerial and relational knowledge to develop skilled analysts in emerging evidence-based management. The growing number of analytically challenged firms can get the most out of their analytics by simultaneously leveraging their technology, talent, and information quality to achieve competitive edges in the data economy.

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Performance landscape modeling in digital manufacturing firm
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Abstract

Purpose – The purpose of this paper is to update existing Kauffman’s NK model to evaluate the manufacturing fitness of strategic business capabilities. The updated model is tested in a digital manufacturing (DM) setting to investigate the sequence for developing cumulative capabilities that can yield the maximum payoff.

Design/methodology/approach – The authors develop a grey–DEMATEL–NK fitness model and show its application, through a case study, to a DM firm in India.

Findings – The grey–DEMATEL–NK model helps evaluate multiple manufacturing capabilities and indicates that quality–flexibility–cost–delivery is the sequence that yields the maximum manufacturing fitness (competitive payoff) for a DM firm. This sequence helps the firm reorganise its internal business processes and is different from that used to develop cumulative capabilities in a traditional manufacturing setting (quality–delivery–flexibility–cost).

Originality/value – This study presents a pilot model for computing the cumulative capabilities payoff and prescribes a sequence for developing cumulative capabilities within a DM context.

Keywords Positioning, NK model, Digital manufacturing, Cumulative capabilities, Grey–DEMATEL–NK, Performance landscape

Paper type Research paper

1. Introduction

The use of digital manufacturing (DM) technologies is the latest best practice to ensure competitiveness in a volatile, uncertain, complex and agile world. DM technologies, such as advanced digital infrastructure, three-dimensional (3D) printers, automated material handling and cloud-based sensor intelligence, allow manufacturers to develop a product in incremental steps (Deradjat and Minshall, 2017; Holmström and Partanen, 2014). DM is fast replacing the traditional metal cutting-based approach in several industries, including automobile (Khorraram Niaki and Nonino, 2017), aerospace (Khajavi et al., 2014), medicine (Deradjat and Minshall, 2017) and rapid prototyping (Ucraft and Fletcher, 2003), because of its advantages in producing complex, intricate and customised products.

The development of strong manufacturing capabilities is associated with an improvement in manufacturing performance. In fact, the theory of performance frontiers (TPF) recommends that firms positioned away from the frontier pursue cumulative capabilities to achieve maximal performance (Schmenner and Swink, 1998; Vastag, 2000). Interestingly, the cumulative capabilities theory posits that the sequence in which manufacturing capabilities (cost (C), quality (Q), flexibility (F) and delivery (D)) are developed is a key determinant of lasting performance improvement (Amoako-Gyampah and Meredith, 2007; Ferdows and De Meyer, 1990; Sarmiento, 2010). However, empirical studies investigating cumulative
capabilities across firms have prescribed different sequences (Corbett and Claridge, 2002; Sarmiento et al., 2010): quality–delivery–cost–flexibility–innovation (Q–D–C–F–I) (Noble, 1995); quality–delivery–flexibility–cost (Q–D–F–C) (Ferdows and De Meyer, 1990) and quality–delivery–cost–flexibility (Q–D–C–F) (Boon-Itt and Wong, 2016). The lack of a consensus makes it difficult for managers to select a sequence that can provide the maximum payoff from among the strategic choices available. A sequence that is not aligned with the business processes can adversely affect the firm and impede its competitive edge. For DM firms looking to develop their capabilities, this problem is compounded by the fact that digital technologies tend to push the bar of maximal performance, thus, rendering the current performance far from optimal (Brumme et al., 2015; Clark, 1996; Hayes et al., 2005; Hayes and Pisano, 1994).

In this work, we explore how a DM firm can develop its manufacturing capabilities. Specifically, we propose a pilot model to investigate the particular sequence of cumulative capabilities that can yield the maximum payoff for a DM firm. For this, we first refer to the evolutionary theory, in which firm performance is determined by two factors: the number of decisions taken (N) and the interdependence among these decisions (K) (Billinger et al., 2014; Ganco and Hoetker, 2009; Kauffman and Weinberger, 1989). Classical NK models typically use the random function to generate fitness values and neglect the strategic context (Ghemawat and Levinthal, 2008; McCarthy, 2004; McCarthy and Tan, 2000). However, this work attempts to accomplish the following:

(1) to update the existing NK-based random fitness model by incorporating the impreciseness and the interdependence of the manufacturing capabilities available to a firm; and

(2) to determine a cumulative capabilities sequence that can yield the maximum payoff for a DM firm.

Our findings based on a case study of a DM firm in India indicate that quality–flexibility–cost–delivery (Q–F–C–D) is the optimal sequence for achieving maximum manufacturing fitness (competitive payoff). Interestingly, this sequence is different from that of traditional manufacturing (Q–D–F–C), proposed in line with the cumulative capabilities theory. Furthermore, we note that aligning business processes with the proposed cumulative capabilities sequence is beneficial for the competitiveness of the firm. These findings can serve as the starting point for a more detailed investigation of cumulative capabilities sequences that can be adopted in a DM context.

The rest of paper is organised as follows. Section 2 presents a review of literature and highlights the need for updating the existing fitness landscape modelling approaches. Section 3 explains the case scenario and the need for fitness landscape modelling. Section 4 explains the developed grey–DEMATEL–NK approach and applies it in a DM context. Section 5 links fitness to firm performance and determines the sequence of capabilities development that a digital firm should adopt. Finally, we discuss the managerial and practical relevance of the developed grey–DEMATEL–NK model.

2. Literature review

Two well-known approaches to developing manufacturing capabilities are “trade-off” and “cumulative capabilities”. The first assumes a differential in the firm’s performance dimensions, as a manufacturing firm cannot be expected to achieve the highest levels of performance on cost, quality, delivery and flexibility (Sarmiento et al., 2013, 2016; Skinner, 1996). On the other hand, the cumulative capabilities approach refers to simultaneous improvements in all performance dimensions (Ferdows and De Meyer, 1990; Ferdows and Thurnheer, 2011; Noble, 1995; Schroeder et al., 2011). Traditionally, the trade-off and cumulative capabilities approaches have been considered contradictory (Boyer and Lewis,
In fact, a central tenet of the cumulative capabilities model is that trade-offs can be resolved (Corbett and van Wassenhove, 1993; Corbett and Claridge, 2002; Ferdows and De Meyer, 1990; Noble, 1995). Interestingly, Schmenner and Swink (1998) proposed TPF by viewing trade-off and cumulative capabilities as distinct but complementary approaches to developing manufacturing capabilities. A performance frontier is the maximum performance that can be achieved with the given policies, investment and technology (Porter, 1996; Schmenner and Swink, 1998). TPF considers a smooth trade-off between performance dimensions and represents the firm’s position in a two-dimensional (2D) space (Figure 1).

Firms positioned inside the performance frontier curve are considered inefficient. These firms are expected to improve multiple performance dimensions simultaneously – by adopting the cumulative capabilities approach (P–Q) – to move towards the performance frontier. On the other hand, firms at the performance frontier tend to experience trade-off (Q–R). Thus, according to TPF, the decision of developing manufacturing capabilities depends on the relative distance of the firm from its performance frontier (Schmenner and Swink, 1998; Vastag, 2000).

Although such 2D representation of performance under TPF has been widely used in the field of manufacturing strategy, it is not without issues (Cai and Yang, 2014; Clark, 1996; Lapre and Scudder, 2004; Porter, 1996; Sarmiento, 2010; Sarmiento et al., 2016; Sarmiento and Shukla, 2010; Schmenner and Swink, 1998; Da Silveira, 2005; Vastag, 2000; Adner et al., 2014). First, TPF mainly focuses on external performance and does not track internal performance development across the four dimensions: cost, quality, delivery and flexibility (Adner et al., 2014; Ferdows and De Meyer, 1990; Ferdows and Thurnheer, 2011; Flynn et al., 1997). Second, TPF may not be useful for determining the sequence for developing cumulative capabilities at the single firm level. For instance, Ferdows and de Meyer (1990) proposed the “sand cone” sequence for the development of cumulative capabilities: Q–D–F–C. However, subsequent empirical studies only found partial support for the sand cone sequence in manufacturing firms (Avella et al., 2011; Größler and Grübner, 2006; Rosenzweig and Roth, 2004). Noble (1995) added innovation to the existing performance dimensions and proposed another sequence for developing cumulative capabilities: Q–D–C–F–I. Recently, Boon-Itt and Wong (2016) studied Thai manufacturing firms and identified Q–D–C–F as the best fit sequence. Although many works have studied cumulative capabilities using performance dimensions, few have attempted an exploratory analysis of the cumulative capabilities models from the perspective of manufacturing...
strategy (Bortolotti et al., 2014). For instance, Flynn and Flynn (2004) reported a substantial
difference in the performance outcomes of sequences across countries and industry types.
Schroeder et al. (2011) noted that plant-level factors such as competition, business
environment, market conditions and strategy also influence the sequence of cumulative
capability development. Overall, the existing investigations on cumulative capabilities
are characterised by two problems: the lack of a firm-specific perspective that is rooted in
the firm’s business environment and strategic context; and the absence of clear support for
the sequence of developing cumulative capabilities.

According to the evolutionary theory, a firm evolves to develop its manufacturing
capabilities and improve its performance. Firm performance is attributed to the number of
decisions taken (N) and the interdependence among these decisions (K). These two constitute
the starting point for the mathematical modelling of performance under Kaufmann’s NK
models (Billinger et al., 2014; Ganco and Hoetker, 2009; Kauffman and Weinberger, 1989).
Mathematically, a firm’s position can be represented as the vector of policies and decisions
that determine its overall fitness value in an NK model (Figure 2) (Adner et al., 2014;
Ghemawat and Levinthal, 1997, 2008). Many researchers have acknowledged the value of an
NK-based performance landscape in exploring the interdependence among strategic decisions
(Celo et al., 2015; Ganco and Hoetker, 2009; Ghemawat and Levinthal, 2008; Levinthal, 1997;
McCarthy, 2004; McCarthy and Tan, 2000).

In this study, we attempt to apply the NK modelling approach to the manufacturing
context. In the next section, we explain the concept of manufacturing fitness and how it can
be studied via NK modelling.

Manufacturing fitness
Tan (2001, p. 107) defined manufacturing fitness as “the ability of the firm to increase their
survivability and competitiveness in the manufacturing environment through inheriting,
imitating and searching for manufacturing capabilities such as cost, quality, delivery,
and flexibility”. This definition links the performance of the firm to its manufacturing capabilities. In the NK model, “N” refers to the elements of manufacturing capabilities (i.e. cost, quality, delivery and flexibility), while “K” refers to the level of complexity (i.e. patterns of interdependence) (McCarthy, 2004; McCarthy and Tan, 2000). Both these factors jointly yield strategic alternatives or manufacturing strategy configurations (Bozarth and Mcdermott, 1998; Ward et al., 1996). Firms can evolve through these manufacturing strategy configurations and achieve a certain level of fitness. The mapping of all possible strategic options according to their fitness level represents the fitness or the performance landscape.

Need for updating the NK method
To date, NK studies have relied on uniform random function generation U (0, 1) for evaluating the fitness contribution of a configuration (Billinger et al., 2014; Celo et al., 2015; Ganco and Hoetker, 2009; Giannoccaro, 2011). However, random generation fails to connect elements and their interactions with fitness values or requires extensive computation to do so. Additionally, context is not considered in random generation of fitness value even though it is vital to strategy formulation. Thus, the existing NK method is not suited to capturing the precise position of the firm within a fitness landscape (Adner et al., 2014).

In this work, we update the traditional NK method – with inputs from the grey system theory and the decision-making trial and evaluation laboratory (DEMATEL) approach – to arrive at a grey–DEMATEL–NK model for developing a fitness landscape. First, we integrate grey theory and NK modelling to build a grey relationship model for the elements and determine the importance of each strategy element. The grey system theory is used to solve uncertainty problems with discrete data and incomplete information (Bai et al., 2017; Bai and Sarkis, 2010, 2011). The Appendix introduces some notations and operations relevant to our application from previous studies on grey theory (Bai et al., 2017; Bai and Sarkis, 2010, 2011; Liu et al., 2011). Finally, we use DEMATEL as a method for building and analysing a structural model of relationships between various elements.

