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Autonomous vehicle solutions and their digital servitization business models

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ABSTRACT

Digitalization and automation play essential roles in how companies create value for their customers in emerging industries, including autonomous vehicle solutions (AVSs) and automated driving. In this study, we explore digital servitization business models in the context of AVS ecosystems. We utilize publicly available company data to discuss cases that illustrate the emerging business models of AVSs in the business-to-business (B2B) context. We contribute to research on autonomous solutions by identifying four types of AVSs: (i) advanced-data-assisted solutions, (ii) semiautonomous platooning solutions, (iii) autonomous demarcated solutions, and (iv) autonomous swarmed solutions. We advance digital servitization and business model research by revealing business models associated with those AVSs, namely: (i) safety as a service, (ii) efficiency as a service, (iii) capacity as a service, and (iv) flexibility as a service. By combining these three fields of research, we enrich the digital servitization research and address the current gap in research on autonomous solutions by focusing on business models. Our analysis enables the development of novel conceptual tools for autonomous solutions and servitization driven by digitalization. Moreover, we suggest the concept of business model fluidity to explain rapid and autonomous business model changes and adaptation to different use contexts and customer contexts.

1. Introduction

New technology development is driven by increased connectivity and autonomy of solutions, contributing to the rise of Internet of Things (IoT), Industry 4.0, and artificial intelligence, among other advancements (Iansiti and Lakhani, 2014; Leminen et al., 2020; Porter and Heppelmann, 2015; Van Brummelen et al., 2018). Autonomous vehicle solutions (AVSs) comprise another area of business that relies on such technological advancements. AVSs refer to 'autonomous vehicles', 'driverless cars' and 'autonomous driving' (cf. Anderson et al., 2016; Bimbraw, 2015; Campbell et al., 2010; Darling, 2011; Fritschy and Spinler, 2019; Bridgelall and Stubbing, 2021), in other words, self-driving vehicles that sense their surroundings, location, and space, and that are operated without human intervention or control.

Hitherto, research on AVSs has focused on various technologies and solutions rather than advising researchers and practitioners on business aspects related to the servitization process, business models, or emerging ecosystems related to AVSs (Lu and Shladover, 2014; Ghosal et al., 2021). Case studies and typologies in the area are sparse even though the development and mass production of AVSs is expected to revolutionize transportation mobility and safety (SAE International, 2018). AVSs as a research field offer a plethora of opportunities to conceptualize both solutions and their associated digitalized services (Narayanan et al., 2020; Thomson et al., 2021). Concurrently, new research avenues within servitization are widely revealed (Kowalkowski et al., 2017; Rabetino et al., 2018; Raddats et al., 2019) and highlight, for instance, the need to stimulate research on digital servitization (Coreynen et al., 2020; Frank et al., 2019) and embed digitalization beyond the boundaries of a single company (Kohtamäki et al., 2019).

Business models based on digital servitization in the AVS context are to date scarcely studied. Considering the potential of AVSs for disruption (Thomson et al., 2021), research on digital servitization business models

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in business-to-business (B2B) markets faced by increasing adoption of AVSs is highly important. Firms improve efficiency in manufacturing and operations, seek better business performance and competitive advantages, in addition to developing novel business models, new modes of value creation, and industrial customer satisfaction because of technological advancements in autonomous solutions. Research on digital servitization emphasizes the relationship between technology and business models instead of merely examining the technological aspects of digitalization (Kohtamäki et al., 2019).

A business model in its simplest form describes a firm's value-creation logic (Ghaziani and Ventresca, 2005). Digital servitization business models involve multiple actors and should thus be studied in the context of ecosystems, which are networks of firms engaged in joint value creation (Overholm, 2015). The building blocks of digital servitization business models are customization (from standardization to customization of offerings), pricing (from product pricing to pricing of outcomes), and digitalization (from mere monitoring to autonomous solutions) (Kohtamäki et al., 2019). However, research on digital servitization business models in the context of AVSs is scarce. Hence, focusing on the relationship between AVSs and digital servitization can increase our understanding of: (i) business model design, (ii) ecosystem orchestration, and (iii) ecosystems in transformation.

In summary, we identify several research gaps in the research fields of autonomous vehicles and digital servitization, particularly the needs to: (i) shift the focus of AVS research from technology to business models and joint value-creation in ecosystems, (ii) provide empirical analysis of how firms address servitization in technology-intensive industries, and (iii) understand the different contexts in which digital servitization is enacted, including their underlying business models and ecosystems, especially in the B2B sector. Based on the scattered and scarce studies of AVSs from the business perspective, we investigate the types of AVSs and aim to identify associated digital servitization business models, thereby specifically addressing the third research gap. We address this gap by exploring AVS business models through the lenses of digital servitization. We aim to introduce a conceptualization of the types of AVSs and identify their associated digital servitization business models to understand how AVSs can create and capture value from connectivity and autonomy. Our research questions are as follows:

RQ1: How can different types of AVS be conceptualized?

RQ2: What types of digital servitization business models do AVSs give rise to?

Our study contributes to research on digital servitization, business models, and autonomous solutions. The key theoretical contributions are threefold. First, we conceptualize a framework to identify and classify AVSs and we introduce four digital servitization business models. Second, we identify a taxonomy of four current AVS types along with four enacted and emerging digital servitization business models related to those AVS types. Third, we introduce the concept of fluidity in digital servitization business models, which can include, for example, when a swarm of autonomous vehicles can make autonomous decisions on how to both organize themselves and adapt the business model to a particular situation.

