Conceptualizing business model piloting: An experiential learning process for autonomous solutions

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Abstract

Business model innovation supports manufacturers in the pursuit of new opportunities. However, successfully innovating a new business model presents a significant learning challenge, especially for highly advanced offerings, such as autonomous solutions. Experiential learning approaches, such as business model piloting, are crucial for fine tuning and scaling new business models, yet the current literature fails to adequately examine business model innovation in the context of advanced industrial offerings. In endeavoring to advance current research, we apply a business model piloting lens to advance understanding of how manufacturers engage in business model piloting for autonomous solutions. Our research builds on a multiple case study of piloting initiatives at two manufacturers, involving 32 interviews with senior managers responsible for autonomous-solution business model pilots. This study proposes a business model piloting framework to support manufacturers in overcoming business model innovation challenges. The framework consists of three phases: business model design, business model validation, and business model institutionalization. Each phase includes key business model piloting activities. We also identify three principles that support experiential learning in business model piloting. We contribute to the business model innovation literature by highlighting the strategic and multi-dimensional nature of business model piloting. This process requires simultaneous configuration of novel technologies for value creation and the design of suitable value delivery and capture mechanisms.

Keywords: business model piloting, business model experimentation, digital servitization, digital business model, digital transformation, artificial intelligence

1. Introduction

In the current age of rapid technological development, manufacturers increasingly recognize the importance of leveraging the value of new technologies to remain competitive (Hanelt et al., 2021; Opazo-Basáez et al., 2022; Paiola and Gebauer, 2020; Sorescu, 2017). In particular, digital technologies can transform the way firms do business by enabling new means of creating, delivering, and capturing value (Rachinger et al., 2019; Verhoef et al., 2021; Volberda et al., 2021), such as supporting novel business models in controlled indoor agriculture (Thomson, 2022). However, in many cases, digital technologies fail to live up to their full promise (Lanzolla et al., 2020). Instead, the majority of cases use digital technologies to drive internal efficiency and effectiveness improvements (Björkdahl, 2020), such as cutting costs and optimizing production in manufacturing operations (Sjödin et al., 2018). However, the major challenge that manufacturers face is using digital technologies to grow their businesses (Björkdahl, 2020; Chen et al., 2021). This requires manufacturers to engage in business model innovation (BMI) to change the way they create, deliver, and capture value (Baden-Fuller and Haefliger, 2013; Gambardella and McGahan, 2010). Yet, BMI presents many uncertainties and challenges (Rachinger et al., 2019; Vendrell-Herrero et al., 2018; Verhoef et al., 2021), especially for manufacturers who deliver complex offerings, such as autonomous solutions (Leminen et al., 2022; Sandvik et al., 2021; Thomson et al., 2021). Autonomous solutions[1] (the context of this study) refer to the capacity of mobile machines to function independently of a human operator, thereby enabling radical changes in how industrial operations are performed (Leminen et al., 2022; Sandvik et al., 2021; Thomson et al., 2021). For instance, Caterpillar's autonomous vehicle solutions are leading the transformation of the mining industry by reducing

[1] Autonomous solutions represent a sub-stream of the literature on digital servitization (e.g., Kolagar et al., 2022) also referred to as smart solutions (e.g., Kohtamäki et al., 2022a) and the most advanced types of digital servitization offering. Related streams of research are digital business model innovation (e.g., Sjödin et al., 2022) and digital transformation (e.g., Llopis-Albert et al., 2021).

the requirement for human operators, improving safety, and enabling more predictable and consistent operations (Caterpillar 2021).

However, engaging in BMI for emerging autonomous solutions embodies high levels of uncertainty and represents a fundamental learning challenge for traditional, product-centric manufacturers (Sandvik et al. 2021). This is because shifting to autonomous solutions demands significant changes to all elements of the business model (BM) – or, in other words, BMI. That means changing the way firms create, deliver, and capture value for their customers (Sjödin et al. 2020a; Chen et al. 2021; Schroeder et al. 2020; Sklyar et al. 2019b; Baines et al. 2017). Succeeding in this endeavor requires successive rounds of experimentation and learning to fine-tune the BM (McGrath, 2010; Teece, 2010). For example, manufacturers need to experiment with new value propositions, revenue models, and delivery routines for autonomous solutions to unlock the value of autonomous technologies (Thomson et al., 2021). Second, since the underlying technology is new and not fully proven, industrial manufacturers must learn to configure and customize novel digital technologies and BMs in tandem in order to deliver autonomous solutions that convincingly address unique customer needs (Desyllas et al., 2022). This requires the BM to be tested on a "real customer paying real money in a real economic transaction" (Chesbrough, 2010, p. 360). Finally, for BMI to be profitable, it must progress from the initial trials and systematically embrace scaling (Palmié et al., 2023). This means that routines and knowledge must be created and disseminated throughout the organization (Berends et al., 2016). Resolving these challenges presents many uncertainties for industrial manufacturers, who are not only working with an immature value proposition but are also ascertaining how to deliver it and how to price it (Baden-Fuller and Morgan, 2010). In order to succeed, industrial manufacturers need to engage in trial-and-error experimentation of their BM (Teece, 2010). The BM logic needs to be "tested and retested, adjusted and tuned as the evidence with respect to original assumptions becomes clarified" (Teece, 2010, p. 188). While these are key practical challenges in digital BMI, the academic literature on BMI has yet to adequately explore this domain.

We seek to address these challenges and further strengthen the conceptual foundations of BMI by examining such processes through the lens of piloting (Billé and Duchemin, 2010; Bocken et al., 2017; Glass, 1997). Piloting presents a systematic approach to trial-and-error learning and refers to smaller-scale, agile trials of new solutions to assess feasibility (Billé and Duchemin, 2010; Glass, 1997). Small-scale pilots support primary data collection in a real world setting and delay full-scale investment decisions prior to obtaining better information (Girotra and Netessine, 2013). Such a perspective may further illuminate the organizational dynamics of BMI. In particular, we argue that adopting a BM piloting perspective on BMI allows further detailing of the processes of change, learning, and refinement in complex and uncertain contexts (Geissdoerfer et al., 2022; Hu, 2014; Ricciardi et al., 2016), as in the case of BMI for autonomous solutions. Indeed, industrial manufacturers of autonomous solutions are challenged when developing novel and complex technologies whilst simultaneously managing uncertain levels of performance and solution scalability, which necessitates BM piloting. For example, Volvo Trucks in collaboration with Brönnöy Kalk has been piloting autonomous solutions that transport material from a quarry to a port with the explicit goal of understanding the appropriate BM. BM piloting, therefore, presents a promising perspective to increase understanding of BMI for novel digital applications. We identify two key research gaps in this domain.

First, there is a *need to better understand the business model piloting process.* Although Geissdoerfer et al. (2022) have conceptualized the overall principles of BM piloting, they provide scant details on the actual process and its phases. Prior research exploring different learning approaches for BMI has emphasized the importance of incremental trial-and-error experimentation (Sosna et al. 2010; Morris et al. 2005) as well as cognitive search and experiential learning (Berends et al. 2016). Yet, few studies have explored and outlined the different phases through which industrial manufacturers transition as part of their BM piloting efforts toward BMI. We argue that this is a key gap in our knowledge, which needs to be closed and the literature on BMI meaningly augmented. Indeed, experiential learning through piloting has been proposed as a lens capable of increasing understanding of how BMI occurs in established firms. It supports these firms in managing the uncertainties of new technology and business development (Chesbrough, 2010). However, despite the potential of BM piloting to support BMI, surprisingly little is known about it (Geissdoerfer et al., 2022).

Second, there is a *need to identify the learning activities that industrial manufacturers undertake to understand appropriate configurations of value creation, delivery, and capturing elements* along the piloting process. Despite a general acceptance of experiential learning's importance in supporting BMI (Berends et al., 2016; Chesbrough, 2010; Girotra and Netessine, 2013; Sosna et al., 2010), the extant literature largely fails to define what takes place at a practical level to unlock such learning. While the BM piloting perspective offers a promising step in this direction, there is a lack of conceptual clarity on what constitutes BM piloting and the activities it entails (Geissdoerfer et al., 2022). Thus, there is a need for further understanding of the principles and structures underpinning systematic BM piloting activities in the industrial domain. In particular, the contextual evaluation of BMs is important as "a business model cannot be assessed in the abstract; its suitability can only be determined against a particular business environment or context" (Teece, 2010, p. 191). A key challenge with the literature on piloting is that it draws heavily on earlier research within the IT domain (Glass, 1997). Despite hinting at systematic approaches to BM piloting, we only have limited empirical insights in industrial business-to-business (B2B) contexts (Geissdoerfer et al., 2022).

In endeavoring to advance current research, we adopt a BM piloting lens, which we argue provides a more in-depth view of BMI processes. This study seeks to develop an understanding of *how manufacturers engage in business model piloting for autonomous solutions.* We build on insights from two Swedish industrial manufacturers based on thirty-two interviews with respondents involved in the development and implementation of autonomous solutions (i.e., self-driving industrial vehicles). The novel technological and BM changes required to develop and commercialize self-driving industrial vehicles make this context particularly suited to the purpose of this study.