3. Research methodology
Case scenario
We used a case study approach as it allows researchers to combine various data sources, such as archives, interviews, questionnaires and observations, to propose, develop or test theory within a single setting (Eisenhardt, 1989; Yin, 2017). It is important to mention that the sample size for this study was rather limited because DM is an emerging trend, and not many firms have adopted it. We chose ABC company as our case study because it is a pioneering DM firm engaged in the application of 3D printing technology. It has been producing 2,500 parts daily for the past ten years and serves more than 4,000 customers.

Many studies argue that a single respondent case study may not present an accurate or holistic picture of the studied organisation. Furthermore, such studies are susceptible to individual biases (Ketokivi and Choi, 2014; Voss et al., 2002). Despite these limitations though, we obtained data from only one company in order to derive grounded and valuable insights from focusing on a single digital firm. We followed the approach by Bennigson (1996) and Clark (1996) to explore the sequence of cumulative capabilities in a DM firm. Moreover, the source of our data was the director and CEO of the firm, who determined the firm’s strategy and had considerable experience in both traditional manufacturing and DM. The firm exemplified the top-down approach to strategy design followed by most firms.

Data collection and analysis progressed in the following stages: first, semi-structured interviews were conducted with the director-CEO of ABC as he was responsible for designing the strategy and performance of the entire firm and other verticals. Second, pairwise interrelation among the firm’s manufacturing capabilities was captured. We used Gemba walks, which is a central aspect of lean management principles and entails a
Data collection

We conducted a semi-structured interview with the director-CEO of ABC. It helped us understand the process of DM, its context, the competitive market landscape, related investment decisions, operational policies and firm routines. Next, we studied the manufacturing capabilities as strategy elements: cost, quality, delivery and flexibility. The strategic importance of each element was understood as its impact on the performance of the firm. We ascertained the firm-level strategic importance of each element from a linguistic scale used by the director-CEO of the firm.

Because a decision maker may find it difficult to determine an element’s relative strategic importance when considering all the elements simultaneously, we used the pairwise comparison method, which can yield more reliable and consistent weights (Lekurwale et al., 2015). Relative weights were assigned to the elements using the grey-based importance scale – from I (0.0) to VH (1.0). A score of “I” signifies that the interrelation between the two criteria has no strategic importance, whereas “VH” indicates that the interrelation has very high strategic importance to the fitness of the firm. The grey scale also helped us capture imprecision and vagueness in the responses (Liu et al., 2011). Table I presents the linguistic assessment and the associated grey values.

We used information about the strategic importance of manufacturing capabilities to develop a grey–DEMATEL–NK model and determine the sequence of development with the maximum payoff. To mitigate some of the problems associated with a single respondent, we visited the firm again after the analysis and discussed our theoretical sequence for developing manufacturing capabilities with the director-CEO of ABC. We also discussed the implications of the sequence for underlying business processes and on the sustainability of performance improvements.

4. Grey–DEMATEL–NK method and illustration

In this section, we explain the procedure of applying the grey–DEMATEL–NK model (Figure 3) to the DM firm ABC.

Step I: problem formulation

Assumptions

1. \( N = 4 \) (manufacturing capabilities elements: quality, delivery, flexibility and cost).
2. \([\text{VH}] = \) outstanding level of strategic importance to the fitness of the firm; \( I = \) no strategic importance to the fitness of the firm.
3. \( A = 2 \) (levels of individual elements: absent (0) or present (1)).

<table>
<thead>
<tr>
<th>Linguistic assessment</th>
<th>Associated grey values</th>
</tr>
</thead>
<tbody>
<tr>
<td>No strategic importance [I]</td>
<td>[0, 0]</td>
</tr>
<tr>
<td>Very low importance [VL]</td>
<td>[0, 0.25]</td>
</tr>
<tr>
<td>Low importance [L]</td>
<td>[0.25, 0.5]</td>
</tr>
<tr>
<td>High importance [H]</td>
<td>[0.5, 0.75]</td>
</tr>
<tr>
<td>Very high importance [VH]</td>
<td>[0.75, 1.0]</td>
</tr>
</tbody>
</table>

Table I. Linguistic assessment of strategic importance and the associated grey values
(4) [VH] represents the presence of the element as the constituent of fitness with coded value [1] and [H, L and VL] represent the absence of the element in the fitness. These are represented by coded value [0] in manufacturing strategy configurations.

(5) Total number of configurations in the landscape = \( A^N = 2^4 = 16 \).

(6) A firm with complete strategic consensus, characterised by absolute fit between the designed strategy elements and the realized elements at the operational level (Schoenherr and Narasimhan, 2012).

(7) The firm is positioned away from the performance frontier and does not experience trade-off (Sarmiento et al., 2010; Schmenner and Swink, 1998; Vastag, 2000).

**Steps II and III: pairwise comparison of manufacturing capabilities and establishing the grey direct-relation matrix**

To measure interdependencies between the manufacturing strategy elements \( C = \{C_i; i = 1, 2, 3, \ldots, n\} \), we used the grey numbers assigned to the five linguistic terms (Table I). Thus, we introduced grey paired relationships among the elements of manufacturing capabilities. Initially, we set the grey interrelation for the same element as \( I = [0, 0] \). Further pairwise interrelations obtained from the strategy expert at ABC were converted into the grey scale, as shown in Table II.
The procedure and detailed mathematical proof for Steps IV–VII for developing the grey–DEMATEL–NK model is explained in the Appendix.

Using this procedure, we computed the overall fitness values for all the \(2^4 = 16\) manufacturing strategy configurations. Table III summarises the overall fitness values for the 16 strategy configurations.

### Step VIII: adaptive walk of the firm on the fitness landscape

All firms seek fitness values that are better than their existing ones. In NK modelling, this process is known as the adaptive walk, wherein firms move away from their position in search of peaks. In the next few steps, we explore theoretically the best sequential path that ABC company should follow:

1. Consider the firm starts at the origin with fitness value 0. This suggests that the firm does not possess any capability. So, we set the sequential path \(S_{qp} = \pi\). By the end, \(S_{qp}\) will be the order of manufacturing capabilities (1, 1, 1, 1).

2. Select the element of manufacturing capabilities, \(i\), which has the maximum grey fitness value and let \(C_i = 1\) into \(S_{qp}\) using following equation:

\[
\max(\otimes F(S_{qp} + C_i)) \text{ then } C_i \Rightarrow S_{qp}.
\]

3. Repeat the second step until all the strategy elements are selected into \(S_{qp}\) at all \(C_i = 1\). Then, the sequence of the selected strategy element in \(S_{pq}\) may be the sequential path for better fitness value for the firm.

### Table II.

<table>
<thead>
<tr>
<th>ABC company</th>
<th>Quality</th>
<th>Delivery</th>
<th>Flexibility</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality</td>
<td>I [0, 0]</td>
<td>L [0.25, 0.5]</td>
<td>VH [0.75, 1]</td>
<td>VH [0.75, 1]</td>
</tr>
<tr>
<td>Delivery</td>
<td>L [0.25, 0.5]</td>
<td>I [0, 0]</td>
<td>L [0.25, 0.5]</td>
<td>L [0.25, 0.5]</td>
</tr>
<tr>
<td>Flexibility</td>
<td>VH [0.75, 1]</td>
<td>L [0.25, 0.5]</td>
<td>I [0, 0]</td>
<td>VL [0, 0.25]</td>
</tr>
<tr>
<td>Cost</td>
<td>H [0.5, 0.75]</td>
<td>L [0.25, 0.5]</td>
<td>VL [0, 0.25]</td>
<td>I [0, 0]</td>
</tr>
</tbody>
</table>

### Table III.

<table>
<thead>
<tr>
<th>Cost</th>
<th>Flexibility</th>
<th>Delivery</th>
<th>Quality</th>
<th>Lower</th>
<th>(\otimes F)</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2.2152</td>
<td>6.9188</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1.115</td>
<td>4.7567</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.576</td>
<td>5.6413</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1.3584</td>
<td>5.2236</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3.3302</td>
<td>11.6755</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>3.7912</td>
<td>12.5601</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2.9344</td>
<td>10.8649</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2.691</td>
<td>10.398</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2.4734</td>
<td>9.9803</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.9344</td>
<td>10.8649</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2.9344</td>
<td>10.8649</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>4.0494</td>
<td>15.6216</td>
</tr>
</tbody>
</table>

The overall fitness values for manufacturing strategy configurations:

<table>
<thead>
<tr>
<th>Cost</th>
<th>Flexibility</th>
<th>Delivery</th>
<th>Quality</th>
<th>Lower</th>
<th>(\otimes F)</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>6.2646</td>
<td>22.5404</td>
</tr>
</tbody>
</table>
In our case study, the firm started with $C_i = 0$ or a fitness value of 0, indicating that the firm did not possess any distinguishing manufacturing capability. Per the first step, ABC’s option for capability development was C–Q–D–F. However, according to the focused factory concept, a firm cannot achieve the best performance in all dimensions or attain a strategy configuration of [1, 1, 1, 1] immediately. Hence, ideally, ABC should develop its capabilities sequentially.

Next, we considered the adaptive walk of the firm across the fitness landscape, which consists of all possible strategy configurations and their corresponding fitness values. We plotted all the 16 manufacturing strategy configurations and developed a four-dimensional (4D) polyhedron model with 16 vertices (Figure 4). We assigned the computed fitness values for each capability configuration (Table III) to each of the polyhedron vertex. The proposed grey–DEMATEL–NK model was used to determine the payoff for each vertex and identify multiple paths to reach the maximum payoff vertex. In the process, the polyhedron also helped identify certain vertices as “traps” with poor payoffs. Firms stuck in such trap vertices have to necessarily increase their efforts (realign business processes) to move away from these vertices and reach the maximum payoff vertex.

Each of the four elements of manufacturing capabilities (quality, delivery, flexibility and cost) was assigned to a separate direction, as shown in Figure 4. For example, the quality capability was assigned to the horizontal direction. We simplified this illustration by using planer considerations. We developed six planes: QF, FD, CD, FC, QC and QD. Each plane captured the change in a given pair of dimensions, while the remaining pair dimensions remained unchanged. For instance, the QF plane illustrated a change in quality and flexibility dimensions, while the cost and delivery dimensions remained unchanged. We also developed a colour scheme for better visual representation of the polyhedron and the adaptive walks of the firm.

The polyhedron illustration also helped us better explore the dynamics of strategic change in ABC company. Strategic change is the process of moving from an existing strategy configuration to another in search of improved fitness. For example, from the origin point [0, 0, 0, 0], the firm may improve either in quality, delivery, flexibility or cost. The resultant co-ordinates would be [0, 0, 0, 1], [0, 0, 1, 0], [0, 1, 0, 0] and [1, 0, 0, 0], respectively. The 4D polyhedron model also showed the grey fitness range of these respective points as [2.215–6.918], [1.115–4.756], [1.358–5.223] and [1.576–5.641]. Using Equation (5), we find that
the grey fitness range for [0, 0, 0, 1] is the maximum. Hence, the firm should move towards [0, 0, 0, 1] – develop its quality capabilities.

At [0, 0, 0, 1], the firm has three options: [1, 0, 0, 1], [0, 1, 0, 1] and [0, 0, 1, 1]. The respective fitness values for these configurations are [2.9344, 10.8649], [3.7912, 12.5601] and [3.3302, 11.675]. Because the second fitness value [3.7912, 12.5601] is the highest, the firm should develop its flexibility capability next. Thus, ABC can arrive at the optimum development path towards maximum payoff as follows: [0, 0, 0, 0] → [0, 0, 0, 1] → [0, 1, 0, 1] → [1, 1, 0, 1] → [1, 1, 1, 1]. Our analysis showed that the sequence for developing manufacturing capabilities to derive the maximum fitness payoff is Q–F–C–D for ABC company. In other words, quality management practices are as important in DM as in traditional manufacturing. With quality as the primary capability, the firm can improve on its production flexibility, unit cost reduction and delivery.