The remainder of the article is structured as follows. First, we provide a conceptual background explicating the core concepts of the article. Second, we explain the methodology and provide a classification and initial conceptualization of AVSs. Third, we analyze publicly available company case examples to reveal four types of AVS and their associated digital servitization business models. Fourth, we discuss the results, suggest theoretical and managerial contributions, identify limitations of the study, and provide ideas for further research.

2. Conceptual background

In this section, we review the literature related to the core concepts of the study, namely AVSs and digital servitization.

2.1. Autonomous vehicle solutions

Technological advancement in the early 21st century has fostered the development of AVSs, including driverless cars and trucks (Gurumurthy and Kockelman, 2020; Hudson et al., 2019). A driverless car, also termed as a self-driving car or an autonomous car, is a robotic vehicle that operates without human intervention (Kaur and Rampersad, 2018; Lee et al., 2019; Liu and Xu, 2020). AVSs are considered part of the ongoing technological development stream linked to robots and other complex autonomous solutions (Hudson et al., 2019). Inspired by prior studies in autonomous solutions (Broggi et al., 2013; Seo et al., 2016; Van Brummelen et al., 2018; Thomson et al., 2021) and digital servitization (Coreynen et al., 2017; Narayanan et al., 2020), we regard an AVS to have the following characteristics: (i) capability to sense locations and spaces, (ii) capability to move and interact with the surroundings to fulfill value-producing activities, and (iii) inclusion of digitally enabled services in autonomous operations.

Contemporary AVS features are still quite limited. For instance, automotive manufacturers across the world, such as BMW, Honda, Ford, Mercedes, Hyundai, Volvo, and Audi have developed different technologies for self-parking, traffic-aware cruise control, automatic lane changes, and semiautomatic navigation for AVSs (Penmetsa et al., 2019; Eriksson and Stanton, 2017; Lee et al., 2019; Marletto, 2019). However, fully autonomous driving still requires a lot of development, along with changes in traffic laws, regulations, and interpretation of liabilities. Nonetheless, the willingness of leading automotive industry players to invest in AVS development indicates that autonomous solutions will become a disruptive innovation in transportation (Liu and Xu, 2020).

Although automotive industry players and technology firms such as Google are investing heavily in research and development on AVSs, fully autonomous vehicles are unlikely to become mainstream anytime soon (Hudson et al., 2019; Kaur and Rampersad, 2018; Li et al., 2019). Marletto (2019) notes that scholarly studies on the topic typically make no statement about the expected time horizon of a wide-scale adoption of AVSs or place it broadly sometime between 2030 and 2050. There are numerous technical, legal, ethical, and societal issues to solve before a wide-scale adoption of AVSs can take place. For instance, the need for cybersecurity to prevent hacking of AVS communications systems becomes important as AVSs shift from independent autonomous systems to cooperative, connected vehicle systems (Shladover, 2018). Also, regulations, standards and interpretation of liabilities are essential for building compatible systems and settling legal disputes in cases of malfunction and accidents (Mallozzi et al., 2019; Osório and Pinto, 2019). In addition, when autonomous cars and trucks replace the need for taxi drivers and truck drivers, there may be negative impacts on the labor force (Hudson et al., 2019; Li et al., 2019; Westerlund, 2020).

2.2. Digital servitization

The term 'servitization' refers to combining products and services (Kuijken et al., 2017) into a solution that provides a full continuum of product–service systems (Baines and Lightfoot, 2013). This may require the firm to reposition itself in the value system or ecosystem to be capable of offering additional services, which are often produced by other firms in the value system (Mol et al., 2005; Neely, 2008). As noted by Brax and Visintin (2017), servitization invites change to the scope and types of firms' market offerings (de Blok et al., 2010), business models and their orientation (from product-focused to service dominant or customer-focused) (Ng and Wakenshaw, 2017; Svahn et al., 2017; Palo et al., 2019), as well as structures, capabilities and relationships on the organizational and network levels (Coreynen et al., 2020). Related concepts include service transition (Fang et al., 2008; Oliva and Kallenberg, 2003; Ulaga and Loveland, 2014), service addition strategy (Matthyssens and Vandenbempt, 2010), business logic (Leminen, 2001),

and service infusion (Gustafsson et al., 2010; Kowalkowski et al., 2013), indicating that research on servitization remains fragmented.

Most recently, an emerging stream of research on servitization has emphasized the focus on digital technologies. Servitization and digitalization are distinct but intertwined concepts (Frank et al., 2019) that converge under the umbrella concept of 'digital servitization' (Lerch and Gotsch, 2015; Vendrell-Herrero et al., 2017; Raddats et al., 2019). Digital servitization is defined as offering solutions using digital technologies (Kohtamäki et al., 2019; Sklyar et al., 2019a). Digitalization is a technical process that converts analogue information into digital form (Tilson et al., 2010) and digital channels (Weill and Woerner, 2013). It is considered an enabler of servitization (Coreynen et al., 2017; Sklyar et al., 2019a), and some scholars treat digital technology as an integral part of the total offering (Vendrell-Herrero et al., 2017; Kohtamäki et al., 2019).