Our findings contribute to the literature on BMI and autonomous solutions by creating a *BM piloting framework,* showing how industrial manufacturers systematically engage in piloting through small-scale, agile trials prior to BM scaling. The framework outlines three BM piloting phases: *business model design, business model validation,* and *business model institutionalization*. Each phase consists of a set of key BM piloting activities that contribute to an iterative, incremental, and learning-oriented BMI process for autonomous solutions. Additionally, we find three key principles that support experiential learning during BM piloting for autonomous solutions: *lean learning*, *systematic evaluation*, and *scaling preparation*. Adhering to these principles of experiential learning throughout the BM piloting phases supports industrial manufacturers to benefit from this approach. We contribute to the literature on business model innovation by demonstrating that the piloting of business models is a strategic and multi-dimensional process requiring concurrent development of novel technologies, as well as appropriate value delivery and capture mechanisms.

2. Theoretical background

2.1 The uncertain context of autonomous solution business models

Digital technologies are having a transformative effect on the ability of firms to create, deliver, and capture value (Casadesus-Masanell and Ricart, 2010; Paiola and Gebauer, 2020; Snihur et al., 2018). New business opportunities opened up by emerging digital technologies (e.g., cloud computing, artificial intelligence) garners significant performance improvements and enhances the competitiveness of firms (Appio et al., 2021; Björkdahl, 2020). Yet, utilizing new digital technologies can be challenging and uncertain (Baden-Fuller and Haefliger, 2013). For example, industrial manufacturers delivering advanced solutions, such as autonomous vehicles, need to establish agreed levels of solution performance with their customers, despite having limited to no prior experience of how the solution will perform (Thomson et al., 2021). Moreover, uncertainty is present when industrial firms succeed in leveraging the value from digital technologies, potentially making numerous products, services, and entire BMs obsolete (Chesbrough and Rosenbloom, 2002). Consequently, BMI is increasingly being mentioned as a key strategic concern for industrial firms (Björkdahl, 2020; Hsuan et al., 2021; Sjödin et al., 2022, 2020a). This is relevant for the development of advanced digital offerings, such as autonomous solutions, which require new BMs capable of leveraging their potential value (Leminen et al., 2022; Thomson et al., 2021).

Autonomous solutions are transforming how a firm's BM is configured and are leading to the creation of novel digital BMs (Baines et al., 2017; Jovanovic et al., 2021; Leminen et al., 2022; Sjödin et al., 2020b). Emphasis on the term "digital" implies that the BM is heavily shaped by this component (Chen et al., 2021), as is the case with autonomous solutions (Thomson et al., 2021). Autonomous functionality is made possible by the combined effects of novel digital technologies that enable the sensing of the external environment and interaction with it (Leminen et al., 2022; Thomson et al., 2021). This makes autonomous solutions one of the most advanced and uncertain forms of digital solution (Kohtamäki et al., 2019; Porter and Heppelmann, 2015; Sandvik et al., 2021). However, new technologies have no inherent value in and of themselves. They require the complementary innovation of a BM capable of actualizing their potential as new technologies (Chesbrough, 2010). Despite this, prior literature has tended to focus on the technological aspects of autonomous solutions to the neglect of the requirement for BMI to achieve successful commercialization (Baden-Fuller and Haefliger, 2013; Leminen et al., 2022; Teece, 2010).

Recent contributions seeking to address the lack of business model focus have conceptualized autonomous-solution BMs according to their level of autonomous capability and solution complexity (Leminen et al., 2022), conceptualizing them as part of a business-focused maturity framework (Thomson et al., 2021). Yet, research on the BMI of autonomous solutions is scarce (Leminen et al., 2022). Only a few descriptive studies have assessed the processes of BMI and the means through which organizational change occurs (Parida et al., 2019; Kohtamäki et al., 2019; Sjödin et al., 2021). Overall, little is known about the complex changes underlying the BMI process for autonomous solutions. Consequently, there is a need to further understand the learning activities of industrial firms engaging in digital BMI, and autonomous solutions specifically.

2.2 Business model innovation

A BM describes the "design or architecture of the value creation, delivery and capture mechanisms" of a firm (Teece, 2010, p. 191). BMs comprise three key elements: (1) value creation refers to the value proposition and the resources and processes that underlie the development of bundles of products and services; (2) value delivery describes how the firm organizes to deliver value to the customer; and (3) value capture describes the revenue models and processes of value appropriation (Parida et al., 2019; Teece, 2010). BMI is defined as "designed, novel, nontrivial changes to the key elements of a firm's business model and/or the architecture linking these elements" (Foss and Saebi, 2016, p. 201).

BMI is an essential aspect of organizational strategy for firms seeking to remain competitive in a rapidly changing business environment (Chesbrough, 2010; Foss and Saebi, 2016) and improve their organizational performance (McGrath, 2010; Zott et al., 2011). However, incumbent firms often face challenges when innovating their BMs, particularly when introducing advanced technologies, such as autonomous solutions, which require them to address inherent paradoxes (Sandvik et al., 2021). For example, the opportunity to use digital technologies for solution customization must be balanced with retaining efficient standardization (Kohtamäki et al., 2020). Incumbent organizations are particularly challenged when attempting to experiment and innovate BMs (Berends et al., 2016). They rarely succeed at the first attempt (Sosna et al., 2010). Challenges include surmounting organizational inertia from pre-existing dominant logics, resource allocation tensions with more established and profitable BMs (Berends et al., 2016; Demil and Lecocq, 2010), challenges with organizational alignment, and overcoming a fear of negative consequences (Sosna et al., 2010).

In order to grasp the complexity of BMI for incumbents, it is necessary to go beyond a snapshot visualization of the key business activities of value creation, capture, and delivery and explain the *processes of change* through BMI (Demil and Lecocq, 2010). Indeed, BMs do not emerge fully formed from careful conceptualization and design alone. They require trial and error as well as subsequent adaptation based on trial feedback (Chesbrough, 2010). Recently, the three approaches of prototyping, experimentation, and piloting have been proposed as intermediary, step-wise measures to manage the uncertainty of BMI rather than aiming for a fully scalable BM at the outset (Geissdoerfer et al., 2022). BM piloting presents a particularly promising approach for incumbent firms to test and learn about more developed BM concepts in a target-market setting before scaling up (Bocken et al., 2017; Geissdoerfer et al., 2022). This makes BM piloting especially relevant in the case of autonomous solutions, which have advanced beyond the stage of prototypes and experimentation. However, their continued development retains high levels of uncertainty and risk. This is due to the radical changes embodied in the value-creation (e.g., autonomous vehicles), value-capture (e.g., outcome-based models, software licensing), and value-delivery (e.g., accountability for function) dimensions of the BM (Thomson et al., 2021).

2.3 Toward an understanding of business model piloting

BM piloting is a process of learning by doing that allows firms to test and validate their BMs in a real-world setting, prior to full-scale implementation (Geissdoerfer et al., 2022). It is defined as “a semi-controlled launch of the business concept in parts of the target market, testing all elements of the business model within a smaller-scale and easier to analyze setting to test contingencies, costs, and feasibility, at reduced initial investment and risks compared to the implementation of a full-scale project” (Geissdoerfer et al., 2022, p. 571). Conducting BM pilots provides several benefits. Critically, testing a BM with a customer provides a realistic trial from which firms can learn (Chesbrough, 2010). Indeed, BMI presents many uncertainties that requires firms to develop new knowledge and capabilities to succeed (Foss and Saebi, 2016). For instance, firms frequently need to acquire knowledge about new technologies, the effects on the organization of which are uncertain (Glass, 1997) and which necessitate experimentation with innovative organizational structures (Billé and Duchemin, 2010). BM pilots help firms to overcome the inertial effects of path dependency and to more effectively manage “the complexities and uncertainties intrinsic to technological developments” (Geissdoerfer et al., 2022, p. 565). Despite these benefits, few studies have sought to explore BM piloting in B2B industrial contexts. Indeed, previous studies of BM piloting have tended to focus on startups and corporate venturing, neglecting the BMI activities of incumbent B2B firms (Blank, 2013; Brown and Katz, 2011; Geissdoerfer et al., 2022).

While we do not know much about BM piloting, technological pilots have been conceptualized as consisting of several distinct phases, including planning, designing, conducting, evaluating, and using (Glass, 1997). Despite providing valuable guidance, the activities in these phases were developed to implement new technology in the computing industry (Glass, 1997). We seek to build on this by advancing understanding of piloting into the context of BMI in industrial firms. We conceptualize BM piloting for autonomous solutions as an emergent process based on experiential learning (Sosna et al., 2010; Berends et al., 2016). Indeed, experiential learning is an essential analytical lens through which the BM piloting process can be investigated and understood (Andries et al., 2013; Berends et al., 2016; Morris et al., 2005; Sosna et al., 2010). Notably, the BM literature has used trial-and-error learning approaches (Sosna et al., 2010; Bocken and Snihur, 2020) that consider how action and cognition iteratively interact to deliver BMI (Berends et al., 2016). Yet, these studies do not address the actual processes and, in particular, the elements of BM piloting. Building on earlier work of BM piloting (Geissdoerfer et al., 2022; Glass, 1997) and organizational learning (Berends et al., 2016; Sosna et al., 2010; Andries et al., 2013), we conceptualize three BM piloting phases.