We discussed the computed sequence above with the director-CEO. We recapped the inputs received and shared the processing of those inputs to arrive at Q–F–C–D as the sequence for developing manufacturing capabilities at ABC company. Interestingly, the director-CEO confirmed that the computed sequence Q–F–C–D was indeed the path adopted by the company for developing its manufacturing capabilities. The expert also provided additional information that helped us understand the business processes of a digital firm. With quality as its primary capability, ABC company used statistical measures of process control and updated its processes and equipment, which in turn improved product performance and reliability. Emphasising the value placed on quality throughout the organisation, he explained, “Quality is the broad and impregnable base of sand cone, on which the company can rely for sustainable performance. Scrap and defect rate, frequency of failure, inspection time reduction are the primary performance measures that we monitor as the part of quality performance assessment”.

On the topic of flexibility, he said, “In the digital context, there are no economies of scale, and the complexity is free. Thus, product flexibility is the innate characteristic of the digital world”. ABC company handled changes in its product mix and adjusted its capacity rapidly within a short period. To improve its flexibility capability, the company focused on routing flexibility, batch size, product-part mix and the number of products introduced.

In traditional subtractive manufacturing, unit cost reduction is achieved through workforce optimisation, inventory control and overhead reduction. The expert added, “Mere cost reduction would not provide a long-term competitive edge for the firm. The capital cost in digital manufacturing is relatively higher with higher capital investment in equipment, processes, and materials. Thus, the applications of classical cost controlling techniques would remain a mirage in digitized paradigm. The emphasis on quality and flexibility reinforce the unit cost reduction through a reduction in quality failures, indirect overheads, material costs. Unit cost can then only eventually come down with a long-term approach, tolerance, and patience in a digital context”.

The director-CEO of ABC company shared an interesting dilemma about the development of delivery vs cost capabilities. He noted, “Mass customization means there is no chance of error and reduces the entry barrier. Mass customization enabled competition which focused on faster delivery as a way to capture the market. So, everyone plays the delivery game. We dug in and persevered through losing customers by shifting to cost emphasis. Interestingly, at the end, we bailed out the competitors – we enhanced our portfolio when the competition withered due to cost pressure and their absence of modified business processes”.

The dilemma between developing delivery and cost capabilities was also reflected in our grey–DEMATEL–NK model. The fitness value of the sequence Q–F–C (quality, flexibility and cost) [5.1496, 17.7837] is higher than that of Q–F–D (quality, flexibility and delivery) [4.9062, 17.3168]. Although the difference is marginal, we can link the initial decline in ABC
company to the lower fitness value. By modifying the business processes associated with inventory management, value chain management and scheduling, ABC company opted for Q–F–C–D as the pathway yielding maximum fitness.

5. Results and discussion

With advanced digital infrastructure, 3D printers, automated material handling and cloud-based sensor intelligence, DM offers new avenues for modern firms to compete. In this work, we explore how a digital firm can leverage these technologies and develop its manufacturing capabilities. One of the main contributions of this study is the development of the grey–DEMATEL–NK model, which allows firms to evaluate various options for developing their manufacturing capabilities. Using data from a DM firm in India, we tested the model and identified Q–F–C–D as the optimal sequence yielding maximum manufacturing fitness (competitive payoff). The sequence can also help a firm reorganise its business processes. Moreover, the route to developing cumulative capabilities in a DM firm (Q–F–C–D) is different from that adopted in traditional manufacturing (Q–D–F–C). Finally, the director-CEO of ABC company, our case study firm, shared the firm’s approach to building manufacturing capabilities. This step not only helped validate the model but also offered insights from a practitioner’s perspective into the sequence of developing cumulative capabilities at the firm level.

As in any manufacturing firm, quality is the bedrock of capability development in a DM firm. The next strategic capability to develop is flexibility. A DM firm with high level of production flexibility can be a game changer and a leading driver of mass customization. The third important strategic element is cost. Mass customization can lead to poor differentiation in digitally manufactured products. Hence, a firm should focus on cost strategies to ensure differentiation. It is important to add that cost here does not refer to reduction alone, rather it reflects the firm’s preparedness for economies of scope rather than scale. Finally, the firm should focus on its delivery capability.

Building each capability requires the firms to take certain manufacturing decisions. These decisions are implemented via the business processes. In this work, the validation discussions helped us map the cumulative capabilities sequence to the associated business processes and performance measures (Table IV).

<table>
<thead>
<tr>
<th>Elements of manufacturing capability</th>
<th>Business process implications</th>
<th>Performance measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality</td>
<td>Applications of statistical process control methods</td>
<td>Scrap and rework, per cent defective, frequency of failure, inspection time reduction, product warranty period</td>
</tr>
<tr>
<td></td>
<td>Updating process equipment/technologies</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Improving product performance and reliability</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Obtaining quality certifications</td>
<td></td>
</tr>
<tr>
<td>Flexibility</td>
<td>Handling changes in product mix</td>
<td>Routing flexibility, no. of setups, batch size, machine-product flexibility, product-part mix</td>
</tr>
<tr>
<td></td>
<td>Adjusting capacity rapidly within a short period</td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td>Reducing material cost</td>
<td>Unit cost, overhead cost, machine utilisation, work in process, production capacity, reduced labour, product price, replacement cost</td>
</tr>
<tr>
<td></td>
<td>Reducing overhead costs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reducing inventory</td>
<td></td>
</tr>
<tr>
<td>Delivery</td>
<td>Meeting delivery promises</td>
<td>Setup and changeover time, make-span time, throughput time, lead time of product delivery to customer</td>
</tr>
<tr>
<td></td>
<td>Providing faster deliveries</td>
<td></td>
</tr>
</tbody>
</table>

Table IV. Business process implications of developing manufacturing capabilities
The sequential development of manufacturing capabilities to ensure sustainable performance is the ultimate goal. Performance measurement identifies the appropriate milestone to ensure that the company stays on the right track. In fact, future studies should try to map these performance measures in terms of their computed fitness value.

The present investigation of a firm-specific sequence for developing manufacturing capabilities makes the following contributions to business process theory. First, the sequence approach to developing manufacturing capabilities allows for better monitoring of firm performance and reinforces the fundamental principles of manufacturing – sustainable performance. The sequence also assists in analysing the effects of a manufacturing strategy on firm improvements. Second, the sequence illustrates the firm-specific primary capability, which is the starting point for developing manufacturing capabilities, and triggers a synergistic effect towards fulfilling the competitive requirements of the firm.

The polyhedron model (Figure 4) is analogous to a fitness landscape and can assist practitioners in evaluating all the available paths to developing cumulative capabilities. It also helps them determine the path of maximum payoff through a “walk on the fitness landscape” approach. The identified sequence can assist in reorganising business processes towards better competitiveness.

The strength of the proposed analytical model can be summarised as follows: the grey set theory captures the impreciseness of the strategic importance of manufacturing capabilities; DEMATEL considers the specific strategy context and the interrelationship between manufacturing capabilities; the NK model allows for evaluating and developing an optimal sequential path with the highest payoff; and a 4D polyhedron helps visualise the pathway for cumulative capabilities development.

We believe that the sequence for developing cumulative capabilities should consider the contextual aspects of the firm (Flynn and Flynn, 2004; Schroeder et al., 2011). Interestingly, the optimal sequence for ABC company (Q→F→C→D) contrasts with that followed in traditional manufacturing (Q→D→F→C). This is possibly due to the digital nature of manufacturing. The sequence variation along with the payoffs reveals that the cumulative reinforcement of a pattern in DM is more complex than the existing theories on traditional manufacturing.

6. Conclusions
Although many firms aspire to become world-class, lean and flexible, not all of them succeed because they fail to identify a strategic approach to differentiate their capabilities in the market. These capabilities are not achieved by chance or intuitive decisions but through a structured and strategic approach to manufacturing (Brown, 2000, 2012).

The cumulative capabilities approach is a widely accepted idea in the field of manufacturing strategy. This work presents an analytical model based on grey–DEMATEL–NK to identify the sequence of cumulative capabilities that yields the maximum payoff for a DM firm. It presents a “sense, seize and optimise” approach to DM diffusion: the grey–DEMATEL–NK model helps sense and evaluate the options to develop manufacturing capabilities that yield the maximum payoff. Then the model provides strategic pathways with associated payoffs (manufacturing fitness value) and guides the firm towards the optimal decision.

Our findings serve as a starting point for further analysis, both for the theory and practice of DM. They should be viewed as guidelines rather than a prescription for practice. The adoption of digital technologies, advanced manufacturing processes, innovations in products, processes and services can facilitate simultaneous progress in multiple performance dimensions. Thus, manufacturing capabilities may not necessarily develop sequentially but may progress simultaneously (Boon-Itt and Wong, 2016). Further investigations are needed to identify the relative proficiency of manufacturing capabilities per se, apart from their sequence. These findings present initial results, and the proposed
model is a prototype of the approach to modelling cumulative capabilities. It is likely that further application of optimisation techniques may help the firm identify the quickest path to achieving the maximum payoff.

We have neglected the effect of zero-sum trade-off as proposed by Sarmiento and Shukla (2010) in this study. Future studies could consider the interactions between cumulative capabilities and extend the model to wider set of firms in order to generalise the results. Plotting the development pathways for each business unit, at the firm level and at the group level, can also be another extension of this work.

With the broadening scope of manufacturing, firms need to scale up their manufacturing capabilities to meet technology as well as market requirements. There is no single generic or superior strategy to satisfy the capability needs of all firms. In fact, even firms within the same industry frequently prefer to use several functional strategies. Before deploying such strategies, firms should evaluate the strategic options available to them and align their strategy with their competitive priorities and operational plans. We hope the present study initiates more discussion on strategic evaluations of available options for modern firms to excel and compete in a digital era.

References


Appendix

Establishing grey relationship

**Definition I**

Let $x$ denote a closed and bounded set of real numbers. A grey number $\otimes x$ is defined as an interval with known upper and lower bounds but unknown distribution information for $x$ (Liu et al., 2011). That is,

$$
\otimes x = [\underline{x}, \overline{x}] = [x' \in x \mid x' \leq x' \leq \overline{x}]
$$

where $\underline{x}$ and $\overline{x}$ are the lower and upper bounds of $\otimes x$, respectively.

**Definition II**

Let $\otimes x_1 = [\underline{x}_1, \overline{x}_1]$ and $\otimes x_2 = [\underline{x}_2, \overline{x}_2]$ be the two grey numbers. Some basic grey number mathematical operations are represented by the following relationships:

\begin{align}
\otimes x_1 + \otimes x_2 & = \left[\underline{x}_1 + \underline{x}_2, \overline{x}_1 + \overline{x}_2\right], \tag{A1} \\
\otimes x_1 - \otimes x_2 & = \left[\underline{x}_1 - \underline{x}_2, \overline{x}_1 - \overline{x}_2\right]. \tag{A2} \\
\otimes x_1 \times \otimes x_2 & = \left[\min(\underline{x}_1, \underline{x}_2, \overline{x}_1, \overline{x}_2), \max(\underline{x}_1, \underline{x}_2, \overline{x}_1, \overline{x}_2)\right]. \tag{A3} \\
\otimes x_1 \div \otimes x_2 & = \left[\frac{\underline{x}_1}{\overline{x}_2}, \frac{\overline{x}_1}{\underline{x}_2}\right]. \tag{A4}
\end{align}

**Definition III**

Let $\otimes x_1 = [\underline{x}_1, \overline{x}_1]$ and $\otimes x_2 = [\underline{x}_2, \overline{x}_2]$ be the two grey numbers, $l(\otimes x_1) = \overline{x}_1 - \underline{x}_1$ and $l(\otimes x_2) = \overline{x}_2 - \underline{x}_2$. The Possibility degree, a larger value of two numbers can be defined as $P(\otimes x_1 \geq \otimes x_2)$ and be expressed mathematically as follows:

$$
P(\otimes x_1 \geq \otimes x_2) = \begin{cases} 
1; & x_1 \geq x_2 \\
\frac{\overline{x}_1 - \underline{x}_2}{l(\otimes x_1) + l(\otimes x_2)}; & \overline{x}_1 \geq x_2 \land \underline{x}_1 < \overline{x}_1 \\
0; & \underline{x}_1 \leq x_2
\end{cases}
$$

where the possibility value of a grey number $\otimes x_1$ is a grey number $\otimes x_2$. $0.5 \leq P(\otimes x_1 \geq \otimes x_2) \leq 1$ indicates $\otimes x_1$ dominates $\otimes x_2$. This relationship is denoted by $\otimes x_1 D \otimes x_2$. These basic operations and possibility degree are utilised in the fitness evaluations to advance NK model considering the importance of strategy elements.
Mathematical proofing of grey-DEMATEL-NK model
Processing the inputs as shown in Table III, we develop a matrix \( M \) illustrating the grey direct interrelationship among the manufacturing capabilities (Table AI).

\[ N = s.M = s.m_{ij}; \ s.m_{ij}, \]

where \( s = 1/\max \sum_{j=1}^{n} m_{ij}; \ i, j = 1, 2, 3, \ldots, n. \)

Step IV: normalising the grey direct-relation matrix
From the grey direct interrelationship among manufacturing capabilities, the normalised matrix \( N \) is obtained by the following equation:

\[ N = s.M = s.m_{ij}; \ s.m_{ij}, \]

where \( s = 1/\max \sum_{j=1}^{n} m_{ij}; \ i, j = 1, 2, 3, \ldots, n. \)

\[ m_{ij} \text{ and } m_{ij} \text{ represent the upper and lower values of the strategic importance of the manufacturing capabilities.} \]

\( s \) denotes the multiplication factor. Now, illustrating the calculations for this multiplication factor with following the stepwise procedure:

1. Obtain the sum of all the upper values.
   For illustration, we take sum of quality.
   \[ 0 + 0.5 + 1 + 1 = 2.5. \]
   Similarly, obtain a sum for all elements of manufacturing capabilities. These values are listed in the column “Sum of upper elements”.