Digital servitization drives the transition towards smart systems by combining products, services, and software. It enables value creation and capture through core digital features, namely monitoring, control, optimization, and autonomous function. Digital servitization also encompasses a research stream on the intersection of servitization and IoT, the latter being an enabler of the former (Barrett et al., 2015; Lerch and Gotsch, 2015). Ng and Wakenshaw (2017) describe this phenomenon as a system of uniquely identifiable and connected products (or things) that create an internet-like structure. It enables a real-time flow of sensing, operation, and location data. Thus far, studies have mainly examined remote monitoring of product performance (Rymaszewska et al., 2017) and product operations (Ardolino et al., 2018), in addition to general reflection of the relation between IoT and digital servitization (Naik et al., 2020; Paiola and Gebauer, 2020). Digital servitization enables a platform for interaction with customers and other stakeholders (Cenamor et al., 2017), which allows for decision support based on richer and more reliable data and analytics (Hasselblatt et al., 2018).

AVSs embed digital technologies, which propagates the definition of AVSs to include digitally enabled services (Kohtamäki et al., 2019; Thomson et al., 2021). AVSs introduce an array of new and innovative services and digital activities linked to physical products and operational processes. AVSs thus form distinct contexts for digital servitization, which refers to the use of digital tools to transit from a product-centered to a service-centered business logic (Sklyar et al., 2019a). Examples of digital servitization in AVSs include remote monitoring (Ulaga and Reinartz, 2011), predictive methods for monitoring groups of vehicles (Parida et al., 2019), and the integration of multiple data-collecting sensors in vehicles (Jovašević-Stojanović et al., 2015). Digital servitization drives the transition towards smart systems, enabling value creation and capture through core digital features, namely monitoring, control, optimization, and autonomous function.

3. Methodology

This study applies a two-step research design and process. First, we conducted a literature search following the logic of an integrative literature review (Snyder, 2019; Torraco, 2005; Cronin and George, 2020) to develop a framework for conceptually categorizing AVSs. The first step attempts to address RQ1 and informs the empirical analysis of AVSs. Second, we utilized the developed framework to explore illustrative cases of digital servitization business models, focusing on RQ2.

3.1. Literature search strategy

To understand the opportunities and emerging ecosystems regarding AVSs, we searched for literature related to AVS concepts. The search terms were designed to extract several concepts simultaneously, namely business models, digital servitization, and AVSs. The purpose of the literature search was not to employ literature systematization techniques, nor was it to explore the interrelationships of the articles. Rather, the goal was to inform our understanding of the studied contexts of AVSs and digital servitization business models and aid us in constructing a theoretical framework to deploy in an empirical context. A theoretical framework covering extant literature helps to ensure that emerging theory is based on constructs that have been manifested as meaningful and applicable in prior studies (Eisenhardt, 1989). We thus chose the approach of an integrative literature review (Snyder, 2019; Torraco, 2016). The purpose of the integrative review is not to screen all articles ever published but to draw on insights from different fields or research traditions (Snyder, 2019) and to address new and emerging topics (Torraco, 2005).

The integrative literature review is specific from other types of literature reviews (such as systematic or narrative reviews). The integrative literature review may cover several areas or broader topics (Torraco, 2016), it may identify what topic should be studied as well as how and why (Cronin and George, 2020; Elsbach and Knippenberg, 2020), or it may lead to a new conceptual framework, taxonomy, or classification (Fan et al., 2022). Conducting an integrative literature review may follow the techniques from other literature review types or apply a tailored and/or unique creative process for collecting and analyzing literature deemed relevant for the studied topic (Snyder, 2019; Torraco, 2005). When conducting our integrative literature review, we adopted a two-stage research process. First, we developed means for identifying relevant literature to develop a data pool. Second, following our research questions, we analyzed and synthesized literature.

In the first stage, we stated our inclusion and exclusion criteria. We carried out a search related to digital servitization and/or business models in the context of AVSs. The context of AVSs is highly sensitive to recent technological advancement, so we restricted the search to articles published in 2017 or later. We searched for relevant peer-reviewed scientific research articles written in English using both Web of Science (WoS) and Scopus. These two databases were chosen due to their comprehensive journal coverage in the fields of business and technology. We excluded conference proceedings, book chapters, research notes, and unpublished research studies. Following the example of Kepes et al. (2012) to avoid publication bias, we did not apply any limitations to how the journals were ranked. Exclusion criteria were minimal but included a lack of a clear business context, such as a pure technology or patent focus, or the lack of the AVS perspective.

To identify relevant literature on digital servitization, AVSs and business models, the choice of keywords or search strings is crucial. We ran multiple pre-tests to check search results and to validate the search strings. We reduced the search strings to seven (see Table 1); these search strings cover AVSs and digital servitization, and they focus on business models. The key concepts on autonomous solutions are listed and defined in Appendix 1. In terms of identifying relevant articles on servitization, we followed Zhang and Banerji (2017)'s example by listing servitization* OR servitisation* OR servicizing* OR servicising* conjointly with other keywords. The focus of this article being on the business dimension and specifically value creation and capture of AVSs and their link to digital servitization rather than a systematic literature

Table 1
Search strings and search results.