Phase 1: Conceptualization – traditional product manufacturers transitioning to the delivery of advanced solutions, such as autonomous vehicles, need to conceptualize new ways of creating, delivering, and capturing value for the target market or customer (Baines et al., 2017; Chen et al., 2021; Schroeder et al., 2020; Sjödin et al., 2020a; Sklyar et al., 2019). This requires upfront planning and design of the BM before a pilot can be conducted. Prior literature emphasizes activities such as establishing a clear definition of the problem through careful examination, as well as design of pilot tasks and success criteria (Glass, 1997). These piloting activities are well suited to the testing of well-developed technologies that are ready to pilot in a customer organization. They support the subsequent analysis of a large set of alternative options that can be conceptualized and assessed at low risk to the organization (Gavetti and Levinthal, 2000). Yet the guidance lacks the more strategic view needed to develop novel BMs. For example, manufacturers developing autonomous solutions need to conceptualize new ways in which they can resolve customer problems and create value. This may be through the conceptualization of new arrangements for value delivery, such as partnering with suppliers to reduce risk (Berends et al., 2016), or alternative revenue models that incentivize solution uptime (Leminen et al., 2022).

Phase 2: Implementation – prior literature emphasizes the importance of ensuring practical validation of BM concepts in support of BMI (Sosna et al., 2010; Andries et al., 2013). This is due to the inherent uncertainties of developing an underlying technology, such as autonomous solutions, which is not fully proven and which is accompanied by a novel BM (Gavetti and Levinthal, 2000). Indeed, industrial equipment manufacturers must learn when they are configuring and customizing novel digital technologies by undertaking testing with their customer. Glass highlights the importance of the activities of data collection and analysis to BM implementation (Glass, 1997). Through activities such as these, the implementation phase of BM piloting enables organizations to deal with the uncertainties of an emerging BM through the stepwise accumulation of knowledge (Sosna et al., 2010), supporting the creation of novel BMs (Berends et al., 2016). Yet, little is known of how industrial firms refine the value proposition and the BM as part of the implementation process. Anecdotally, we know this to be critical to the development of novel and advanced solutions, such as autonomous vehicles. Yet, we lack empirical insights into this.

Phase 3: Evaluation – following a pilot implementation, industrial firms need to capture and institutionalize new knowledge. Institutionalized knowledge is reflected in new organizational designs, systems, routines, and processes, which enable the exploitation of that knowledge (Sosna et al., 2010). We argue that such institutionalized knowledge is critical to scale BMI beyond the individual pilot to other customers. Indeed, progressing from the initial pilot cases to a scalable BM is vital to the profitability of BMI (Lindgart et al., 2009). Glass emphasizes the activities of reviewing operational success criteria, documenting recommendations, and using these to inform ongoing alternatives (Glass, 1997). These activities are important elements in most evaluation exercises, yet we lack insight into how they are shaped in the context of digital BMI, a domain that the academic literature has yet to adequately explore. Figure 1 presents a theoretical framework for BM piloting.

---INSERT FIGURE 1 ABOUT HERE---

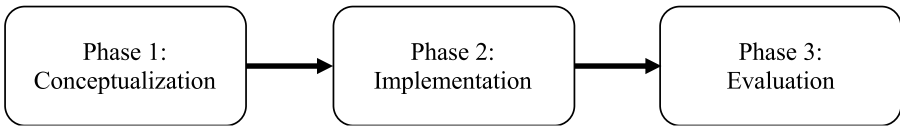

Figure 1: A theoretical framework for business model piloting

In summary, BM piloting is a valuable approach for incumbent firms seeking to commercialize autonomous solutions and other advanced technologies. Indeed, piloting has been identified as an important component of BMI (Geissdoerfer et al., 2022, 2017). By testing and validating their BMs in a real-world setting, firms can mitigate the risks associated with introducing new technologies and improve their chances of success. However, our extant understanding of piloting is predominantly derived from a study of IT industry pilots in the 1990s (Glass, 1997). Despite providing a valuable base on which to build, the activities attributed to piloting fail to account for the strategic view required for the development of novel BMs (Chesbrough, 2010). Moreover, despite the growing importance of BM piloting, previous research has tended to focus on startups and corporate venturing, neglecting the BMI activities of incumbent B2B firms (Blank, 2013; Brown and Katz, 2011; Geissdoerfer et al., 2022). This research seeks to address these gaps in understanding by studying the BMI activities of incumbent industrial manufacturers engaged in the BMI of autonomous solutions.

3. Methodology

3.1. Research design

The present study adopts a qualitative approach to investigate *how manufacturers engage in business model piloting for autonomous solutions.* Qualitative research is favored when studying nascent topics with limited theorizing (Hair et al., 2007), as is the case with studying BM piloting in advanced B2B settings (Blank, 2013; Brown and Katz, 2011; Geissdoerfer et al., 2022). The study follows an exploratory design, seeking to discover new relationships and revealing “how” BM piloting is carried out (Saunders et al., 2016; Stebbins, 2001). A multiple case study research strategy is subsequently chosen because it is apposite for building emergent theory (Eisenhardt and Graebner 2007), where the boundaries of the surrounding context are unclear and where in-depth understanding is being pursued (Edmondson and Mcmanus, 2007; Yin, 2018). This makes the multiple case study strategy particularly suited to the in-depth study of an emerging BM piloting literature stream in need of new theory.

3.2. Case selection

To address the research purpose, we build on insights from two industrial manufacturers actively engaged in the BM piloting of autonomous solution BMs, referred to by the pseudonyms of Rockcorp and Truckcorp. Both manufacturers have their headquarters in Sweden and operate internationally. Rockcorp provides industrial mining equipment and solutions globally, while Truckcorp is a global provider of transportation solutions, including trucks and buses. Two key criteria informed the selection of the case companies. Firstly, the case companies needed to be actively engaged in BM piloting initiatives of autonomous solution B2B offerings. This enabled us to explore the dynamic processes of BM piloting in order to address the overarching research purpose. Second, since we wanted to capture in-depth data, it was preferable that the case companies we selected were firms with whom we had established long-standing research cooperation. The existence of prior research relationships with both Rockcorp and Truckcorp enabled us to gain access to rich case insights and facilitated full support in the data-collection process. Cases at the two firms were selected based on their facility in answering the research question using a theoretical sampling approach. This method of sampling supports the selection of cases with the potential to be particularly illuminating examples that can inform emergent theory (Eisenhardt and Graebner, 2007; Saunders et al., 2016). Both case companies were pursuing several BM piloting initiatives in support of BMI for autonomous solutions. Five BM pilots informed the study – three at Rockcorp, two at Truckcorp. A description of the five cases is provided in Table 1.

3.2 Data collection

Data were collected for the present study primarily through semi-structured interviews but also through secondary data sources, such as company presentations and publicly available online material. The use of interviews to collect data cohered with the overarching research purpose and exploratory approach, seeking to address the open-ended question of "how" (Yin, 2018). An advantage of using a semi-structured approach is that theoretical insights pre-informing the study can be used to develop guiding questions whilst not precluding potential deviations to explore emergent and relevant topics from the interviews. The selection of informants was carried out in collaboration with the main research contacts at each of the case companies. Purposive sampling with the research goal in mind ensured the strategic selection of knowledgeable and experienced informants engaged in the provision of autonomous solutions (Bryman and Bell, 2015). The informants represented a range of functional roles, such as senior business managers, project managers, R&D managers, and automation specialists. Collectively, this organizationally and functionally diverse group of informants provided a broad overview of operations working toward the delivery of autonomous solutions. This was essential to effectively undertake this study, given that the piloting of autonomous solution BMs requires co-ordination and collaboration across many organizational functions. A total of 32 interviews were conducted with informants across the two case companies, all between 37 minutes and 1 hour and 22 minutes long, with an average duration of 50 minutes. The interviews were conducted between February 2020 and January 2021. Table 1 provides an overview of the case companies and the interviewed informants.

---INSERT TABLE 1 ABOUT HERE---

Table 1: Overview of the case company informants

Company pseudonym and description	**Autonomous solution business model pilot cases**	**Informants (equivalent titles for anonymity). Number of interviews shown in [brackets]**
Rockcorp - A global provider of mining equipment and solutions - 14,000 employees - 40 billion SEK turnover	1) First BM pilot for an underground loader. Four machines in pilot. Pilot approximately half-way to completion. Pilot is operational at customer in Australia. 2) First overground haulage automation pilot for a customer in Australia. Initial pilot on 10 vehicles. Pilot preparing to expand to full fleet automation. 3) BM pilot to automate drilling rigs completed for customer in Australia. Solution being scaled to new markets and customers.	**(21 interviews):** Senior Project Manager [1], R&D Director [1], Regional General Manager [1], Business Line Manager #1 [1], Solution Owner #1 [2], Solution Owner #2 [2], Director Digital Solutions [3], Global Portfolio Manager #2 [3], Regional Manager [3], Business Line Manager #2 [2], Director Autonomous Solutions [2].
Truckcorp - A global provider of trucks and buses - 52,000 employees - 137 billion SEK turnover	4) Pilot initiative of a single first-generation autonomous truck completed. Piloted in mining operations for a customer in Australia completed. 5) Exploration of opportunity to pilot autonomous trucks at a port in the Netherlands.	**(11 interviews):** Business Development Manager #1 [2], Automation Solutions Manager [2], Head of System Design [1], Intelligent Transport Systems Manager [1], Business Development Manager #2 [1], Manager of Automation [1], General Manager [1], Manager Mature Markets [1], Project Manager Digital Solutions [1].