2. Identify the maximum value of column “Sum of upper elements”. It is 2.5 in the illustration example.

3. Take the inverse of the maximum value obtained at Step 2. We get 0.4 as the inverse of 2.5 with the multiplication factor \( S \).

Table AII shows the normalised grey direction matrix and the associated calculations for multiplication factor \( S \).

Step V: determining the grey total relation matrix
The grey total relation matrix (\( T \)) is determined by the following expression:

\[ T = (T, T) = \left( N(I-N)^{-1}, N(I-N)^{-1} \right), \]

where \( I \) represents an \( n \times n \) identity matrix. Table AIII shows the grey total relation matrix.

We now explain the stepwise procedure to obtain the grey total relation matrix:

1. Obtain \( T \) by multiplying inverse of a matrix \((I-N)\) with \((N)\):

\[
\begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
- \begin{bmatrix}
0 & 0.1 & 0.3 & 0.3 \\
0.1 & 0 & 0.1 & 0.1 \\
0.3 & 0.1 & 0 & 0 \\
0.2 & 0.1 & 0 & 0
\end{bmatrix}
^{-1}
\begin{bmatrix}
0 & 0.1 & 0.3 & 0.3 \\
0.1 & 0 & 0.1 & 0.1 \\
0.3 & 0.1 & 0 & 0 \\
0.2 & 0.1 & 0 & 0
\end{bmatrix}
\]

\[ = \begin{bmatrix}
0.2114 & 0.1978 & 0.3832 & 0.3832 \\
0.1854 & 0.0507 & 0.1607 & 0.1607 \\
0.382 & 0.1644 & 0.131 & 0.131 \\
0.2608 & 0.1446 & 0.0927 & 0.0927
\end{bmatrix}. \]

Similarly, we obtain \( T \) by multiplying the inverse of a matrix \((I-N)\) with \((N)\).

2. Compile matrix \((T, T)\) as a grey total relation matrix.
Step VI: determining the overall grey importance ($\otimes P_i$) of the elements of manufacturing capabilities

Determine the overall grey importance ($\otimes P_i$) of the elements of manufacturing capabilities. The values ($\otimes P_i$) show total net cause and effect index:

$$\otimes P_i = \{\otimes R_j + \otimes D_j; i = j\},$$

$\otimes R_j$ represents the sum of influence by the strategy element $i$ on other strategy elements, and $\otimes D_j$ represents the sum of direct and indirect influence by the other elements acting on the decision component. Table AIV details the overall grey importance ($\otimes P_i$). For instance ($\otimes P_i$) for quality can be calculated as $1.175 + 1.0396 = 2.2152$ and $3.5940 + 3.3242 = 6.9182$.

Step VII: identification of overall grey fitness value for each strategy configuration

Each element of manufacturing capability can have a fitness value. The objective now is to find the overall grey fitness value for the various configurations on the landscape. The overall fitness value $\otimes F$ of the system is the sum of values assigned to each element ($C_i$) and the interdependencies with other components $C_j$, that are also selected ($C_i = 1$):

$$\otimes F(C_i; C_i = 1) = \sum_{i \in \{C_i = 1\}} \left( \otimes P_i + \sum_{j \in \{C_j = 1\}; j \leq k} \otimes t_{ij} \times \otimes P_i \right), \quad i \neq j,$$

here, \{C_i; C_i = 1\} represents the configuration of components ($C_i = 1$).

For example, if only quality is present, the corresponding manufacturing strategy can be represented as [0, 0, 0, 1]. Fitness value $F$ is equal to $\otimes (R_j + D_j)$, i.e. $F = [2.215, 6.918]$. Similarly, the fitness value in the presence of flexibility can be $F = [1.576, 5.641]$ with manufacturing strategy configuration as [0, 1, 0, 0]. If a firm develops a joint configuration strategy of quality and flexibility, the strategic configuration would be represented as $C [0, 1, 0, 1]$, and the fitness value will be $[2.215, 6.918] + [1.576, 5.641] = [3.791, 12.560]$. In this case, we consider the only direct effect on manufacturing capabilities corresponding to the notion of cumulative capabilities (Ferdows and De Meyer, 1990; Ferdows and Thurnheer, 2011).

<table>
<thead>
<tr>
<th>ABC company</th>
<th>Quality</th>
<th>Delivery</th>
<th>Flexibility</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower value</td>
<td>Upper value</td>
<td>Lower value</td>
<td>Upper value</td>
<td>Lower value</td>
</tr>
<tr>
<td>Quality</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
<td>0.5</td>
</tr>
<tr>
<td>Delivery</td>
<td>0.25</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Flexibility</td>
<td>0.75</td>
<td>1</td>
<td>0.25</td>
<td>0.5</td>
</tr>
<tr>
<td>Cost</td>
<td>0.5</td>
<td>0.75</td>
<td>0.25</td>
<td>0.5</td>
</tr>
</tbody>
</table>
### Table AII.
Normalised grey direct-relation matrix

<table>
<thead>
<tr>
<th>ABC company</th>
<th>Quality</th>
<th>Delivery</th>
<th>Flexibility</th>
<th>Cost</th>
<th>$\otimes R_j$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>U</td>
<td>L</td>
<td>U</td>
<td>L</td>
</tr>
<tr>
<td>Quality</td>
<td>0.211</td>
<td>0.8468</td>
<td>0.197</td>
<td>0.7655</td>
<td>0.3832</td>
</tr>
<tr>
<td>Delivery</td>
<td>0.1854</td>
<td>0.7207</td>
<td>0.0507</td>
<td>0.3964</td>
<td>0.1607</td>
</tr>
<tr>
<td>Flexibility</td>
<td>0.382</td>
<td>0.9623</td>
<td>0.1644</td>
<td>0.6429</td>
<td>0.131</td>
</tr>
<tr>
<td>Cost</td>
<td>0.2608</td>
<td>0.7944</td>
<td>0.1446</td>
<td>0.5733</td>
<td>0.0827</td>
</tr>
</tbody>
</table>

### Table AIII.
Grey total relation matrix

<table>
<thead>
<tr>
<th>ABC company</th>
<th>Quality</th>
<th>Delivery</th>
<th>Flexibility</th>
<th>Cost</th>
<th>$\otimes D_j$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>U</td>
<td>L</td>
<td>U</td>
<td>Sum of upper elements</td>
</tr>
<tr>
<td>Quality</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
<td>0.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Delivery</td>
<td>0.25</td>
<td>0.5</td>
<td>0</td>
<td>0.25</td>
<td>1.5</td>
</tr>
<tr>
<td>Flexibility</td>
<td>0.75</td>
<td>1</td>
<td>0.25</td>
<td>0.5</td>
<td>1.75</td>
</tr>
<tr>
<td>Cost</td>
<td>0.5</td>
<td>0.75</td>
<td>0.25</td>
<td>0.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

### Table AIV.
Overall grey importance of MS elements

<table>
<thead>
<tr>
<th>ABC company</th>
<th>Quality</th>
<th>Delivery</th>
<th>Flexibility</th>
<th>Cost</th>
<th>$R_j$</th>
<th>$\otimes (R_j + D_j)$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>U</td>
<td>L</td>
<td>U</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Quality</td>
<td>0.211</td>
<td>0.8468</td>
<td>0.197</td>
<td>0.7655</td>
<td>0.383</td>
<td>0.991</td>
</tr>
<tr>
<td>Delivery</td>
<td>0.1854</td>
<td>0.7207</td>
<td>0.0507</td>
<td>0.3964</td>
<td>0.160</td>
<td>0.630</td>
</tr>
<tr>
<td>Flexibility</td>
<td>0.382</td>
<td>0.9623</td>
<td>0.1644</td>
<td>0.6429</td>
<td>0.131</td>
<td>0.580</td>
</tr>
<tr>
<td>Cost</td>
<td>0.2608</td>
<td>0.7944</td>
<td>0.1446</td>
<td>0.5733</td>
<td>0.082</td>
<td>0.581</td>
</tr>
<tr>
<td>$D_j$</td>
<td>1.0396</td>
<td>3.3242</td>
<td>0.5575</td>
<td>2.3784</td>
<td>0.767</td>
<td>2.783</td>
</tr>
</tbody>
</table>
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How to turn managers into data-driven decision makers
Measuring attitudes towards business analytics

Kevin Daniel André Carillo, Nadine Galy, Cameron Guthrie and Anne Vanhems
Toulouse Business School, Toulouse, France

Abstract
Purpose – The purpose of this paper is to emphasize the need to engender a positive attitude toward business analytics in order for firms to more effectively transform into data-driven businesses, and for business schools to better prepare future managers.

Design/methodology/approach – This paper develops and validates a measurement instrument that captures the attitude toward business statistics, the foundation of business analytics. A multi-stage approach is implemented and the validation is conducted with a sample of 311 students from a business school.

Findings – The instrument has strong psychometric properties. It is designed so that it can be easily extrapolated to professional contexts and extended to the entire domain of business analytics.

Research limitations/implications – As the advent of a data-driven business world will impact the way organizations function and the way individuals think, work, communicate and interact, it is crucial to engage a transdisciplinary dialogue among domains that have the expertise to help train and transform current and future professionals.

Practical implications – The contribution provides educators and organizations with a means to measure and monitor attitudes toward statistics, the most anxiogenic component of business analytics. This is a first step in monitoring and developing an analytics mindset in both managers and students.

Originality/value – By demonstrating how the advent of the data-driven business era is transforming the DNA and functioning of organizations, this paper highlights the key importance of changing managers’ and all employees’ (to a lesser extent) mindset and way of thinking.

Keywords Business analytics, Employee attitudes

Paper type Research paper

Introduction
Over the last decade, the business world has been shaken by an unprecedented wave of digital disruption that is thoroughly reshuffling the cards of competition (Weill and Woerner, 2015). Big data analytics, cognitive computing, the “Internet of Things,” machine learning and artificial intelligence are all “grand challenges” that companies must face as they promise to significantly impact their workforce (George et al., 2016). Whereas such large-scale digital disruption was originally perceived as a mere technological revolution (Agarwal et al., 2008), both practitioners and researchers have acknowledged that we have been witnessing a change of much greater scope: a global paradigm shift from a business era to a data-driven business era (Carillo, 2017; Fosso Wamba et al., 2015; Daniel et al., 2017; Fosso Wamba, 2017; Hillol and Viswanath, 2017). Leveraging big data and analytics should allow organizations “to generate insights into business processes, improve organizational learning, and enable innovative business models” (Kohlborn et al., 2014).