Search strings	WoS	Scopus
autonomous* AND solution* AND business model*	33	45
autonomous* AND solution* AND business model* AND vehicle*	16	16
autonomous* AND solution* AND business model* AND car*	11	14
autonomous* AND solution* AND business model* AND truck*	0	0
autonomous* AND solution* AND business model* AND digital*	7	6
autonomous* AND solution* AND business model* AND digital* AND servitization* OR servitisation* OR servicizing* OR servicising*AND	2	0
business model* AND digital* AND servitization* OR servitisation* OR servicizing* OR servicising*	107	40
Total	176	121

review on the servitization research stream, we excluded associated concepts such as product–service system, service infusion, and service addition strategy or service transition. The article delimits to digital servitization.

The literature search yielded 297 articles. We selected the relevant articles that seemed to provide interesting examples of AVSs and digital servitization business models. Two of the researchers made an initial assessment of relevance based on the title, keywords, and quality of the papers, and we eliminated duplicates and articles not conforming to the selection criteria (see Fig. 1). After reading the abstracts, the sample size was narrowed down to 45. After reading the full articles, 35 articles were deemed relevant. We then applied a snowballing technique to identify additional articles using the list of references of the articles, adding 13 articles to the sample. These 48 articles were selected for constructing the theoretical framework (see Appendix 2 for an overview). These articles also met the pre-set inclusion criteria. Table 1 summarizes the literature search process, following Di Vaio et al. (2021) and Cruz-Cárdenas et al. (2021).

After identifying the relevant articles, we analyzed them qualitatively, that is, we conducted a thematic analysis in search of concepts, patterns, and value capture elements that indicate potential for business models. We coded the articles based on: (i) AVS definition, (ii) elements of digital servitization (AVS) and (iii) elements of digital servitization (business model). The coding scheme aimed at mapping different descriptions that illuminate the context from each examined research perspective (AVSs, digital servitization, business models). The integrative literature review resulted in a categorization tool for AVSs and their subsequent digital servitization business models.

3.2. Case selection

In the second step of the research process, we analyzed and exemplified illustrative company cases and their digital servitization business models utilizing the constructed framework. Case examples are commonly used in management research literature to illustrate conceptual frameworks (Siggelkow, 2007). Illustrative case examples are often used in business studies, for example, the internationalization of small and medium-sized enterprises (Bell and Loane, 2010); structural marketing (Lee et al., 2015); innovative family businesses (De Massis et al., 2016); dynamic capabilities, ambidexterity, and discontinuous change (Birkinshaw et al., 2016); and corporate identity and reputation (Koporcic and Halinen, 2018). We searched for comparable and illustrative cases of companies that were as diverse as possible in terms of their: (i) development approaches to AVSs and (ii) context regarding industry setting and logic. Prior studies focused on categorizing business models in a particular industry have utilized a similar approach (e.g., Rajala and Westerlund, 2008; Westerlund et al., 2008; Leminen et al., 2020).

A total of seven cases from the automotive and heavy machinery manufacturing industries were identified that corresponded with our definition of AVSs. These industries are in transformation and provide interesting and relevant examples of digital servitization business models (cf. Leminen et al., 2020). The cases were chosen due to these industries leading the development of AVSs and automated systems (Andersson and Mattsson, 2015; Tongur and Engwall, 2014). In addition, one of the co-authors has wide-ranging work experience in developing digital service solutions for these industries. Each case suggests distinct models of operation. This approach is vital when cases are used in the search for new theoretical insights through complementary