A semi-structured interview guide supported the conduct of interviews. This guide was continually updated as the interviews progressed, enabling us to pursue interesting deviations to the originally intended lines of questioning and to complement our data (Eisenhardt, 1989). This supported a shift in emphasis from initially exploring autonomous solutions more broadly to refining the study's focus toward a better understanding of the innovation of autonomous solution BMs. For example, in the initial interviews, informants were asked questions such as: *What are the key challenges in delivering autonomous solutions? How do you develop the* *autonomous solution portfolio?* and *How do you collaborate with the customer to improve autonomous functionality?* Although the focus on BMI for autonomous solutions was retained from the initial interviews, questioning became increasingly focused on the key activities and phases of BMI and how these shaped the development of scalable BMs. For example, informants were asked to reflect on *how the organization conceptualizes and conceives autonomous-solution business-model opportunities, how trial-and-error learning is used to counter inherent uncertainty in autonomous solution development, and how new lessons are captured and embedded in the organizational memory*. Accordingly, our interviews sought to map the company's processes, phases, and activities for learning and refining BMs through piloting. Informants were encouraged to elaborate on their answers through follow-up questions and by adopting a flexible approach to interesting and relevant deviations from the protocol (Yin, 2018). Appendix 1 includes a sample interview guide.

In order to strengthen the verifiability of the findings, data were triangulated by both data source and data type (Miles and Huberman, 1994). Data source triangulation was achieved by sampling a broad range of functional roles across two case companies. Data type triangulation was achieved by complementing interview data with an analysis of secondary data sources, such as company presentations and publicly available online materials. This effort helped to corroborate the data and provide a richer contextualization of the informants' responses. All the interviews were taped and transcribed. The transcripts were then used as the principal data source for subsequent analysis.

3.3 Data analysis

The data analysis followed an approach similar to the thematic analysis proposed by Gioia et al. with the intent of effectively identifying patterns in a large and complex data set (Gioia et al. 2013). Thematic analysis supports scrutiny of the large quantities of qualitative data obtained from the interviews, and the development of theory by identifying new themes and concepts

(Saunders et al., 2016). The first stage of analysis focused on immersion in the data by reading and re-reading the transcripts to become familiar with the material. This included highlighting key terms in the transcripts that were deemed relevant to the study. Subsequently, the highlighted segments were given a coded description that summarized the coded segments' meaning (Saunders et al., 2016). For example, informant statements, such as *"That's how you want to work because they need to improve their processes and adapt as well"*, was coded under the theme, *"supporting the customer to develop new operational routines"*. In total, 165 coded segments were created that expressed the views of the informants in words that were close to their own. Microsoft Excel was utilized to support data coding, with all the highlighted segments from the manuscripts copied into a common Excel table where they were subsequently assigned first-order codes. Although more cumbersome than using dedicated software, such as MaxQDA, this was an easily accessible, simple, and effective way to perform the data coding. The first author conducted the first-order data coding, while the entire writing team collaborated in developing the second-order themes and aggregate dimensions to support a coherent and robust analysis. Following the first-order coding, the next stage of analysis sought to identify similarities and differences between the large number of first-order codes, which then allowed us to condense them into a more manageable number of eighteen.

Informed by the literature on BMI and BM piloting, the second stage of analysis consisted of analyzing the condensed listing of first-order codes and considering their connections to theory. This led to the development of six second-order themes that bridge the first-order empirics with theory, and represent a higher-level of theoretical abstraction (Gioia et al. 2013). For example, the second-order theme of *"operational pilot execution"* builds on the first-order coding of *"testing on live customer sites"*, *"monitoring real-time KPI (key performance indicator) data"*, and *"iterative solution testing and refinement"*. These themes emerged as a result of an iterative, non-linear, abductive process of systematic combining (Dubois and Gadde

2014). Systematic combining shifts between empirical observations and theory to effectively and accurately develop a theoretical model of best fit through matching (Dubois and Gadde, 2002). For example, the second-order theme of "operational pilot execution" results from moving abductively between the empirical material of study and the literature related to BMI and BM piloting. This approach enabled us to handle the many interrelated research processes that occur when moving back and forth between data and theory to find new variables and relationships (Dubois and Gadde, 2014). We argue that this evolution has helped us orientate the study to the theoretical perspective most suited to understanding the phenomena of interest. Next, aggregate dimensions building on the second-order themes were theorized; they represent the final level of abstraction resulting from the data analysis. For example, the second-order themes of *"operational pilot execution"* and *"business model refinement"* connect to the aggregate theme of *"business model validation"*. This aggregate theme builds on the initial theorizing at the outset of the study, which identified *implementation* as the second phase of BM piloting but further refines it by building on first-order categories and second-order themes. The final step of the data analysis includes the development of a data structure as inspired by Gioia et al. (Gioia et al., 2013). The data structure illustrates the relationships between the first-order concepts, second-order themes, and aggregate dimensions, as shown in Figure 2. The purpose of the data structure is to explicitly show the connections between data and theory, thereby supporting as well as facilitating the demonstration of rigor (Gioia et al., 2013).

---INSERT FIGURE 2 ABOUT HERE---

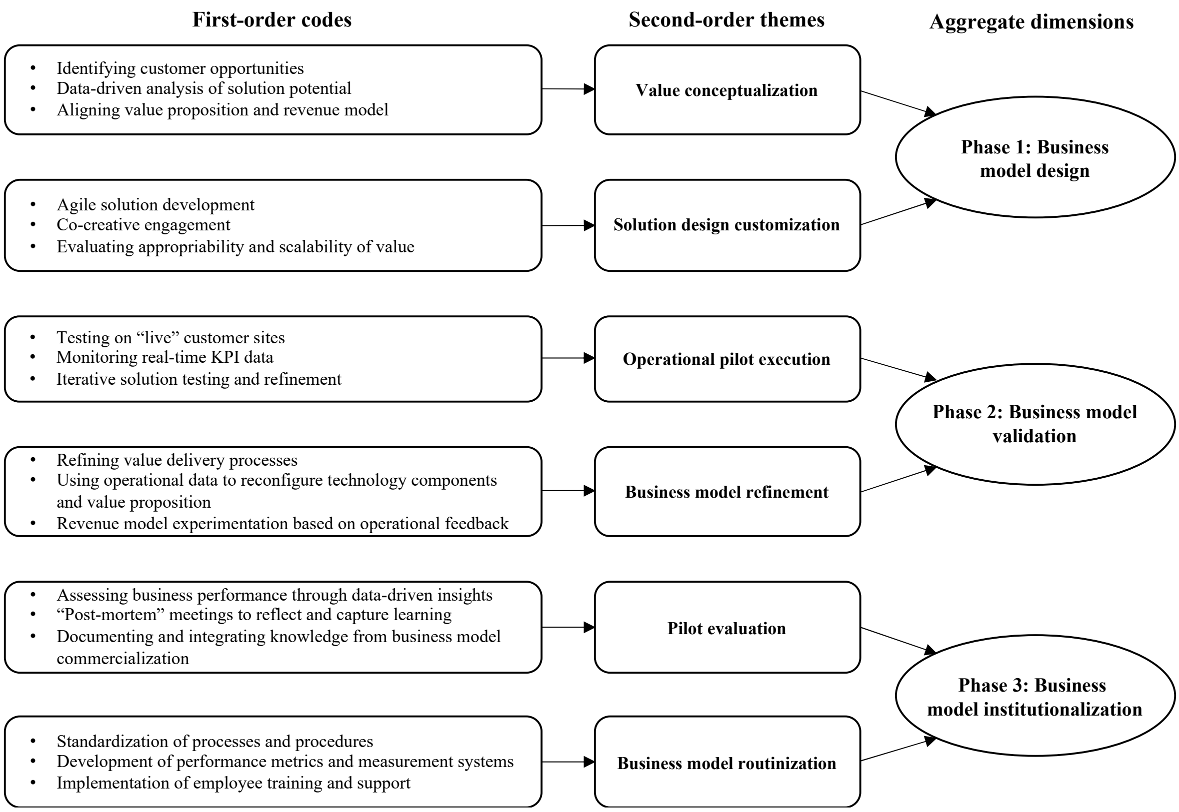

Figure 2: Data Structure

4. Findings

In this section, we present our findings, showing *how manufacturers engage in business model piloting processes for autonomous solutions*. We find that BM piloting processes follow three overall phases: 1) business model design 2) business model validation 3) business model institutionalization. Each phase includes sub-steps and activities instrumental to the learning process in creating, delivering, and capturing value from autonomous solutions.