Data-driven businesses need to redefine their overall strategy and business model (Chen et al., 2015; Akter et al., 2016; Roden et al., 2017), while data-driven decision making, “the practice of basing decisions on the analysis of data rather than purely on intuition” (Provost and Fawcett, 2013, p. 53), must be infused into all levels of management. Consequently, entering the data-driven business era cannot be limited to gaining analytics
skills simply through the recruitment of data scientists. Instead, business analytics must become a part of organizational culture that is shared amongst all employees and more specifically amongst decision makers (Müller and Jensen, 2017). Managers must “attend to the big data era” (Mishra et al., 2017, p. 565), become skilled in its methods and analytics, and learn to explore big data to develop competitive advantage. Furthermore, career opportunities and potential earnings in the digital age will also depend on developing suitable digital knowledge, abilities, skills and attitudes (Murawski and Bick, 2017).

Such cultural change presents challenges for both management development in organizations and management education in business schools. As business education’s main mission is to best prepare future managers to the challenges of an ever-changing business world (Seethamraju, 2012), it is the responsibility of business schools to engrain an analytical mindset in future managers (Carillo, 2016). Courses such as database management, advanced modeling, programming and data science need to be offered to teach business students the blend of data management and statistical modeling required in practice. Yet business schools still have difficulty successfully building the foundational knowledge for students’ analytical thinking: business statistics (Hsu et al., 2009). Despite the ubiquity of statistics in society and its mandatory nature in most university programs (Gould, 2010), statistics courses have long been the most anxiety-inducing course in business schools and most university degrees (Chew and Dillon, 2014).

We argue that a sine qua non condition for business education to succeed in engraining an analytics mindset in students is to implement means and resources that aim at developing a longstanding positive attitude toward analytics. The study of statistics anxiety has a long tradition in disciplines such as education, pedagogy and the social sciences (Onwuegbuzie, 2003). More precisely, the understanding and measuring of attitudes toward statistics has been an active research sub-stream over the last 30 years and has provided an array of results and recommendations to schools and universities (Gal et al., 1997; Hood et al., 2012; Schau, 2003a, b). In today’s data-driven age, a better understanding and measurement of attitudes toward statistics is a prerequisite for the development of the level of data and analytics literacy expected in the workplace (Miller, 2014; De Mauro et al., 2016; Matthias et al., 2017).

The goal of our research is to develop and validate a measurement instrument that captures attitudes toward statistics. Developing analytics thinking goes hand in hand with working toward the generation of an overall positive attitude toward statistics. The research question of this paper is the following:

RQ1. How can we measure the attitude toward statistics in order to improve the overall attitude toward analytics?

We extend the Survey of Attitudes Toward Statistics (SATS) (Schau, 2003b), a widely used instrument that measures attitudes toward statistics, by developing an instrument with stronger psychometric properties and which could be used and extrapolated to other concepts that characterize data-driven business and analytics such as data science, machine learning and artificial intelligence.

The remainder of this paper is structured as follows. First, the necessary evolution of managers into manager-scientists with the advent of the data-driven business era is explained and the implications for managers’ skills are presented. This is followed by a review of the recurrent statistics anxiety problem that educational institutions and organizations face despite the growing importance of analytics. The SATS tool is then presented and critiqued. The research methodology that was implemented is detailed followed by a presentation of results. The paper ends with a discussion and the implications of the instrument for research, educational institutions and organizations.
Literature review

Big data, data-driven business and analytics DNA

In the early 2010s, industry experts predicted that the big data phenomenon could “create significant value for the world economy” and enhance the productivity and competitiveness of companies overall (Manyika et al., 2011, p. 1). Nearly a decade later, academics and practitioners have no doubt that this vision has come true (Mishra et al., 2017). While attention was initially paid to handling datasets which were unprecedented in both size and complexity (Fosso Wamba and Mishra, 2017; George et al., 2014), companies rapidly understood that competitive advantage could be gained by extracting knowledge from big data (Fosso Wamba et al., 2015). Companies have been massively investing in big data analytics technologies ever since. According to the market analyst firm IDC, the worldwide big data technology and services market is estimated to grow at a compound annual growth rate of 22.6 percent from 2015-2020 and reach $58.9bn in 2020 (Nadkarni and Vesset, 2016). There is however a gap between investing in big data analytics technologies and being able to effectively derive business insights and performance from big data: companies must also develop the organizational capability to use big data analytics, including big data analytics infrastructure, management and personnel capabilities (Bumblauskas et al., 2017; Fosso Wamba et al., 2017).

As companies have implemented big data analytics, the impact has been much broader in scope with repercussions for corporate strategy, business models and processes (Chen et al., 2015) as well as society at large (Loebbecke and Picot, 2015). Past research has, for example, demonstrated the positive impact of big data analytics on innovation (Zhan et al., 2017), supply chain (Tan et al., 2015) and decision-making (Brynjolfsson et al., 2015) processes. Behind the “big data bubble” looms, an overall shift from a business-driven to a data-driven perspective (Lavalle et al., 2011) and the emergence of a new data-driven business era (Carillo, 2017). In data-driven organizations, big data and digital technologies have engendered as new means of working, interacting and communicating (Loebbecke and Picot, 2015) while management practices have been “revolutionized” (McAfee and Brynjolfsson, 2012). Indeed, big data analytics allow managers to measure and analyze their businesses in ways which totally redefine the scope of management skills and function (McAfee and Brynjolfsson, 2012). In other words, managers are becoming manager-scientists (see Figure 1) whose skillset lays at the cross-roads of conventional business and management knowledge, data management, and analytical and modeling techniques (Carillo, 2017).

Beyond the challenge of equipping managers with the right knowledge, skills and tools, organizations that have engaged on a “data-driven business transformation” path face the more delicate task of cultivating an analytics mindset (Carillo, 2017). However, the anxiety felt by students toward statistics during their business education reappears when they are required to use analytical tools in organizations. Since business education’s main mission is to train tomorrow’s managers, companies can only succeed in developing and nurturing an analytics mindset if they work hand in hand with business educators to ensure that solid foundational knowledge is acquired early on.

In this paper, we argue that turning students or managers into manager-scientists is not simply a question of learning a set of analytics-related methodological skills and knowledge but it also requires developing an overall positive attitude toward statistics. Including big data analytics concepts into curricula is a relatively straightforward task, but the development of a “pro-analytics attitude” that helps connect the different analytics-related concepts and techniques together is a much more subtle and difficult challenge.

The statistics paradox

Statistics is a cornerstone of analytics (Klimberg and Miori, 2010). As a discipline, it provides “a rigorous scientific system for managing data collection, their organization,
analysis, and interpretation” (Dodge, 2008). Not surprisingly, there is an introductory statistics class in the curriculum of most of today’s business analytics courses (Gorman and Klimberg, 2014; Phelps and Szabat, 2017). In a survey of 1,379 faculty, students and industry practitioners about university-level business analytics courses, programs and recruiter perspectives, Wixom et al. (2014) noted an increasing focus by educators on “core, foundational skills” such as basic analytics and advanced statistics skills, while employers considered “basic analytics, such as descriptive statistics, regression and ANOVA” as the third most important skill when making recruitment decisions. A review by the authors of syllabi from several US- and UK-based universities in November 2017 confirms the presence of an introductory statistics course in almost all entry-level analytics courses or programs[1] (see Tables AI–AIII for an overview). Despite the pedagogical importance of the discipline, educators have long noted a marked aversion by business students to statistics education. While business school students generally understand the importance of statistics for their future careers (Griffith et al., 2012), for many statistics remains “the most hated, most unpopular course in the business program” (Nonis and Hudson, 1999, p. 233). There would appear to be a “statistics paradox”: the discipline is both revered and reviled.

Statistics educators have worked for the past three decades to improve the quality and perception of statistics classes in business schools. For example, the American Statistical Association has brought together academia and industry every year since 1986 at its “Making Statistics More Effective in Schools of Business” conference to reflect on how to improve the effectiveness of statistics in MBA and undergraduate business school curricula (Easton et al., 1988). While major curriculum improvements have been made (Love and Hildebrand, 2002), “change has been disappointingly slow” (McAlevey et al., 2001). Similar negative attitudes have been observed toward mathematics education and researchers have demonstrated that beliefs, attitudes and emotions influence learning outcomes (Eccles et al., 1983; McLeod, 1992; Wigfield and Eccles, 2000). Statistics anxiety can generate much deeper feelings compared to mathematics anxiety (Cruise et al., 1985; Onwuegbuzie et al., 1997;
Zerbolio, 1999; Zeidner, 1991) and lead to depression and panic (Onwuegbuzie et al., 1997), procrastination problems and inhibition (Onwuegbuzie, 2004). It can also affect student performance in other classes (Lalonde and Gardner, 1993; Onwuegbuzie, 2000; Onwuegbuzie and Seaman, 1995; Zanakis and Valenzi, 1997). The impact of statistics anxiety on academic performance has convinced researchers of the need to better identify it in the classroom (Chew and Dillon, 2014) and to find ways to help students overcome it (Williams, 2010).

Measuring and monitoring attitudes toward statistics

There has been much work in the academic literature to identify and measure attitudes, and notably through the lens of expectancy-value theory (e.g. Atkinson, 1958). As recalled in Eccles et al. (1983) “this theory […] focuses on individual differences in the motive to achieve and on the effects of subjective expectancy on both this motive and the incentive value of success” (p. 59). Eccles et al. (1983) have proposed a detailed conceptualization of the mediators of expectancies and values applied to mathematics attitudes. This theory, based on multidimensional factors, has inspired research into attitude-related phenomena in the domains of education and pedagogy and more specifically to model attitudes in statistics (Schau et al., 1995; Schau, 2003b). Indeed, learning statistics is as much about acquiring a statistics culture as it is mastering quantitative tools and methods. Students must also know when and how to use tools and make them evolve if necessary. As noted by Ramirez et al. (2012), students must believe that they are able to understand and use statistical tools; think that statistics are useful both in their professional and personal lives; recognize that statistics can be an interesting subject; be willing to invest and make efforts to acquire skills and a statistics culture; and acknowledge that statistical tools are not easy to learn but not too difficult either. These five points summarize one’s “attitude” toward statistics (Schau, 2003a, b).

There has been a lot of research on student attitudes toward statistics, but there is not much consensus as to how it should be conceptualized and operationalized. This lack of consensus is illustrated by the variety of questionnaires designed to measure attitude. Ramirez et al. (2012) counted 15 questionnaires in the literature, four of which have been used most frequently by researchers. These instruments are: Statistics Attitude Survey (SAS) (Roberts and Bilderback, 1980; Roberts and Saxe, 1982), Attitude Toward Statistics (Wise, 1985), and Survey of Attitudes Toward Statistics-28 (SATS-28) (Schau, 1992) and Survey of Attitudes Toward Statistics-36 (SATS-36) (Schau, 2003b).

Roberts and Bilderback (1980) designed SAS to predict student success in statistics with a single overall attitude score. Among the issues raised by the SAS include its one-dimensional attitude score for statistics is questionable in light of most attitude theories (Albarracin et al., 2005) and its assumption that students had already followed a prerequisite class in statistics (Wise, 1985; Gal and Ginsburg, 1994; Rhoads and Hubele, 2000). To address the issues raised by the SAS, Wise (1985) developed the “ATS” which measures two separate components of attitude. Schau (1992), Schau et al. (1995) then developed the SATS-28 questionnaire followed by the SATS-36 questionnaire (Schau, 2003b), which significantly improved previous measurements. The SATS-28 instrument contains 28 items measuring four components of attitude: “affect,” “value,” “cognitive competence” and “difficulty.” The second version of SATS has two additional components: “effort” and “interest.” The SATS instrument is the most recent and widely used questionnaire in business schools (Li, 2012; Griffith et al., 2012; Ashaari et al., 2011). It has also been translated into several languages including Italian (Chiesi and Primi, 2009), Russian (Khavenson et al., 2012), Turkish (Emmioglu and Capa-Aydin, 2012), Serbian (Stanisavljevic et al., 2014) and French (Carillo et al., 2016). The six components of the SATS instrument are presented in Table I.
Criticism
Several studies have criticized the reliability and validity of SATS. The main criticisms concern item parceling (for some constructs, items were grouped then summed or averaged and not treated individually), content validity, structural validity and internal validity. While item parceling can present some advantages (Hilton et al., 2004; Dauphinee et al., 1997; Schau et al., 1995; Tempelaar et al., 2007), it remains a controversial technique (Bandalos and Finney, 2001; Kline, 2011). The criticism of the instrument’s content validity concerns the lack of rigor in the item construction process (Nolan et al., 2012). The third criticism of the instrument’s structural validity concerns the choice of the number of dimensions that can be different among the research studies: four dimensions in Dauphinee et al. (1997) or Schau et al. (1995), and two dimensions in Cashin and Elmore (2005). The choice between four and six constructs has also been questioned (Vanhoof et al., 2011; Carillo et al., 2016). The last issue concerns the instrument’s poor internal validity as reflected in the low value of its Cronbach’s $\alpha$ statistic which captures the coherence in each construct (Cashin and Elmore, 2005; Chiesi and Primi, 2009; Hilton et al., 2004).