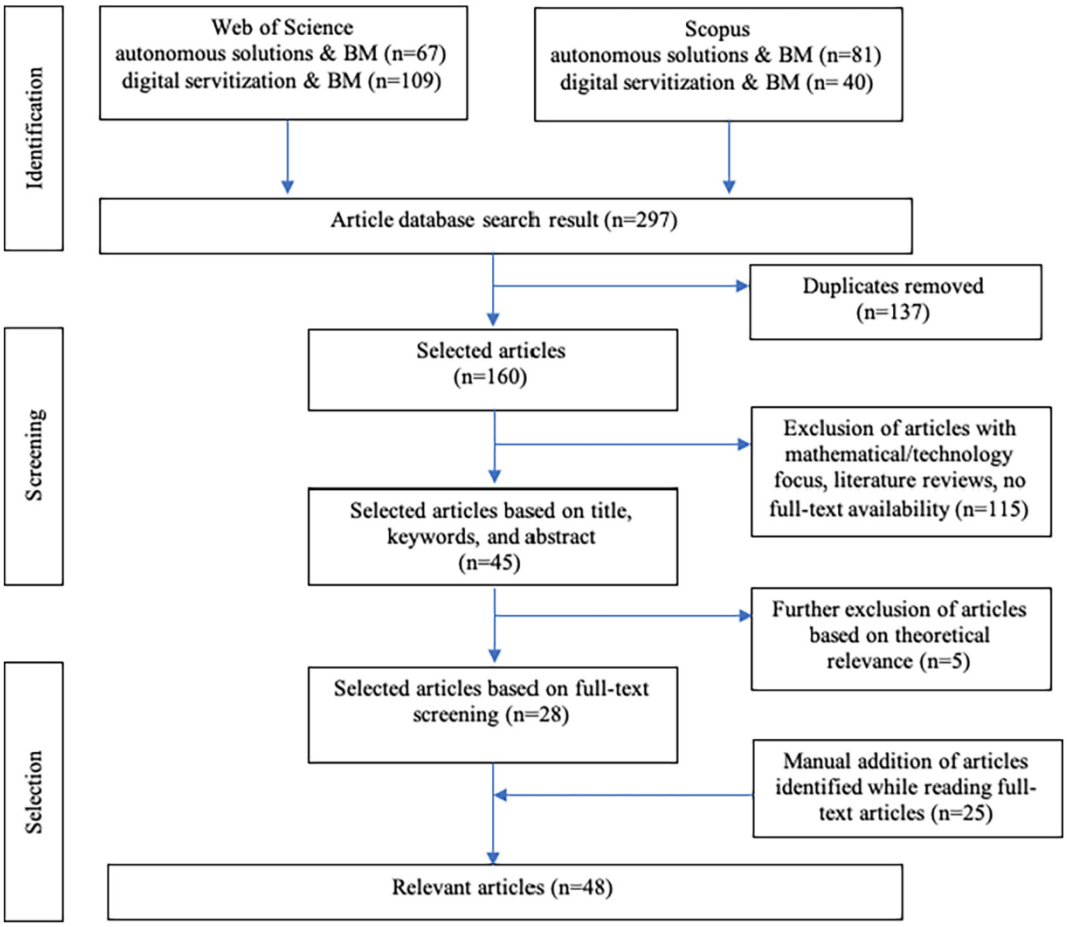

Fig. 1. Flow chart of articles included in the theoretical framework.

aspects (e.g., Siggelkow, 2007).

The selected case companies are among the front-runners in their industries, and there is ample information about them available publicly. As suggested by Jensen and Rodgers (2001), with snapshot studies on the illustrative cases, we developed illustrations, or descriptive accounts, of the prevailing landscape. In other words, we used these case examples to concretize the theoretical concepts presented in the framework. The material for the cases were drawn from the companies' websites, showcasing descriptions and presentations of the solutions, and other public sources (contemporary and scholarly articles). We thus extracted publicly available written descriptions, presentations, and articles on AVSs. The collected data amounted to 10–30 pages of written material per case, and some cases also included videos (YouTube, Vimeo) showcasing their AVS.

First, we organized the data by case, then we analyzed the data following the principles of thematic analysis in qualitative research (Fugard and Potts, 2019). In each case, we coded the data based on: (i) autonomy (how is the solution's autonomy described?), (ii) servitization focus (how is a service linked to the product and autonomy in the solution?), (iii) value-producing activities (what are the service offerings?), (iv) business model (what kind of a business model is emerging?), and (v) digitalized service ecosystem (what actors are involved in producing the solution?). We discussed the cases comprehensively and compared the coding outcome in search for emerging patterns. In the next step of our analysis, we classified the cases according to the four types of AVSs identified in our literature search. As the last step, we explored the link between digital servitization and business models of each case to further understand the emerging ecosystem of AVSs. We focused on only a few concepts to clarify the essence of the studied models and gain a deeper understanding (Lowy and Hood, 2004). An overview of the empirical material is presented in Table 2.

Table 2
Illustrative cases used in this study.

Illustrative case	Sources
Case 1: Volvo Group Vehicle, equipment, and engine manufacturer. It also sells solutions for financing and service. About 96,000 employees. Net sales USD 40 billion (2020). Headquarters in Gothenburg, Sweden. Production facilities in 18 countries.	www.volvo.com
Case 2: Scania Provider of transport solutions. Part of Volkswagen Truck and Bus GmbH. About 50,000 employees. Net sales USD 16 billion (2019). Operates in about 100 countries. Production in Europe, Latin America, and Asia. Research and development in Sweden. Headquarters in Södertälje, Sweden.	www.scania.com
Case 3: Iveco S.p.A. CNH Industrial brand, global manufacturer of light, medium and heavy commercial vehicles, city and intercity buses and coaches, vehicles for construction and mining work, etc. Production sites in 11 countries throughout Europe, Asia, Africa, Oceania, and Latin America. Sales and service outlets in over 160 countries. About 25,000 employees. Revenue EUR 4.9 billion. Headquarters in Turin, Italy.	www.iveco.com
Case 4: Rio Tinto World's second largest metals and mining corporation. Produces iron ore, copper, diamonds, gold, and uranium. Operations in refining. About 45,000 employees. Revenue USD 45 billion (2020). Head offices in London, UK, and Melbourne, Australia.	www.riotinto.com
Case 5: Komatsu Manufacturer of construction and mining equipment, utilities, forest machines, and industrial machinery. About 63,000 employees. Turnover USD 22 billion (2019). Headquarters in Tokyo, Japan.	https://home.komatsu/en/
Case 6: LoadRunner A collaborative logistics system based on high-speed automated guided vehicles (AGVs) developed and tested at the Fraunhofer Institute for Material Flow and Logistics. Builds on autonomously acting elements that can negotiate and fulfill orders individually, but also act cooperatively.	ten Hompel et al., 2020
Case 7: Uber for trucks On-demand trucking platforms, for example Uber Freight, are in search of opportunities to obtain market shares. Carriers, vehicle owners or drivers receive bookings via an app or web interface and send quotes or accept bookings via a freight bidding marketplace.	https://mobisoftinfotech.com/resources/blog/list-of-uber-for-trucks-startups-across-the-globe/

4. A taxonomy of AVSs and digital servitization business models

The purpose of an integrative literature review is to explore links and connections between research communities (cf. Torraco, 2016). The integrative literature review allows us to synthesize our current knowledge of the different research streams. In the present paper, these research streams are AVSs and digital servitization business models. This approach enables an in-depth understanding of the studied topics. To summarize the integrative literature review, we first discuss our findings on the concepts of AVSs and digital servitization business models, and then we discuss the link between the AVSs and digital servitization business models.