4.1 Phase 1: Business model design

The BM piloting process starts with BM design toward the targeted piloting customer. BM design refers to the conceptualization of the offering from the perspectives of value creation, capture, and delivery to create a common understanding between the manufacturer and the customer. In other words, BM design occupies the attention of the manufacturer and the customer on the most important features of autonomous solutions in need of testing to confirm value. BM design includes concrete steps related to ***value conceptualization*** and ***solution design customization.***

4.1.1 Value conceptualization

Value conceptualization relates to the initial step of BM piloting focused on identifying customer pains and assessing the potential gains that could be unlocked by the new autonomous solution BM. This includes the activities of *identifying customer opportunities*, *data-driven analysis of solution potential*, and *aligning value proposition and revenue model*.

Identifying customer opportunities refers to engaging with customers in continuous dialogue to understand their needs. Indeed, closer customer engagement is an essential part of the balancing act of aligning the potential benefits of autonomous solutions with customer performance requirements (e.g., pains and gains). A solution owner at Rockcorp explained the importance of close customer engagement to conceptualize autonomous value:

> *"How does the customer look upon automation, what is important for them… and what is it that is driving the value? Then, we have deeper discussions with key customers requesting autonomous solutions to learn about this, what their focus is for automation."*

A crucial part of such value conceptualization is investing in learning efforts to discover the BM that fits the specific customer. A general manager at Truckcorp argued that autonomous solutions will require a different mindset in terms of what a customer relationship is. The reason is that the solution encompasses much more than just the physical equipment because the manufacturer would now be responsible for guaranteeing the autonomous operation of the equipment at the customer site. This requires consideration of new routines for performance monitoring, software updates, debugging, maintenance, and modifications in line with changing operational conditions that are central to the solution. A Rockcorp general manager commented:

> *"It is everything else around it, how you maintain it, how you operate it…how you report on it, report performance of dashboards."*

Data-driven analysis of solution potential includes activities analyzing data from the customer and the installed base of equipment. This analysis serves the critical role of identifying benchmarks for key metrics, targets for testing, and operational success criteria. Examining different alternatives serves to identify appropriate use cases where autonomous solutions would bring the most significant returns. Rockcorp reported by using data analytics to create benchmark cases, visualize solution potential, and feed these to the customer-facing organization as a basis for conceptualizing the value proposition. A business developer at Truckcorp explained: "*Whenever you can come in and show the operational people that you have found a more cost-effective way of running things then you have a case*". A director of autonomous solutions at Rockcorp described the role of data in value conceptualization:

> *"We bring in loads and loads of data from the environments that we operate in and…look at it through more of a strategy lens of connecting the mines value chain [to identify] where's the waste, where are the areas not to spend our time right now…[at this phase] it's not the customer directly talking to us but it's a customer's data."*

Aligning the value proposition and revenue model with customer performance expectations is a critical part of the piloting process. The goal is to translate the autonomous solution requirements from the customer into a comprehensive bundle of product, service, and software components. Making this assessment is a vital part of learning about cost drivers and the potential revenue models that can facilitate negotiations with the customer. For example, Truckcorp described how maintenance costs for the autonomous trucks would be much lower because they are driven more consistently. Indeed, an important aspect lies in balancing value-creation and value-capture requirements to frame a BM that is appealing to customer needs. For example, a Rockcorp regional manager described the need to engage in these uncertain assessments at an early stage:

> *"[We need to] work out how to sell it and how much it's worth and how you're going to license for it."*

4.1.2 Solution design customization

Solution design customization reflects the multi-disciplinary efforts required to develop the autonomous solution for testing with the customer. This includes activities related to *agile* *solution development*, *co-creative engagement*, and *evaluating appropriability and scalability of value*.

Agile solution development concerns activities to secure effective organization for the design and development of autonomous solutions. An essential component of such agile processes is combining internal specialists on autonomous technology (e.g., software development) with specialists on customer knowledge and related business functions. As autonomous solution development involves considerable uncertainty, agile development is critical in facilitating stepwise learning and enabling teams to move faster and make better decisions. A director of digital solutions at Truckcorp noted:

> *"Customer feedback is really important when you are developing in an agile way…getting continuous feedback from them."*

In support of agile solution development, manufacturers need to foster a *co-creative engagement* with customers to jointly learn how the autonomous solution should be configured in line with their operations. The key is creating a BM that is fair and profitable for the customer and aligns with its future strategy. For example, Rockcorp described how it engaged in monthly meetings where each party would propose improvements to the solution and jointly prioritize based on criteria, such as development speed and potential value. Indeed, piloting entailed simultaneous development of technology and the BM for customer operations, placing novel demands on the relationship with the customer. For example, a Rockcorp solution owner described the challenge in taking over a part of the customer process:

> *"Really getting into the customer's process and the whole operation, you are running their production with a software system….it's something on a totally different level."*

Evaluating appropriability and scalability of value requires the adoption of a more strategic view of the pilot to ensure scalability and to capture the value from development efforts. This requires the manufacturer to balance the costs and benefits of developing particular solutions to make sure that efforts to achieve customer focus through customization does not impinge on the scalability potential for new customers. In addition, a broader competitive analysis is required to ensure that there is patent coverage for the new solutions that are developed. Since autonomous technology is rapidly emerging, patent infringement could be a key challenge jeopardizing BMI. Such aspects require strategic assessment, as described by a global portfolio manager at Rockcorp:

> *"We do a freedom-to-operate analysis. We send our patent engineers out, looking around if there is [a competing solution] ...that we could be infringing on. We are trying to keep it very secret and try to avoid being exposed too much."*

4.2 *Phase 2: Business model validation*

Business model validation is a critical phase for testing the assumptions underlying the business model to ensure that it is viable and sustainable in the long term. It entails an iterative and data-driven approach to testing, in which manufacturers gather operational data and refine their business models over time based on real-world results. For business model validation, we identify two key activities: ***operational pilot execution*** and ***business model refinement***.

4.2.1 Operational pilot execution

Operational pilot execution relates to the implementation and trialing of the autonomous solution with the customer. This includes the activities of *testing on "live" customer sites*, *monitoring real-time KPI data*, and *iterative solution testing and refinement*.

Testing on "live" customer sites focuses on validating business value through operational testing of the solution with the customer. The manufacturer experiments with the set-up, configuration, and delivery process of autonomous solutions within the customer's production environment. Although much modeling and simulation can be performed remotely, the "live" production environment exposes the autonomous vehicle to the harsh and unpredictable conditions in which it will ultimately operate, and it provides vital opportunities for learning about the business requirements. A regional manager at Rockcorp commented on the learning potential from real-life piloting on the BM:

> *"You can do all sorts of things in the lab and back in the factory, but the real test is to put it on a mine site and run it in harsh conditions…you can learn a whole lot."*

Monitoring real-time KPI data helps to mitigate the inherent risks and uncertainties associated with the commercialization of autonomous solutions. Informants described how risk could be monitored through jointly agreed KPIs to measure and control contractual performance (e.g., autonomously drilling a certain number of meters per hour). Essentially, these KPIs represent the customer setting the requirements for a full-scale BM (e.g., "get to this target", "hit this availability"). This requires extensive operational data. For example, informants described establishing real-time data feeds to monitor objective measures of machine health (e.g., vibrations) and performance (e.g., productivity, fuel consumption), and identify the actions required to improve them. As an added benefit, increased connectivity allows extensive quantities of operational data to support learning about and continuous improvement of the autonomous solution. A vital element in continuous improvement is setting up distinct KPIs for different phases of testing and development to allow gradual expansion of the knowledge base. A Rockcorp solution owner explained:

> *"We do it in phases because we want to keep certain KPIs at certain points… as we grow the phase…we grow the amount of knowledge."*

Iterative solution testing and refinement can include refinements in technical solutions, delivery support, and revenue models. Indeed, a key aspect of activities in BM piloting concerns iterative testing and refinement of software to ensure that autonomous solutions can create the value envisioned. Informants stressed that these activities brought many challenges because software traditionally played a minor role in product deliveries for industrial manufacturers. However, this has changed significantly with the transition to delivering autonomous solutions and the consequent need to learn new routines. For example, as emphasized by a project manager of digital solutions at Truckcorp, iterative experimentation and testing of software are important elements in a learning process to aid the development of novel and customized autonomous applications.

> *"We need to engage in releasing small [software] packages, small bits of functionality, testing them together with the customer."*

4.2.2 Business model refinement

Business model refinement relates to converting experiential knowledge from BM piloting into adaptations of the BM. This includes the activities of *refining value delivery processes, using operational data to reconfigure technology components and the value proposition*, and *revenue model experimentation based on operational feedback*.