In summary, we argue that organizations have been turning into data-driven entities. This transformation requires a cultural shift toward business analytics and statistics, two domains that are anxiogenic in nature in both companies and educational institutions. Today, there is a growing demand for managers with positive attitudes toward statistics and data analytics. While no research to date has conceptualized and operationalized attitudes toward analytics, past research on the measurement of attitudes toward statistics has provided promising results. The SATS instrument developed by Schau (2003b) has been the most widely used, but researchers have raised concerns over its reliability and validity. As a first step in improving our understanding of attitudes toward analytics, we have developed a new instrument based on SATS to measure attitudes toward statistics.

Methodology
A thorough review of the literature revealed that Schau’s work on SATS was the most acknowledged conceptualization and operationalization of attitude toward statistics (see Table I for a definition of the different dimensions) although opinions diverge regarding its psychometric properties. Researchers have attempted to employ several statistical techniques such as item parceling (Hilton et al., 2004) or various factorial structures (Cashin and Elmore, 2005) to improve the instrument. The review of the literature also concluded that only post-measurement actions had been taken by researchers. In other words, researchers have never assessed the content validity of the items, and the potential bias exerted by various item characteristics has never been investigated (Podsakoff et al., 2003). As the purpose of this study was to provide researchers and practitioners with a valid and robust instrument, it was decided to adapt the SATS-36 initial items and resolve construct validity, item content and item

<table>
<thead>
<tr>
<th>Concept</th>
<th>Definition</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affect</td>
<td>Individuals’ feelings concerning statistics</td>
<td>Schau (2003b), Schau et al. (1995)</td>
</tr>
<tr>
<td>Cognitive competence</td>
<td>Individuals’ attitudes about their intellectual knowledge and skills when applied to statistics</td>
<td>Schau (2003b), Schau et al. (1995)</td>
</tr>
<tr>
<td>Value</td>
<td>Individuals’ attitudes about the usefulness, relevance and worth of statistics in personal and professional life</td>
<td>Schau (2003b), Schau et al. (1995)</td>
</tr>
<tr>
<td>Difficulty</td>
<td>Individuals’ attitudes about the difficulty of statistics as a subject</td>
<td>Schau (2003b), Schau et al. (1995)</td>
</tr>
<tr>
<td>Interest</td>
<td>Individuals’ level of individual interest in statistics</td>
<td>Schau (2003b), Schau et al. (1995)</td>
</tr>
<tr>
<td>Effort</td>
<td>Individuals’ attitudes about the usefulness, relevance and worth of statistics in personal and professional life</td>
<td>Schau (2003b), Schau et al. (1995)</td>
</tr>
</tbody>
</table>
characteristics issues. To do so, we built on well-recognized and well-established approaches for instrument development and validation (MacKenzie et al., 2011; Malhotra and Grover, 1998; Moore and Benbasat, 1991). A multi-stage approach for developing and testing a scale that measures the six components characterizing the attitude toward statistics was implemented. Figure 2 presents the two main phases of the process we followed to develop and validate the instrument and summarizes the key techniques that we employed.

The first phase corresponds to the development and refinement of the instrument. We began with the 36 items initially developed by the researchers (Schau, 2003b; Schau et al., 1995). Three rounds of card sorting procedures (two open and one closed procedure), each accompanied by an expert panel, were conducted to refine the items (Moore and Benbasat, 1991). The first two card sorting procedures involved two distinct sets of five judges while the final round comprised a group of six new judges. All judges were university professors who were selected using a convenient sampling approach. The participation criterion for judges was to have some degree of understanding about statistics and more specifically some pedagogical expertise in teaching statistics. All expert panels involved the same five experts including the research team plus two external members.

Card sorting procedures favor a reduction in the risk of “interpretational confounding” defined by Burt (1976) as “the assignment of empirical meaning to an unobserved variable [e.g. factor] other than the meaning assigned to it by an individual prior to estimating unknown parameters” (p. 4). If judges provide category definitions that match the overall intent of each of the scales, it is then a further indication of construct validity. The procedures helped identify potential convergent and discriminant validity issues. Based on the results of each card sorting procedure, the expert panel gathered at the end of each round and decided to modify or delete problematic items while creating new ones when it was judged necessary.

The second phase sought to validate the revised instrument and consisted of a preparation stage and an application stage. The preparation stage involved several face-to-face meetings to assess the understandability of the survey. In the application stage, we conducted a field survey as a final assessment of the improved measurement instrument and confirmed its strong psychometric properties and in particular its dimensionality, validity and reliability.

Sample
Participants were 312 business students enrolled in the introductory basic business statistics course from a top-10 French business school that is triple accredited (EQUIS, AACSB, AMBA) and that meets the international standards of a business school. The mean age of students was 20.1 years (SD = 0.6) and 54 percent of the sample was female. Students were first-year students in the Master in Management Program (third year in undergraduate studies).
during the 2016–2017 academic year. Most of them did not have previous experience in statistics at a university level but had already received basic instruction in this discipline before. All students participated in the survey on a voluntary basis after the general purpose of the study had been presented to them. The course was mandatory. It covered descriptive and inferential statistics (descriptive statistics, probability, confidence intervals, hypothesis tests, regression) and was taught at a rhythm of 3 hours per week over 12 weeks for a total class time of 36 hours. The newly designed and validated instrument was administered to the students and provided 311 actionable responses.

Results

Phase 1: scale development and refinement

The purpose of this stage was to generate a pool of items with high content validity regarding the definitions associated with their respective attitudinal dimensions. Table II summarizes the various manipulations that were undertaken during each round along with the evolution of the items and associated actions for each attitudinal dimension. There are two overall approaches when assessing the degree of agreement among a set of judges: inter-judge agreement scores and overall item placement scores. Inter-judge agreement scores compare the degree of agreement between each distinctive pair of judges and an average of those scores is used to obtain a global agreement measure. The level of agreement between two judges was assessed by computing raw percentage agreement and Cohen’s $\kappa$ coefficients (Cohen, 1960). The results are summarized in Table III.

At the end of the first round, the results of the sorting procedure (item placement ratio = 78 percent, raw percentage agreement = 64 percent and Cohen’s $\kappa$ = 56 percent) confirmed the lack of solid psychometric properties of the initial instrument. The expert panel’s analysis resulted in the identification of several item-related issues that caused most of the disagreements. For instance, while certain items were centered on the individual (e.g. “Statistics should be a required part of my professional training”), others addressed issues that related to others or people in general (e.g. “Statistics is not useful to the typical professional”). Other problematic aspects related, for instance, to improper item content validity or ambiguity (Podsakoff et al., 2003) and inconsistencies in the grammar tenses being used (past vs present) or in mentions of the notions of learning and using statistics. Finally, 19 items (out of 36) were reversed items and posed a range of convergent and discriminant validity problems.

<table>
<thead>
<tr>
<th>Attitude dimension</th>
<th>Affect</th>
<th>Cognitive competence</th>
<th>Value</th>
<th>Difficulty</th>
<th>Interest</th>
<th>Effort</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial number of items</td>
<td>6</td>
<td>6</td>
<td>9</td>
<td>7</td>
<td>4</td>
<td>4</td>
<td>36</td>
</tr>
<tr>
<td>(SATS-36)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Round 1 – open card-sorting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refined items</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>Deleted items</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Total number</td>
<td>8</td>
<td>6</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>36</td>
</tr>
<tr>
<td>Round 2 – open card-sorting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refined items</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Deleted items</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total number</td>
<td>7</td>
<td>6</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>35</td>
</tr>
<tr>
<td>Round 3 – closed card-sorting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refined items</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>8</td>
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<tr>
<td>Deleted items</td>
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<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Final number</td>
<td>6</td>
<td>5</td>
<td>8</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>32</td>
</tr>
</tbody>
</table>
Taking into consideration the previously mentioned issues, the expert panel recommended refining 20 items while deleting two that were too problematic.

Round 2 results confirmed that the researchers were on the right track with an item placement ratio of 84 percent, a raw percentage agreement coefficient of 79 percent and Cohen’s $\kappa$ score of 75 percent. While the $\kappa$ statistic was 0.59 during the first round, which corresponds to a moderate agreement strength (Cohen, 1960), the second round resulted in a substantial level of agreement (between 0.61 and 0.80). The second expert panel concluded that the instrument could still be improved as there existed new issues that had been spotted by the judges while the agreement level was still perfectible. For instance, item valence issues (Podsakoff et al., 2003; Weijters and Baumgartner, 2012) were identified as a potential source of bias: affect was measured by items such as “I am scared by statistics” and “I will enjoy taking statistics courses” together, for example. In this case, the expert panel decided to refine the first item by reducing the negative valence of the item: “I will be afraid of statistics.” Two items were refined and one deleted at the end of this round.

Finally, the closed sorting procedure (round 3) led to very satisfactory results (item placement ratio $= 87$ percent, raw percentage agreement $= 84$ percent and Cohen’s $\kappa = 81$ percent) reaching an almost perfect agreement level (Cohen, 1960). Three items that remained problematic were dropped, while eight were slightly fine-tuned including six items from the effort and interest dimensions with discriminant validity issues. For example, the researchers had modified the original item “I am interested in learning statistics” into “I am keen to learn statistics” so as to avoid the repetition of the sequence of words “I am interest in” in all four items as this could potentially lead to item characteristics effects that is to say “artificial covariance that is caused by the influence or interpretation that a respondent might ascribe to an item solely because of specific properties or characteristic an item possesses” (Podsakoff et al., 2003, p. 882). The refined item appeared to cross-load with the affect dimension as several judges assigned the item to the affect category. A similar issue occurred with the items capturing “effort.” Based on the overall improvement of the measurement items at this stage, we deemed the operationalization to be sufficiently sound and valid to move on to the validation phase.

### Phase 2: scale validation

This phase served to refine the measurement instrument to a level where it could be confidently used and applied. A preparation stage consisting of an online survey and a pre-test involved several researchers who were asked to provide feedback about the instrument in face-to-face meetings. The online survey was then sent to another group of students who were about to start their business statistics course. The final instrument is presented in Table IV.

**Dimensionality.** It was decided to examine the validity and reliability of our measurement instrument by using structural equation modeling through a confirmatory factor analysis run

<table>
<thead>
<tr>
<th>Measure</th>
<th>Attitude dimension</th>
<th>Round 1 (%)</th>
<th>Round 2 (%)</th>
<th>Round 3 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item placement ratio</td>
<td>Affect</td>
<td>50</td>
<td>68</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>Cognitive competence</td>
<td>57</td>
<td>87</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>Value</td>
<td>91</td>
<td>100</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td>Difficulty</td>
<td>86</td>
<td>87</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>Interest</td>
<td>90</td>
<td>86</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td>Effort</td>
<td>95</td>
<td>96</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>78</td>
<td>84</td>
<td>87</td>
</tr>
<tr>
<td>Raw percentage agreement</td>
<td></td>
<td>0.64</td>
<td>0.79</td>
<td>0.84</td>
</tr>
<tr>
<td>Cohen’s $\kappa$</td>
<td></td>
<td>0.56</td>
<td>0.75</td>
<td>0.81</td>
</tr>
</tbody>
</table>

| Table III. | Overview of inter-judge reliability during card sorting tests |
in SmartPLS 3.0 (using a bootstrap procedure with 5,000 resamples). PLS has the advantage to not require items to be normally distributed as opposed to covariance-based approaches (Chin, 1998). Analysis revealed an issue regarding the factorial structure of the “value” dimension. A further investigation through rounds of exploratory factor analysis revealed that the items loaded onto two distinct dimensions. A closer look at the items revealed that while some items pertained to the professional life of individuals, others specifically addressed their personal life. The Value component was modified into a formative second-order dimension made up of “Val-pers” and “Val-pro,” respectively, pertaining to the items related to personal and professional life. Several statistical tests were run to validate this choice.