4.1. Autonomous vehicle solutions and digital servitization

Existing literature on AVSs is focused on issues related to technology and engineering. Current knowledge of AVSs is varied and complicated, with the literature focused on a limited range of topics. An emerging body of literature deals with sharing models for autonomous vehicles and user acceptance of autonomous vehicles (Hudson et al., 2019; Kaur and Rampersad, 2018). Thomson et al. (2021) regard AVSs as one of the most advanced forms of digital servitization, covering a continuum from remote monitoring to control and optimization to a fully autonomous solution. Autonomous solutions are smart, connected technologies with the ability to change the roles of manufacturers and service producers, as well as to redefine existing industry boundaries. Autonomous solutions are composed of physical components (mechanical and electrical hardware), smart components (computational and data processing capabilities), and connectivity components (wired or wireless communication between the product and the business ecosystem) (Porter and Heppelmann, 2015). AVSs utilize a variety of artificial intelligence and real-time sensorial and processing technologies to automate driving functions. Such functions were previously performed by humans, such a planning and following a route, acceleration and deceleration control, compliance with driving rules, monitoring of the vehicle operations and surroundings (obstacles, other road users), and road conditions for safety and collision avoidance (Cunningham et al., 2019; Lee et al., 2019; Martínez-Díaz and Soriguera, 2018; McCall et al., 2019; Osório and Pinto, 2019; Zhao et al., 2018). AVSs enable vehicles to include a large part of computing, communication, and storage of data (Rauniyar et al., 2018), which allows for digital servitization.

The core idea and value-creating aspect of AVSs emphasized in the literature is *autonomy*. Liu and Xu (2020), Mallozzi et al. (2019), Merfeld et al. (2019), and Thomson et al. (2021) categorize the levels of

autonomy as semiautonomous and fully autonomous. Semiautonomous indicates that a vehicle is steered and controlled partially by a system and partially by a human (driver) typically located in a vehicle (Broggi et al., 2013). Even though a system drives the vehicle quite autonomously, humans can make the final decision, should an unexpected threat emerge or something alarming occur. Conversely, in the fully AVS no human resides in the vehicle as the 'driver'; the vehicle is fully controlled by the technological system and any human riding in the vehicle is strictly a 'passenger' (Van Brummelen et al., 2018).

Another core idea that emerges in the literature on AVSs relate to the *complexity* of the solution. While autonomy relates to the operation of the vehicle, complexity refers to the structure of the solution. For instance, an AVS may be based on a single vehicle or several vehicles, in other words, a fleet. A fleet may have different forms or structures such as a platoon or a swarm of vehicles (Ghosal et al., 2021; Hu et al., 2017; Wang et al., 2019). Platooning of AVSs refers to forming a road train in which autonomous cars or trucks travel safely at high speeds, separated only by spacings that are smaller than that of human-driven vehicles (Martínez-Díaz and Soriguera, 2018; McCall et al., 2019). The fleet communicates and exchanges information as a group. This kind of crowd or swarm intelligence in a fleet consisting of automated vehicles require cooperation, coordination, and prediction components through three stages, namely *collection of data* from sensors placed in vehicles, *conversion of data* into a standard form, and finally *analysis of data* using artificial intelligence techniques (Shit, 2020).

Swarms or crowds of vehicles could make decisions as a group, and their tasks and activities could be dynamically reformulated. The concept of swarm intelligence was introduced by Beni and Wang, 1989 and was inspired by natural systems such as ant and bee colonies. Rauniyar et al. (2018) utilized the concept for describing decision making among fish and birds when they move as an entity. In these systems, each agent acts autonomously, reacts dynamically on inputs, and works collaboratively with other members without central control. According to Schranz et al. (2021), the basic idea is that each individual member follows relatively simple rules, even though a swarm can reach for complex goals. Swarms have no central control, and they can express high adaptation to dynamic deviations, resilience or robustness to damage or component failures, and scalability of performance. Scaling properties are essential for swarms, and swarm-intelligent systems are apt to work better when swarms get larger (Schranz et al., 2021).

4.2. Digital servitization business models

A digital servitization business model refers to building value by customizing the solution, pricing, and digitalization (Kohtamäki et al., 2019). Within the research stream on digital servitization, business model configuration (Kohtamäki et al., 2019) and business model innovation (Paiola and Gebauer, 2020; Chen et al., 2021; Paiola et al., 2021) are emerging as strong perspectives. The origin of the business models based on digital servitization is a current focal area within this research stream. While a basic research question in many articles deals with how business models change concurrently as digital servitization unfolds, mapping and reporting of business models per se is surprisingly limited. Martín-Peña et al. (2018) identified three taxonomies of digital business models in their review, but none relate directly to deducing subsequent value creation or digital servitization business models.

Nonetheless, literature on digital servitization and business models is increasingly pinpointing the importance of the service ecosystem (Edvardsson et al., 2011; Tronvoll, 2017; Sklyar et al., 2019b), that is, a network of interlinked actors that enable digital servitization. It entails an embeddedness of digital servitization, in other words, an actor is affected by its relationships and the surrounding network of relationships (Granovetter, 1985).