Refining value delivery processes is a key learning opportunity derived from pilot implementation. The objective is to refine processes for value delivery by clarifying roles, routines, and on-site capabilities for both the provider and the customer. To ensure value delivery, manufacturers need to provide dedicated and specialized autonomous solution support for the customer by establishing a solution delivery organization with appropriate resources. Indeed, the increased use of digital technologies and the requirement for relational engagement necessitates new customer-centric support processes to realize the value delivery of autonomous solutions. For example, the novelty of autonomous solutions creates significant potential for errors and design flaws that could be very costly given the embeddedness of autonomous solutions in customer operations (i.e., risk of process downtime). As a result, it requires the establishment of continuous software service support for customers. A director of autonomous solutions at Rockcorp explained how the organization had to invest heavily in customer support to improve the availability of its autonomous solutions:

> *Every night at six o'clock and every morning at 6 am, we were on a call with them (the customer)…(then) in our evening and their morning, we could say, "Hey, look, we found the bug. We've identified it, and we'll have a fix due tomorrow," or "We've already fixed it and there's software sitting in your inbox."*

Using operational data to reconfigure technology components and value proposition is an important activity related to increasing the performance of the autonomous solution. For example, a business line manager at Rockcorp commented that they had to develop a higher load capacity for the autonomous vehicles to compensate for their lower operational speeds, thereby providing an acceptable output level. However, most reconfigurations are shaped by the continuous analysis of machine data used to inform software development and further improve the performance of the autonomous solution. A business line manager at Rockcorp confirmed that far-reaching improvements in machine performance could be achieved by using operational data to optimize machine operation in line with the site conditions:

> *"Data-based analysis that we did with the customer to prove that we were getting better and better and better every month and eventually (we) cracked it".*

Revenue model experimentation based on operational feedback recognizes that revenue models are shaped differently depending on the target market. For example, a director of autonomous solutions at Rockcorp reflected on the need for customer-focused development of revenue models for autonomous solutions. Revenue models (e.g., outcome-based, subscription) may differ depending on customer characteristics. A common theme among respondents was that adjusting the autonomous solution revenue model for specific customers has the potential to realize new customer value. For example, a Truckcorp business development manager affirmed the benefit of balancing value creation and value capture for customers:

> *"Depending on…the size of the customer, the focus of the customer, how can we adapt our business model? How can we adapt the payment model in terms of ensuring that we create as much value for our customers as possible?"*

4.3 Phase 3: Business Model Institutionalization

BM institutionalization represents the conscious and coordinated review of BM performance from piloting, resulting in the explicit embedding of new knowledge in organizational memory and routines. In BM institutionalization, the industrial vehicle manufacturer engages in two activities: ***pilot evaluation*** and ***business model routinization***.

4.3.1 Pilot evaluation

Pilot evaluation is concerned with assessing commercial and technological performance and deriving lessons from autonomous solution pilots. The pilot evaluation phase includes *assessing business performance through data-driven insights, "post-mortem" meetings to reflect and capture learning,* and *documenting and integrating knowledge from business model commercialization*.

Assessing business performance through data-driven insights is related to the systemic capturing of data-driven insights for the purpose of reviewing the BM and autonomous solution performance over time. The focus is to capture lessons, uncover potential pitfalls, and identify best practices across all aspects of the BM in relation to how value is created, delivered, and captured. Consequently, data quality, data transparency, and data flow between the provider and customer organizations are instrumental in facilitating pilot evaluation to deliver autonomous solutions at Truckcorp. A project manager of digital services explained:

> *"We share a lot of information…it's to both our benefit (customer and provider) to share information and to share insights."*

"Post-mortem" meetings to reflect and capture learning represent a vital part of pilot evaluation through the conduct of end-of-project evaluations (e.g., post-mortem), where project meetings are held to capture learning across all involved actors and functions. Informants described bringing together representatives from the customer organization, delivery partners, and different units in their own organization to do this. A solution owner at Rockcorp remarked that the focus of post-mortem project meetings was to review what had happened during the pilot and how the BM could be improved. However, informants suggested that pilot evaluation should be a routine practice, even before the formal post-mortem meetings. For example, Rockcorp described how it coordinated periodic meetings for the exchange of intra-organizational best practices to reflect and capture learning over the project's duration. This agile approach to BM assessment is essential to stimulate learning in the uncertain and co-creative environment of autonomous solution implementation. Here, new lessons can be

regularly captured and acted on. A business line manager at Rockcorp described the central role of review meetings to facilitate BMI on a global scale:

> *"We have fortnightly meetings with the [back end] to go through…lessons [from the project]. The dealings with the [back end] are then distributed to our respective [front-end units] so they don't experience the mistakes that we've experienced."*

Documenting and integrating knowledge from business model commercialization is a key activity in pilot evaluation. It includes the integration of knowledge by explicitly assigning responsibility for capturing learning to specific organizational roles. For example, a business line manager at Rockcorp noted that the automation lead managers are responsible for coordinating learning between different organizational units. Such roles are critical to avoid knowledge being trapped in organizational silos. A practical example of capturing new knowledge relates to the development of revenue models. For example, informants contended that, due to the uncertainty over complex revenue models and their associated cost structures, it was challenging to set the pricing mechanism accurately. One way that the back end used to address this challenge was by embedding lessons from the cost structure of ongoing projects and updating pricing lists on a regular basis. Similarly, the knowledge obtained can be integrated into updated licensing models. For example, Rockcorp changed from a "right to develop" to a "right to use" licensing arrangement based on a recommendation to increase safety by one of its automation partners. Changing the licensing model ensured that the customer's equipment had the required safety protocols.

4.3.2 Business model routinization

Business model routinization relates to the standardization and formalization of BM activities based on lessons learned from pilot evaluation. This includes activities related to *the standardization of processes and procedures*, *development of performance metrics and measurement systems,* and *implementation of employee training and support.*

Standardization of processes and procedures is necessary to create a uniform baseline for delivering autonomous solutions. One way in which this is done is through the creation of automation project blueprints and corporate publications. Corporate publications serve the purpose of disseminating routinized information across the organization, and blueprints define how autonomous solutions should be developed and delivered based on best practice. In essence, the blueprint helps to reduce the inherent uncertainty associated with delivering autonomous solutions, acting as a BM template to guide successful commercialization. A Rockcorp director of autonomous solutions commented:

> *"It's written in a way that it's built off of good things and mitigating bad things that have happened before, but it's not written so tight that it won't work in one country like South Africa, and it'll work in the US, two completely culturally different environments."*

Development of performance metrics and measurement systems refines the commercialization processes for autonomous solutions and best practice for customer involvement. Indeed, informants stated that the performance of autonomous solutions is highly contingent on securing the commitment of customers by showing them the value and motivating them to learn. An example of best practice uncovered in the BMI process concerns the strategic use of global data benchmarking analysis in initial sales meetings and during the project. Benchmarking data from the manufacturer's global fleet of connected machinery supports the manufacturer in educating and explaining to customers their operational pain points, improvement possibilities, and prospective investment steps. Informants described the importance of reviewing and selecting the KPIs that will be used in future sales processes based on best practices from earlier automation experience. For example, a Rockcorp senior project manager commented on the benefits of learning from prior initiatives:

> *"We had some experience especially when it comes to KPIs for example, that it's really good when you're starting to measure and trying to put up statistics…That is something that we used to get help with from the [prior] automation project."*

Another vital function of BM routinization relates to the *implementation of employee training and support*. One way in which this has been done is through the establishment of training centers or "boot camps". Informants described how the boot camps have acted as a way of institutionalizing knowledge by assimilating diverse lessons and educating both employees and customers. Heavily involved in their creation and development, a Rockcorp director of autonomous solutions commented on their merit:

> *"It's a very hands-on intensive week to a week and a half here to start them off right…then we'll typically send them somewhere else in the world to watch one of their peers…(he learned a lot) so that when he went back to his own mine, he'd been through boot camp, and he'd already seen somebody else do it."*

Furthermore, global meetings for coordination and learning facilitate knowledge sharing across the organization and help to break traditional silos. This is a critical activity for the successful scaling of autonomous solutions across global markets with varying customer needs and business practices.

4.4 A framework for business model piloting of autonomous solutions

Based on our findings, we present a framework for BM piloting in the context of autonomous solutions (see Figure 3). The framework illustrates how industrial manufacturers engage in a three-phase process of BM piloting for autonomous solutions: i) business model design, ii) business model validation, and iii) business model institutionalization. The BM piloting process begins with an input in the form of a new BM concept often relating to a new technology – for instance, autonomous solution technology. Following this, the BM pilot moves through the three phases before reaching the process output. The output from BM piloting is increased knowledge of the appropriate configurations of value creation, value delivery, and value capture. These BM dimensions have been refined throughout the BM pilot and lead to the second output of a commercial proof of value that can subsequently be scaled to other use cases or customers. In each phase, iterative cycles of activities ensure the integration of activities, roles, resources, and knowledge that gradually refine the BM piloting process toward developing a scalable BM. Although we have chosen to present the framework in a sequential fashion in the interest of clear communication, we recognize the importance of viewing BM piloting as a dynamic, iterative, and complex practice where experiential learning builds cumulatively through the different piloting phases. Beyond identifying phases and key activities, we uncover three key principles for BM piloting that underly experiential learning within the BM piloting process: *lean learning*, *systematic evaluation*, and *scaling preparation*. We contend that these principles should be considered throughout BM piloting, and we describe them in greater detail below.