We first evaluated the absolute contribution of the formative sub-dimensions to the higher-order value dimension by examining the indicator weights (Ringle et al., 2012; Wright et al., 2012). As Table V shows, both weights are above 0.30 and highly significant, confirming that it was reasonable to posit that the two value sub-dimensions explain the higher-order value dimension. We then assessed the relationship between the lower-order and higher-order dimensions by computing an adequacy coefficient $R^2_a$ (MacKenzie et al., 2011; Schmiedel et al., 2014). The adequacy coefficient of 0.57 exceeded the threshold of 0.50 and attested that the majority of variance in the formative sub-dimensions was shared with
the aggregate Value dimension. Multicollinearity was also examined using the variance inflation factor (VIF) (Ringle et al., 2012). With both VIF scores being equal to 1.4, none of the two sub-dimensions exceeded the most restrictive cut-off value of 3.30 (Straub, 2007) showing that multi-collinearity was not an issue. We can conclude that the value dimension is formed of two related components. The item loadings and cross-loadings provided by the confirmatory factor analysis are reported in Table VI.

**Common method bias (CMB).** In social sciences, CMB should also be addressed, since the estimates of a model’s structural parameters can be inflated, potentially leading to erroneous conclusions (Straub, 1989; Straub et al., 2004). Harman’s one-factor (or single-factor) test is a recommended method to assess CMB when the collection through data using different methods or sources is not possible in a single-method research design (Podsakoff et al., 2003). An exploratory factor analysis with unrotated solution resulted in a six-factor solution accounting for 64.5 percent of the total variance, while the covariance explained by a forced one-factor solution was found to be only 29.1 percent. In the presence of CMB, the EFA analysis would have resulted in a single-factor outcome accounting for a large

<table>
<thead>
<tr>
<th>2nd-order dimension</th>
<th>Lower-order construct</th>
<th>Weight</th>
<th>Significance</th>
<th>VIF</th>
<th>Adequacy coefficient $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>Val-pers</td>
<td>0.42</td>
<td>$p &lt; 0.001$</td>
<td>1.41</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>Val-pro</td>
<td>0.35</td>
<td>$p &lt; 0.001$</td>
<td>1.41</td>
<td></td>
</tr>
</tbody>
</table>

### Table V. Value dimensionality assessment

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Item ID</th>
<th>AFF</th>
<th>COG</th>
<th>DIF</th>
<th>EFF</th>
<th>INT</th>
<th>VAL-PRO</th>
<th>VAL-PERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affect</td>
<td>Af1</td>
<td>0.67***</td>
<td>0.42</td>
<td>-0.27</td>
<td>0.35</td>
<td>0.66</td>
<td>0.34</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>Af2</td>
<td>0.82***</td>
<td>0.29</td>
<td>-0.33</td>
<td>0.07</td>
<td>0.43</td>
<td>0.17</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>Af3</td>
<td>0.87***</td>
<td>0.38</td>
<td>-0.46</td>
<td>0.07</td>
<td>0.32</td>
<td>0.06</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>Af4</td>
<td>0.67***</td>
<td>0.31</td>
<td>-0.24</td>
<td>0.33</td>
<td>0.75</td>
<td>0.27</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>Af5</td>
<td>0.81***</td>
<td>0.42</td>
<td>-0.54</td>
<td>0.00</td>
<td>0.36</td>
<td>0.10</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>Af6</td>
<td>0.72***</td>
<td>0.41</td>
<td>-0.38</td>
<td>0.16</td>
<td>0.64</td>
<td>0.26</td>
<td>0.47</td>
</tr>
<tr>
<td>Cognitive competence</td>
<td>Cog1</td>
<td>0.47</td>
<td>0.82***</td>
<td>-0.49</td>
<td>0.15</td>
<td>0.38</td>
<td>0.19</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>Cog2</td>
<td>0.27</td>
<td>0.76***</td>
<td>-0.32</td>
<td>0.18</td>
<td>0.27</td>
<td>0.17</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>Cog3</td>
<td>0.40</td>
<td>0.81***</td>
<td>-0.41</td>
<td>0.12</td>
<td>0.37</td>
<td>0.16</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>Cog4</td>
<td>0.37</td>
<td>0.78***</td>
<td>-0.40</td>
<td>0.24</td>
<td>0.39</td>
<td>0.21</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>Cog5</td>
<td>0.45</td>
<td>0.82***</td>
<td>-0.32</td>
<td>0.15</td>
<td>0.42</td>
<td>0.14</td>
<td>0.30</td>
</tr>
<tr>
<td>Difficulty</td>
<td>Dif1</td>
<td>0.45</td>
<td>-0.58</td>
<td>0.88***</td>
<td>-0.11</td>
<td>-0.33</td>
<td>-0.14</td>
<td>-0.30</td>
</tr>
<tr>
<td></td>
<td>Dif2</td>
<td>0.37</td>
<td>-0.30</td>
<td>0.72***</td>
<td>0.06</td>
<td>-0.14</td>
<td>0.04</td>
<td>-0.04</td>
</tr>
<tr>
<td></td>
<td>Dif3</td>
<td>0.47</td>
<td>-0.36</td>
<td>0.81***</td>
<td>0.08</td>
<td>-0.26</td>
<td>-0.03</td>
<td>-0.10</td>
</tr>
<tr>
<td>Effort</td>
<td>Eff1</td>
<td>0.21</td>
<td>0.25</td>
<td>-0.11</td>
<td>0.74***</td>
<td>0.35</td>
<td>0.34</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>Eff2</td>
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<td>0.16</td>
<td>-0.01</td>
<td>0.90***</td>
<td>0.37</td>
<td>0.29</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>Eff3</td>
<td>0.05</td>
<td>0.10</td>
<td>0.06</td>
<td>0.91***</td>
<td>0.29</td>
<td>0.25</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>Eff4</td>
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<td>0.22</td>
<td>-0.05</td>
<td>0.80***</td>
<td>0.29</td>
<td>0.31</td>
<td>0.22</td>
</tr>
<tr>
<td>Interest</td>
<td>Int1</td>
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<td>0.30</td>
<td>0.54*</td>
<td>0.41</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>Int2</td>
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<td>0.97***</td>
<td>0.41</td>
<td>0.53</td>
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<td></td>
<td>Int3</td>
<td>0.38</td>
<td>0.27</td>
<td>-0.19</td>
<td>0.35</td>
<td>0.68***</td>
<td>0.36</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>Int4</td>
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<td>-0.16</td>
<td>0.34</td>
<td>0.80***</td>
<td>0.33</td>
<td>0.40</td>
</tr>
<tr>
<td>Value – professional</td>
<td>Val-Pro1</td>
<td>0.22</td>
<td>0.22</td>
<td>-0.15</td>
<td>0.30</td>
<td>0.43</td>
<td>0.19</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>Val-Pro2</td>
<td>0.14</td>
<td>0.19</td>
<td>-0.03</td>
<td>0.34</td>
<td>0.34</td>
<td>0.28***</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>Val-Pro3</td>
<td>0.13</td>
<td>0.07</td>
<td>-0.01</td>
<td>0.10</td>
<td>0.18</td>
<td>0.64***</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>Val-Pro4</td>
<td>0.18</td>
<td>0.10</td>
<td>-0.01</td>
<td>0.18</td>
<td>0.30</td>
<td>0.77***</td>
<td>0.40</td>
</tr>
<tr>
<td>Value – personal</td>
<td>Val-Pers1</td>
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<td>0.28</td>
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<td>0.19</td>
<td>0.48</td>
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<td>Val-Pers2</td>
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<td>0.22</td>
<td>0.42</td>
<td>0.41</td>
<td>0.83***</td>
</tr>
<tr>
<td></td>
<td>Val-Pers3</td>
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<td>0.32</td>
<td>-0.15</td>
<td>0.28</td>
<td>0.53</td>
<td>0.54</td>
<td>0.87***</td>
</tr>
</tbody>
</table>

**Notes:** ***,****Significant at 10, 5 and 1 percent risk levels, respectively
proportion of the covariance among the measurement items (Podsakoff et al., 2003). Consequently, the results of Harman’s one-factor test strongly attested to the absence of CMB in the data set (Liang et al., 2007).

We also conducted latent common method factor analysis following Podsakoff et al. (2003) and adapted to PLS analysis by Liang et al. (2007) (see detailed results in Tables AI–AIII). The results were moderately satisfactory as a small number of the method factor loadings were significant while the average indicator variance caused by the substantive constructs was larger than the average variance explained by the method factor (62 vs 16 percent for the method factor). Overall, considering the moderately low magnitude and insignificance of the method variance, we could partially conclude that CMB was not a serious concern in this study. We hypothesize that the measure of attitudinal concepts is particularly prone to response biases due to social desirability. Moreover, some concern was raised regarding five of the Affect items which had relatively high and significant method factor loadings. Again, social desirability bias may have been responsible for these issues. The results of the tests for potential method bias were globally satisfactory, although certain issues were identified that merit further investigation and research.

Subsequent tests and assessments. Unidimensionality is a prerequisite for validity and reliability (Schmiedel et al., 2014). We used two measures, namely, Cronbach’s α and composite reliability, both of which should respectively exceed the thresholds of 0.7 and 0.8 (Chin, 1998; Nunnally, 1978). All computed coefficients were satisfactory (see Table VII). We then assessed convergent validity by first examining the factor loadings for all items. These were all significant and ranged from 0.64 to 0.97 with the exception of the “Interest” item that had a significant factor loading of 0.54 but which we decided to retain for content validity reasons. Second, the average variance extracted (AVE) for the all the attitudinal (sub)dimensions was computed and results ranged from 0.53 to 0.72 (see Table VII), all above the cut-off of 0.50. All convergent validity conditions were met. Discriminant validity was assessed first using the Fornell–Larcker criterion (Fornell and Larcker, 1981) involving the examination of item cross-loadings, and, second, by computing the heterotrait–monotrait (HTMT) ratio of correlations (Henseler et al., 2014). The assessment of construct discriminant validity did not raise any concerns as all the item loadings were higher on their respective dimension than with any of the other dimensions while the square root of the AVE of each dimension was found to be greater than the correlations of the dimension with the other dimensions. Recent research has demonstrated the superiority of the HTMT method over the Fornell–Larcker criterion and the assessment of cross-loadings (Henseler et al., 2014). HTMT ratios are estimates of the correlations between constructs and the rationale is that if these ratios are below the threshold of 0.85 (Kline, 2011), then the true correlations between constructs are most likely to be less than 1, thus ensuring the absence of discriminant validity issues between constructs (Henseler et al., 2014). All HTMT ratios between the attitudinal dimensions were found to be well below 0.85, except for “Affect” and “Interest” whose satisfactory ratio of 0.84 was just below the threshold. The card sorting procedure had already allowed us to qualitatively identify the rather high correlation between the two dimensions, but the results derived from the different discriminant validity tests allowed us to conclude that the issue remained at a level that did not affect validity.

Discussion and implications
Summary of the results
This paper emphasizes the need to encourage positive attitudes toward analytics so that firms can more effectively transform into data-driven businesses and business schools can better prepare future managers. Based on the assumption that business statistics form the
<table>
<thead>
<tr>
<th>Dimension</th>
<th>C's</th>
<th>α</th>
<th>Rho</th>
<th>AVE</th>
<th>AFF</th>
<th>COG</th>
<th>DIF</th>
<th>INT</th>
<th>EFF</th>
<th>VAL-PERS</th>
<th>VAL-PRO</th>
<th>HTMT ratios</th>
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<td>0.73</td>
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<td></td>
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<td></td>
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<td>COG</td>
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<td>0.64</td>
<td>0.50</td>
<td>0.80</td>
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<td></td>
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</tr>
<tr>
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<td>0.65</td>
<td>0.46</td>
<td>-0.32</td>
<td>0.77</td>
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<td>0.84</td>
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<tr>
<td>VAL-PRO</td>
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<td>0.81</td>
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<td>0.43</td>
<td>0.32</td>
<td>0.54</td>
<td>0.80</td>
<td>0.34 0.25 0.11 0.59 0.40 0.68</td>
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</table>
foundation of business analytics, we developed and validated a measurement instrument that captures the attitude toward statistics building on previous work in the fields of education and pedagogy. The revised instrument demonstrates improved psychometric properties including better content, convergent and discriminant validity than the original SATS instrument. Our contribution provides educators and organizations with a means to measure and monitor attitudes toward statistics, the most anxiogenic component of business analytics. This is a first step in monitoring and developing an analytics mindset in both practicing and student managers as well as a data-driven culture in organizations.