Firms pursuing digital servitization must adjust the service ecosystem by adapting their activities to each other (Sklyar et al., 2019b), which consequently affects emerging digital servitization business models. The ecosystem concept depicts a network of interdependent actors aiming at joint value creation (Adner and Kapoor, 2010). Digital servitization depends heavily on a shared vision and shared goals for value creation for both the focal firm and the other ecosystem actors (Sklyar et al., 2019b).

The idea of complexity also emerges from the literature on digital servitization business models. Servitization along with digitalization increases business complexity in service processes, service networks, and in the interplay between digitalization and servitization by increasing multiplicity, diversity, interdependence, and variability (Eloranta et al., 2021; Zou et al., 2018). Related to digitalized service ecosystems, Sklyar et al. (2019a) observed that digital technology has a dual role, both increasing the complexity in resource integration and enabling the successful coordination of that complexity.

4.3. Digital servitization business models for autonomous vehicle solutions

The current body of knowledge does not outline specific types of AVSs nor business models based on digital servitization in the AVS context. Rather, it remains in a nascent stage in explaining how AVSs create value. To reduce insight into the current state of AVSs and their digital servitization business models, we establish a conceptual framework to arrive at a taxonomy of AVSs and to identify associated digital servitization business models in the AVS context. We follow Lowy and Hood (2004) and focus on a core set of variables to enrich the analysis and gain deeper understanding. We propose a strategic 2-by-2 matrix framework depicting four options for AVSs (Fig. 2). The variables are based on the integrative literature review, through which we identified two essential variables related to digital servitization and AVSs, namely autonomy and complexity. These two dimensions (Fig. 1) enable the classification of AVSs and their associated digital servitization business models. Thus, the vertical dimension is labelled 'autonomy', spanning from 'semiautonomous' to 'fully autonomous' (Van Brummelen et al., 2018; Broggi et al., 2013; Thomson et al., 2021), referring to the degree of autonomy. The horizontal dimension refers to the complexity of the service ecosystem: 'single vehicle' versus 'fleet'. Vehicles are linked into a fleet by using digital technologies and data, the size of the fleet and its interconnections forming the complex service ecosystem. For instance, Hyland and Mahmassani (2017) emphasize the importance of the fleet size for studying AVSs.

In line with Rauniyar et al. (2018), we suggest that a service

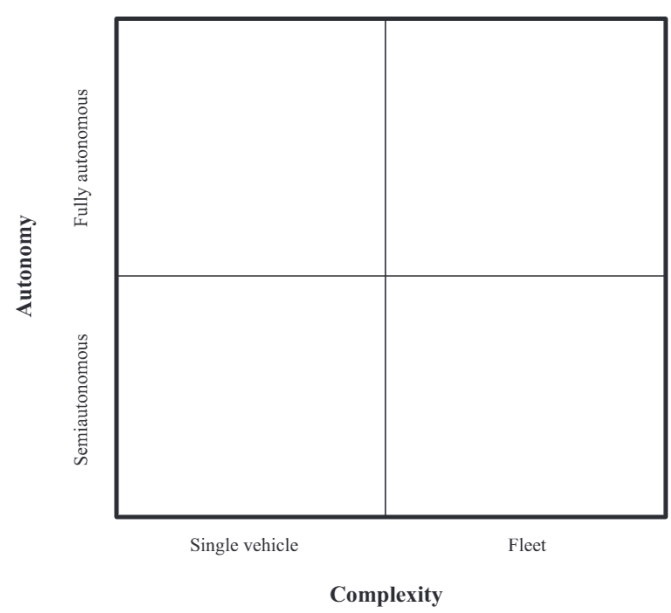

Fig. 2. A conceptual framework for analyzing AVSs.

ecosystem can be built based on individual vehicles or a fleet consisting of groups of vehicles. A vehicle that communicates with another vehicle in a vehicle-to-vehicle (V2V) system (Seo et al., 2016) is considered a single vehicle in a service ecosystem. A fleet consists of a connected group of vehicles, such as cars or trucks.

5. Case analysis of AVSs and their digital servitization business models

Our analysis of illustrative case examples identifies four types of AVSs and their subsequent digital servitization business models (Fig. 3). The framework builds on an idea that a service ecosystem can be built based on semiautonomous or fully autonomous individual vehicles or a fleet of vehicles. Based on the similar patterns and characteristics between the illustrative cases, we labelled the types of AVSs as (i) *advanced-data-assisted solutions*, (ii) *semiautonomous platooning solutions*, (iii) *autonomous demarcated solutions*, and (iv) *autonomous swarmed solutions*. In addition, we identified four digital servitization business models associated with those types of AVSs, namely: (i) safety as a service, (ii) efficiency as a service, (iii) capacity as a service, and (iv) flexibility as a service (see Table 3). The following sections elaborate these four respective digital servitization business models using illustrative case examples from the AVS context.