---INSERT FIGURE 3 ABOUT HERE---

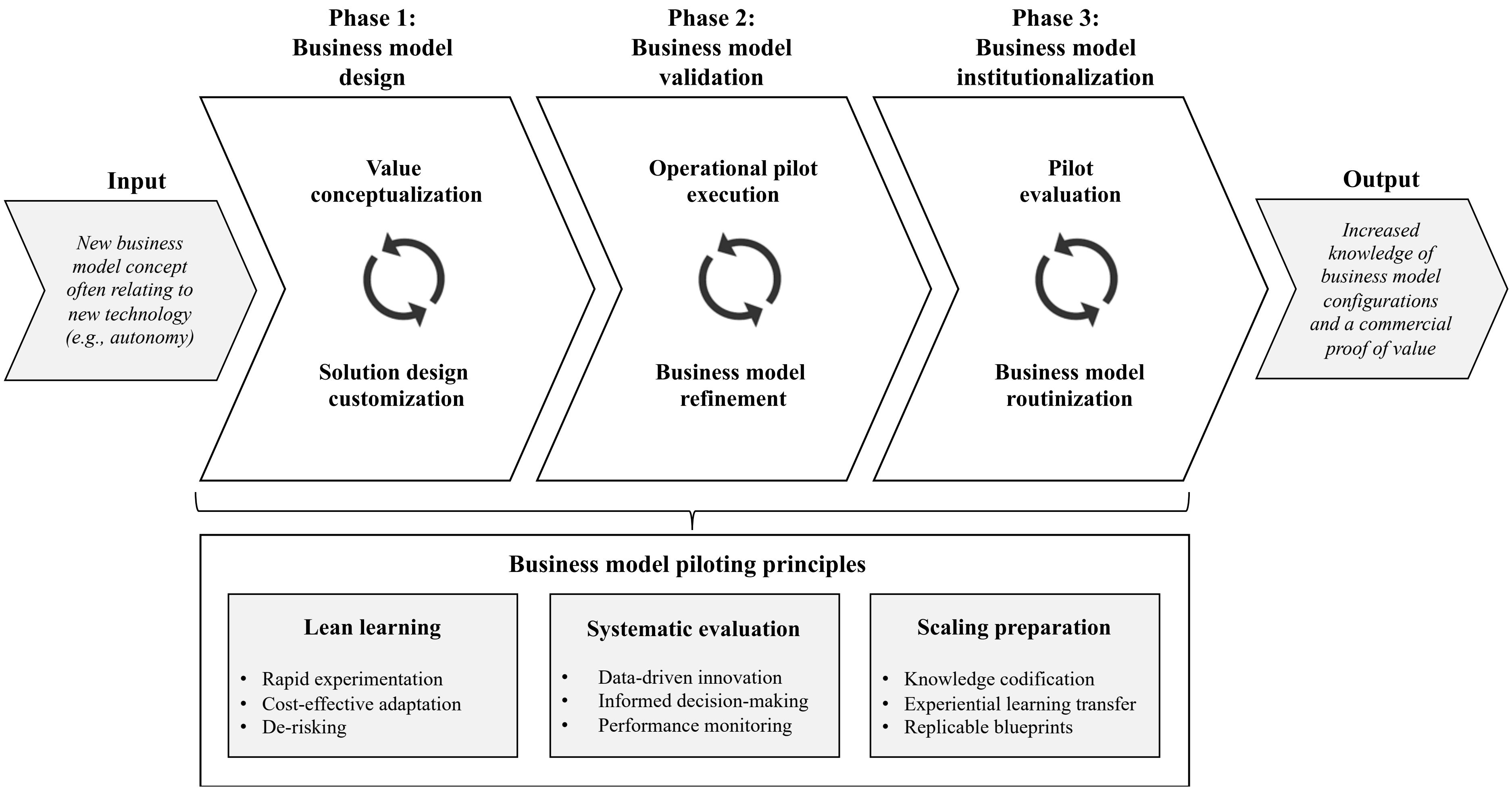

Figure 3: A business model piloting framework for autonomous solutions

First, BM piloting embodies a *lean learning* approach or what could also be referred to as an efficient learning approach. BM piloting is a lean and pragmatic approach to commercializing novel BMs that places importance on de-risking and validating assumptions with minimal resources within a specific target market/customer group. This includes the iterative development of compelling value propositions, along with delivery routines and revenue models that align with the value proposition. Consequently, BM piloting ensures that the emerging BM is finely attuned to meet the needs and context of the target market (e.g., a key customer). This is achieved by concentrating on pivotal features around which the BM will be designed and by using customer feedback to evolve and refine them. By embracing a lean BM piloting approach, businesses can rapidly and cost effectively experiment with new ideas, thereby reducing the risk of failure and enhancing their capacity to adapt (e.g., by reimagining value propositions). Moreover, a focus on lean or efficient learning encourages manufacturers to prioritize the most crucial assumptions for testing, ensuring they channel their resources into the most impactful areas. This approach can assist manufacturers in streamlining their learning process, boosting their capability to iterate and fine-tune their BM.

Second, BM piloting inherently centers on a *systematic evaluation* of the different BM elements. By systematically evaluating data-driven insights in each stage of the process, weaknesses and inefficiencies in the BM can be identified and addressed before they become significant problems. This experiential learning provides decision makers with a clear understanding of what works and what does not, enabling them to make informed choices on which BM design choices to keep, modify, or abandon based on concrete data from commercial application. Additionally, a continuous focus on evaluation enables manufacturers to experiment and test critical assumptions for the value-creation, value-delivery, and value-capture mechanisms. By monitoring data to identify potential risks and challenges, businesses can quickly adjust their BMs and underlying processes to minimize negative impacts. Hence, systematic evaluation plays a vital role in fostering a more data-driven approach to BMI decision making.

Third, *scaling preparation* is a central feature of BM piloting. Scalability is considered throughout the BM piloting process. In the BM design phase, tension between scalability to other customers versus customization to address unique customer requirements, are continuously weighed against each other. During the business model validation phase, scaling preparation is visible in the selection of KPIs that reflect a desired future performance of the autonomous solution BM. Finally, in the BM institutionalization phase, scalability is pursued through the codification of knowledge and development of BM routines and blueprints that can support future implementation. In other words, scaling preparation is achieved by leveraging learning from an individual autonomous solution pilot and reflecting this in the BM. This requires a focus on the transfer and consolidation of experiential learning from the BM pilot to support the realization of scalable BMs (e.g., the potential to commercialize beyond initial customer/market segments). For example, the studied industrial manufacturers leverage learning by developing standardized routines, such as project delivery methodologies based on best practice, new sales routines informed by global vehicle fleet insights, and targeted knowledge dissemination. However, scaling BMs beyond individual pilots requires more than a functioning value proposition but also a functioning delivery organization and revenue model. This is a critical factor distinguishing BM pilots from other piloting initiatives, such as product pilots that tend to focus on developing the value proposition. For instance, after Rockcorp's first successful overground pilot for autonomous haul trucks, it signed a deal to provide autonomous capability to all the haul trucks in a customer's fleet based in Australia, making it the world's largest autonomous mine. The decision to scale up was based on the successful pilot of a smaller number of vehicles, where the technical performance of the solution, delivery organization and overall revenue model were refined. The successful completion of the pilot subsequently acted as proof of value for scaling up.

6. Discussion

6.1 Theoretical contributions

This study has sought to advance understanding of *how manufacturers engage in business model piloting for autonomous solutions.* Our study investigates a novel context of industrial vehicle manufacturers engaged in digital BMI at the most advanced level (Kohtamäki et al., 2019; Sjödin et al., 2020a) by developing and commercializing autonomous solution BMs (i.e., the manufacturer-operated self-driving industrial vehicles). Engaging in BMI for autonomous solutions represents an uncertain and complex learning challenge (Sandvik et al., 2021), which necessitates successive rounds of experiential learning through BM piloting to achieve success (Geissdoerfer et al., 2022; McGrath, 2010; Teece, 2010). We follow Geissdoerfer et al. in defining BM piloting as "a semi-controlled launch of the business concept in parts of the target market, testing all elements of the business model within a smaller scale and easier to analyze setting to test contingencies, costs, and feasibility, at reduced initial investment and risks compared to the implementation of a full-scale project" (Geissdoerfer et al., 2022, p. 571). We extend their contribution by conceptualizing BM piloting as an dynamic and evolving experiential learning process (Berends et al., 2016; Sosna et al., 2010). Our core contribution has been to illuminate the phases, steps, and micro-level activities of BM piloting for autonomous solutions in an industrial B2B setting. Our findings offer several implications for research into the organization of BM piloting.