Implications for business education

The instrument should be of interest to schools and companies alike. In schools, it could be used as a reference point throughout a big data or a business analytics curriculum to gauge and monitor a student’s progress on the different dimensions of attitude toward the statistics component. An “attitude profile,” such as the one shown in Figure 3, could be constructed for each student or group using the questionnaire at the beginning of class to identify priority action dimensions. Here for example, we can see that the student or group has a low score on the perceived personal value of statistics (“val-pers”) dimension. Equipped with this information, an educator could ask the student or group to look for examples of statistics in their daily life, such as those reported in the news. Targeted improvements to any one dimension of attitude should improve student attitudes toward statistics overall.

Students of statistics or analytics could also be provided with absolute or relative-to-class data on their personal attitudinal dimensions through “learning analytics dashboards” to give feedback to favor the self-regulation of their learning (Corrin and de Barba, 2014) in analytics.

In addition, this instrument can be used to design programs and classes that favor the development of positive attitudes. If administered before the start of a statistics, analytics or big data course, the instrument could allow an instructor to diagnose student perceptions and attitudes and then adapt the course accordingly. For example, if feelings toward the course were globally negative (“affect”), a more “playful” pedagogy could be adopted using learning tools such as interactive quizzes during the class or proposing a flipped classroom where students present to the whole group what they learned at home before the class. If students perceive the course as globally useless (“value”), then the intervention of professionals testifying to the importance of business statistics in their professional activity could be a solution. Instructors could also form work groups using a homogeneous mix of different attitudes or making sure to include members with complementary perceptions in each group.

Figure 3. Attitude profile based on the SATS instrument.
An increased focus on attitudes and literacy should help schools and universities “fill the gaps” and better “meet the needs of industry talent in terms of the scope and scale of big data analytics in business knowledge” (McLeod et al., 2017, p. 514).

Implications for practice
Organizations could use this instrument as a key tool in their drive to encourage a data-driven culture by measuring, monitoring and improving the attitudes of managers toward statistics and business analytics. Attitude data could be used by HR departments to identify training needs, plan instructional actions and track the impact of training programs in analytics. HR departments could also collate “true effectiveness metrics” that “offer information on whether employees build needed skills not just on participation in training and/or employee and management satisfaction with the training provided” (Lawler et al., 2004). The instrument could also be implemented at different organizational levels for different uses. While it could be used at the employee level to track employee skills and training needs, results could also be collated at the team, department, branch or organizational levels. The instrument could also help managers identify team talent gaps and set priority recruitment criteria. Measuring candidates’ attitudes toward analytics could be added to the various psychometric and aptitude testing procedures used by HR departments during the recruitment process.

Implications for research and future research
As society shifts from a business-driven to a data-driven paradigm, our research attempts to bridge the gap between business research and the fields of education and pedagogy. The emergence of a data-driven business world impacts the way organizations function and the way individuals think, work, communicate and interact, making it crucial to engage in a transdisciplinary dialogue between domains that have the expertise to help train and transform current and future professionals.

Our research contributes to theory and practice in the fields of statistics education and business management. From a theoretical point of view, we have improved an instrument that is widely used in the field of education and pedagogy to capture attitude toward statistics. Our revised instrument demonstrates improved psychometric properties including better content, convergent and discriminant validity than the original instrument. At a practical level, our research answers calls in the literature to help managers better deal with the challenge of business analytics (e.g. Chang et al., 2015) and trainers effectively integrate big data analytics into business skill sets and curriculum designs (Wixom et al., 2014; Henry and Venkatraman, 2015; Wymbs, 2016).

Our work opens several exciting opportunities for future research. While statistics remains central to analytics, other skills are needed to develop an analytics mindset including computer programming and data management. There is a need to conceptualize the notion of “analytics culture” and “analytics mindset,” and identify the different components that characterize them. Future research could examine how to measure and monitor attitudes toward these additional dimensions. Furthermore, the instrument was developed and validated within a French business school context. Future research could validate the instrument in an organizational context and also in other countries. The wording of some items may need to be tailored to a professional audience.

Finally, the claim that managers and employees should be trained to adopt an analytics mindset assumes that analytics becomes a component of organizational culture. Indeed, organizational culture is the set of beliefs, values and assumptions that are shared by members of an organization and taught to newcomers as the proper way to think and feel (Schneider et al., 2013; Schein, 1985). The link between the attitude toward statistics/analytics and an analytics-based organizational culture requires further investigation and
could provide important insights to HR departments to guide them in the socialization of new employees. Similarly, the analytics way of thinking along with the attitude toward analytics could be investigated from an “organizational climate perspective.” The study of organizational climate has a long research tradition and has been defined as “the shared perceptions of and the meaning attached to the policies, practices and procedures employees experience and the behaviors they observe getting rewarded and that are supported and expected” (Schneider et al., 2013, p. 362). The introduction of the notion of “analytics or analytical climate” would complement research that has studied different organizational climates such as diversity climate (Cachat-Rosset et al., 2017), innovative climate and “risk-taking climate” (Kang et al., 2016).

Limitations to our research

Our research is not without limitations. First, there is still work needed to fully conceptualize and operationalize attitudes toward business analytics. We decided to first develop a solid foundation upon which future research will be able to build with confidence; the measurement of the attitude toward statistics. Another limitation is that the instrument was validated in a single business school. There is no guarantee that it is readily applicable in other business schools or in other countries. The measure of attitudinal factors, such as the six dimensions composing the attitudinal construct developed in this research, could also suffer from social desirability bias. In other words, society, family or peer-related beliefs and norms about analytics and statistics may bias responses to items toward what is socially acceptable (Podsakoff et al., 2003). If the instrument is used to monitor and adapt pedagogical content and training, this could lead to a mismatch between interventions and the true needs of individuals. A simple remedy would be to inform respondents that the anonymity of the responses will be protected. Existing social desirability scales such as the 33-item Marlowe–Crowne Social Desirability Scale (Crowne and Marlowe, 1960) could also be administered to participants. The scale consists of asking individuals to answer true or false to a set of socially desirable but highly unlikely statements. Shorter versions of the MCSDS scale have also been validated by research (Fischer and Fick, 1993). There also exists a range of statistical techniques that help control and mitigate common method variance problems such as social desirability (Podsakoff et al., 2011). Finally, a larger sample size would have allowed for more advanced statistical analyses and validation.

Conclusion

Companies have been suffering from both a lack of analytics ability in their workforce and a struggle to identify and hire fresh talent to satisfy urgent needs. The emergence of new data- and analytics-related skill sets in organizations have given rise to a plethora of new jobs and functions such as the data scientist, data analyst, data planner, data steward or data visualization analyst. However, no matter the number nor the blends of analytics specialists that companies hire, an organization will only become data-driven when its core, or its “organizational DNA” has assimilated an “analytics gene.” In other words, data and analytics must diffuse into all aspects from corporate strategy, business models, processes and ways of working. Following the “principle of enablement” (Brocke et al., 2014), it should become a dynamic business process management capability that can help organizations effectively respond to future contingencies.

Businesses and educational institutions must work together to determine how to best prepare managers and employees for a data-driven era. While a pro-analytics attitude must be nurtured within organizations, it is up to schools and universities to plant the seed. With the arrival of artificial intelligence and robotics in the workplace, improving attitudes toward statistics may be a sound starting point to better managing these data-driven technologies.
Note
1. The INFORMS Analytics Education Database (www.informs.org/Resource-Center/Search-Education-Database) was searched using the keyword “statistics” over the period November 1-9, 2017.

References


(The Appendix follows overleaf.)
### Appendix 1

<table>
<thead>
<tr>
<th>Program</th>
<th>Institution</th>
<th>Statistics course</th>
</tr>
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<tbody>
<tr>
<td>Master of Science in Analytics</td>
<td>American University, Kogod School of Business</td>
<td>Applied Managerial Statistics</td>
</tr>
<tr>
<td>Marketing Analytics</td>
<td>Bentley University, Graduate School of Business</td>
<td>Managerial Statistics</td>
</tr>
<tr>
<td>Master of Science in Data Analytics</td>
<td>City University of New York</td>
<td>Statistics and Probability for Data Analytics</td>
</tr>
<tr>
<td>Master of Science in Predictive Analytics</td>
<td>DePaul University, College of Computing and Digital Media</td>
<td>Statistics and Data Analysis</td>
</tr>
<tr>
<td>Business Analytics</td>
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<td>Statistics for Business Analytics</td>
</tr>
<tr>
<td>Master of Science in Business Analytics</td>
<td>George Washington University</td>
<td>Statistics for Analytics</td>
</tr>
<tr>
<td>Master of Science in Business Analytics</td>
<td>Michigan State University, Eli Broad College of Business</td>
<td>Introduction to Statistics</td>
</tr>
<tr>
<td>Master of Science in Business Analytics</td>
<td>NYU Stern (New York, Europe, Asia)</td>
<td>Foundations of Statistics Using R</td>
</tr>
<tr>
<td>Master of Science in Business Analytics</td>
<td>Rensselaer Polytechnic Institute</td>
<td>Statistics and Operations Management I</td>
</tr>
<tr>
<td>Master of Science in Business Analytics</td>
<td>University of California – Davis</td>
<td>Statistical Exploration and Reasoning</td>
</tr>
<tr>
<td>Master of Science in Business Analytics</td>
<td>University of Cincinnati, Lindner College of Business</td>
<td>Statistical Methods</td>
</tr>
<tr>
<td>Master of Science in Business Analytics</td>
<td>University of Colorado Denver</td>
<td>Statistics for Business Analytics</td>
</tr>
<tr>
<td>Master of Science in Data Analysis</td>
<td>Southern New Hampshire University</td>
<td>Mathematics and Statistics for Business</td>
</tr>
<tr>
<td>Bachelor of Science – Business Analytics and Information Systems major</td>
<td>University of Iowa</td>
<td>Statistics for Business</td>
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<tr>
<td>Master of Science in Business Analytics</td>
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<td>Introduction to Statistics for Data Scientists</td>
</tr>
<tr>
<td>Master of Science in Business Analytics</td>
<td>University of Notre Dame</td>
<td>Statistics for Managerial Decision Making</td>
</tr>
<tr>
<td>Master of Science in Business Analytics</td>
<td>University of Rochester</td>
<td>Core Statistics for MS Students Using R</td>
</tr>
<tr>
<td>Master of Science in Analytics</td>
<td>University of San Francisco, College of Arts and Sciences</td>
<td>Review of Probability and Statistics</td>
</tr>
<tr>
<td>Master of Science in Business Analytics</td>
<td>University of Southern California, Marshall School of Business and Viterbi School of Engineering</td>
<td>Applied Managerial Statistics</td>
</tr>
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</table>

**Table AI.** Sample of introductory statistics classes listed in US- and UK-based entry-level analytics programs

---
# Appendix 2

## Table AII.

<table>
<thead>
<tr>
<th>Items</th>
<th>Mean</th>
<th>SD</th>
<th>Skewness</th>
<th>Kurtosis</th>
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<tbody>
<tr>
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<td>3.20</td>
<td>1.572</td>
<td>0.350</td>
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<tr>
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Data-driven decision makers
### Appendix 3

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<tr>
<th>Dimension</th>
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<td>Aff4</td>
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<td>0.60***</td>
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<td>0.16</td>
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| Common method bias | Average | 0.78 | 0.62 | 0.28 | 0.16 |

**Table AIII.**

**Corresponding author**

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