First, *we contribute to the literature on BMI by illuminating the phases, steps, and key activities of BM piloting.* In developing the BM piloting framework, this study responds to the call to cultivate an understanding of the complex, dynamic, and evolving BMI processes (Berends et al., 2016; Chen et al., 2021; Foss and Saebi, 2016; McGrath, 2010; Morris et al., 2005; Sosna et al., 2010). Specifically, we identify three phases of BM piloting for autonomous solutions: i) *business model design*; ii) *business model validation;* and iii) *business model institutionalization*. The framework details a gradual progression of experiential learning across the BM piloting phases, showing how successive rounds of trial-and-error learning contribute to the development of a proof of value that can support BM scaling. Critically, our BM piloting framework builds on earlier work focusing on product or technical pilots, revealing a multi-dimensional piloting process that addresses each of the three BM dimensions of value creation, value delivery, and value capture. Despite providing valuable guidance, prior research focusing on technical pilots has lacked the more strategic view required for innovation BMs (see Glass, 1997). We find that BM piloting is radically different to product or technological pilots, especially in the case of autonomous solutions, requiring concurrent development of novel technologies to configure the value proposition, as well as appropriate value-delivery and value-capture mechanisms. Our framework contributes to a better understanding of this strategic and multi-dimensional piloting perspective by emphasizing key activities in which industrial manufacturers engage for the purpose of BM piloting of autonomous solutions. Although our BM piloting framework is presented in a linear and sequential fashion, we emphasize the cumulative, incremental, and iterative nature of BM piloting activities. To illustrate, BM institutionalization (e.g., formalized routines) has an important role to play in nurturing relearning in the next iteration of business-model design and business-model validation phases. We espouse previous research that finds that organizations operate in continuous cycles of trial-and-error learning when innovating new BMs (Berends et al., 2016). Hence, the BM is in a constant state of renewal or "permanently in a state of transitory disequilibrium" (Demil and Lecocq, 2010, p. 240). However, we emphasize the need for concise institutionalization of learning from BM piloting processes. We contend that this perspective on how firms institutionalize learning from BMI in the form of new routines and practices is a vital part of understanding successful BM piloting. By developing the BM piloting framework, we strengthen the conceptual foundations of the BMI literature, providing a lens capable of illuminating foundational logics and key activities in complex BMI.

Second, *we contribute to the emerging literature on digital business model innovation by undertaking an in-depth investigation of the critical factors in achieving success with BM piloting for autonomous solutions*. Kohtamäki et al., in their special issue focusing on autonomous solutions, recognize the importance of intensively investigating the BM's need for advanced digital offerings (Kohtamäki et al., 2022). We concur that industrial manufacturers shifting to autonomous solutions represent a complex case of BMI (Thomson et al., 2021), not frequently encountered in a literature stream that is focused on e-business innovation (Zott et al., 2011). Indeed, research on the BMI of autonomous solutions is scarce (Leminen et al., 2022), with little known about the complex changes underlying BMI. Thus, our study contributes by expanding on existing BMI research to provide in-depth empirical insights into BM piloting in a B2B context within the traditional manufacturing sector. We find that BMI for autonomous solutions differs from product innovation in several ways. These are related to designing and developing the solution on-site in live-production conditions, developing a higher degree of customization to meet customer operational needs and providing jointly agreed performance or outcome guarantees based on the solutions offered. For example, to develop, test, and implement highly advanced technological solutions in live-production environments, BMI of autonomous solutions requires incumbent industrial manufacturers to undergo a fundamental organizational shift from products to the provision of highly customized solutions. The extensive and fundamental BM changes required by incumbent industrial manufacturers to deliver autonomy are not representative of the comparatively simple and more frequently represented examples of business-to-consumer (B2C) BMI, which are present in new digital enterprises (Demil and Lecocq, 2010; Morris et al., 2005) or technologically simpler B2B examples (Sosna et al., 2010). We contend that experiential learning is critical to the successful development of novel and advanced technologies required for applications such as autonomous solutions. We find three key principles that support experiential learning during the BM piloting for autonomous solutions: *lean learning*, *systematic evaluation*, and *scaling preparation*. Adhering to these principles throughout the BM piloting phases supports industrial manufacturers in fully embracing and benefitting from an experiential learning approach when innovating their BM. Accordingly, we argue that this study helps to articulate an alternative view of BMI beyond the scope of digital ventures or simpler B2C and B2B offerings presently characterized in the BMI literature.

6.2 Managerial implications

Our study carries several managerial implications for senior managers in R&D, operations, and business development positions in industrial manufacturing firms who are responsible for driving autonomous solution BMI. In particular, we argue that our framework enhances understanding of how BM piloting can help manufacturers to succeed and profit from new technologies, such as autonomous solutions. Below, we provide three recommendations.

First, we offer encouragement and guidance to industrial manufacturers to engage in the continuous trial and error of small adaptations, rather than the pursuit of a rigid innovation program, as the most advantageous way to move BMI processes toward realizing scalable autonomous solutions. Specifically, the proposed BM piloting framework developed in this study can guide senior managers through the experiential learning approach needed for the development of autonomous solution BMs. Indeed, we urge managers to grasp the importance of experiential learning in addressing the inherent uncertainty associated with developing advanced and novel technologies and, at the same time, plan how best to deliver and price them. Attempting to finalize the conceptualization and design of these elements from the outset of a new initiative is neither desirable nor practicable.

Second, we encourage managers to create standardized learning resources and formalized routines to overcome the challenges of transferring knowledge for the purpose of scaling autonomous solution BMs. In this regard, it is important to emphasize that the knowledge required to engage in complex learning processes for the BMI of autonomous solutions is not equally distributed across the different organizational units of manufacturing firms. Certain units, by virtue of their customers and projects, are considerably more experienced and capable than others in driving local efforts to promote BMI. Thus, starting BM experimentation in selected customer-facing business units by promoting strong customer relationships, developing promising autonomous use cases, and building a skilled delivery organization would be highly desirable. Based on this initial experience, industrial vehicle manufacturers should prioritize the creation of standardized routines for knowledge transfer across different organizational units to support the scaling of autonomous solution BMs.

Finally, we recommend that successful methods and approaches for BMI adopted from B2C contexts may need more careful modification for them to work in an industrial B2B setting. Although industrial vehicle manufacturers engage in trial and experimental learning to develop, test, and implement autonomous solutions, it is a far cry from the mantra of "fail fast, fail cheap, and fail early". Instead, we find that successful technology-driven innovations in this context are built on hard-earned trust through a relational engagement between manufacturer and customer seeking to co-create value. For example, the safety and productivity consequences of potentially malfunctioning autonomous solutions can create a high-risk delivery environment. This will necessitate a strong customer relationship supported by advanced analytics that can demonstrate performance in accordance with agreed KPIs. Thus, a customer-centric approach to BMI is of particular importance for the BM piloting processes of autonomous solutions.

6.3 Limitations and further research

The present study builds on the findings from two industrial equipment manufacturers engaged in the BM piloting of autonomous solution BMs. This provides rich data but reduces the scope for cross-case learning. Despite the inclusion of examples from several automation projects, we acknowledge that including cases from additional companies and other industries would help to further untangle complex BM piloting processes. In addition, we advocate research on the role of different organizational units in a rapidly changing industrial service environment. For example, recent trends toward increasing digitalization, sustainability, and circularity necessitate significant innovation not only in BM design but also in the roles, structures, and operating models of firms.

Furthermore, the industrial manufacturer perspective adopted in this study could be further complemented with an external perspective from different ecosystem actors – such as digitalization and automation suppliers – and from customers, and how they engage with and contribute to the BM piloting activities required for the BMI of autonomous solutions. In particular, the customer perspective could receive enhanced emphasis in future studies to better understand how various functions within the receiving organizations contribute to the processes of BM piloting. This relational buyer–supplier perspective is of marked importance for autonomous solutions, which must be closely integrated into customer business operations to deliver the promised benefits. Finally, we surmise that ample research opportunities remain to further investigate the challenges of scaling autonomous solution BMs. Autonomous solutions constitute an exponential and cutting-edge technological opportunity whose successful commercialization and implementation is representative of a new industrial frontier that demands fundamental changes in manufacturing operations.

Appendix 1. Sample Interview Guide

Sample of questions and themes from an earlier iteration:

1) Personal background
    a. What is your role?
    b. How are you involved in the innovation of autonomous solutions?
2) Case background
    a. What is the case?
    b. What is its status?
    c. How is it unfolding?
    d. What are the challenges?
    e. How do you solve them?
3) Business model
    a. What is the value proposition?
    b. How do you charge for it?
    c. How is the solution delivered?
    d. How does it differ from other business models?

Sample of questions and themes from a later iteration:

4) Early phase conceptualization
    a. How did it unfold?
        i. What were the objectives?
        ii. What were the key activities?
        iii. What were the key challenges?
        iv. Can you provide examples?
5) Trial and experimentation
    a. How did it unfold?
        i. What were the objectives?
        ii. What were the key activities?
        iii. What were the key challenges?
        iv. Can you provide examples?
6) Institutionalizing learning
    a. How did it unfold?
        i. What were the objectives?
        ii. What were the key activities?
        iii. What were the key challenges?
        iv. Can you provide examples?

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