5.1. Advanced-data-assisted solutions and the 'safety-as-a-service' business model

Advanced-data-assisted solutions (I) merely support the driver in charge of a single vehicle. These solutions are characterized by semiautonomous operations and focus on a single vehicle. Semiautonomous vehicles are already far onto development, but semiautonomous operations, nevertheless, require an intervening driver who can take control of the vehicle if an unexpected event occurs. Semiautonomous vehicles can only drive on prescribed routes. If something changes, for example, if a vehicle drives beyond the route map, the solution may not function, and a driver must take control of the vehicle (Stern, 2020). Examples of cars containing such advanced-data-assisted solutions include Volvo (Case 1) (cf. Volvo XC60) (Volvo, 2021; Kurczewski, 2020). In the Volvo case, the truck can follow a pre-programmed route and steer, accelerate, and decelerate without the driver being actively involved. There are several benefits for the various stakeholders related to the solution. For example, technically, such a vehicle should be able to improve passenger

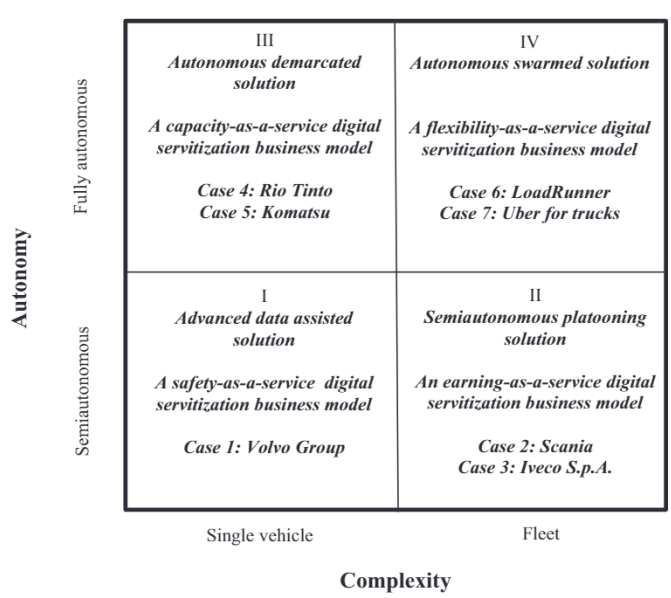

Fig. 3. AVSs and their associated digital servitization business models.

security and the flow of the traffic, as well as save wear and tear and fuel consumption to a certain extent, thus creating value both for passengers and owners of the vehicle (Choi et al., 2016). The challenges are, however, that the route must be pre-programmed and driven as if there were no unexpected events, objects, or other obstructions on the road. Another challenge is that the distance equipment, such as automatic brakes, lidar (light detection and ranging, distance measurement by usage of laser) and automatic lane centering, may not work well under certain conditions. For instance, in snowy conditions, the sensors may be covered and malfunction, pulling up failure warnings to inform the driver that the system does not function properly–a problem known in the Northern hemisphere (Beresford, 2020).

The *Safety-as-a-service* digital servitization business model is associated with Advanced-data-assisted solutions, highlighting the role of safety in semiautonomous and autonomous solutions. Prior studies have widely discussed AVSs from a safety perspective, but their main argumentation resides in decreasing unexpected events and human errors in autonomous and semiautonomous solutions to promote safety (Cunningham et al., 2019; Lee et al., 2019; Martínez-Díaz and Soriguera, 2018; McCall et al., 2019; Osório and Pinto, 2019; Zhao et al., 2018). The digital servitization business model is thus based on promoting safety: advanced-data-assisted solutions aid driving tasks per se but also make driving safer and traffic flow smoother. For example, a driving support system mitigates vehicle-on-vehicle collisions by automatically braking the vehicle to avoid or mitigate a rear-end collision, and offers a holistic view of future travel, depicting it as autonomous, electric, connected, and safe. In addition, the *Safety-as-a-service* digital servitization business model emphasizes functionalities that lower fuel consumption. The underlying assumption is to make travelling safer and easier for the user.

5.2. Semiautonomous platooning solutions and the 'efficiency-as-a-service' business model

In semiautonomous platooning solutions (II), operations are semiautonomous and based on a fleet model, for instance, a group of vehicles joined together. Semiautonomous platooning solutions may be, for example, trucks 'coupled in a chain' that enhance platooning transportation services. The objective of platooning is for all vehicles to maintain the exact same speed as the lead vehicle, keeping a certain distance between vehicles according to safety policies and driving within the lane (Lu et al., 2017). The key behind this close-formation haulage model is autonomy of a truck based on real-time processing of data received from connected trucks in the fleet, enabling aerodynamic drafting and lane capacity increase, while ensuring collision-free hauling of freight (Monios and Bergqvist, 2019; Shladover, 2018). In addition, similar to the advanced-data-assisted solutions (I), there is a need for a human driver in the vehicle even though the human driver no longer needs to actively monitor the environment. That said, the semiautonomous platooning solutions (II) are more advanced than advanced-data-assisted solutions (I), because most of the actual driving tasks are transferred from a human to the automated system. Further, the semiautonomous system differs fundamentally from AVS (I), where there is only a single operating vehicle. AVS II encompasses a fleet, consisting of a group of vehicles in a platoon, thus representing a significantly more complex digitally enabled solution.

A driver remains responsible for intervening when alerted by the automated system. The driver can safely turn their attention away from driving tasks but must still be prepared to intervene within a limited time if alerted by the automated system or the vehicle departing from the platoon. However, platooning could avoid some hours-of-service restrictions on drivers. Drivers may be resting, helping with drop-offs and pick-ups, and perhaps performing administrative tasks, but driver jobs may also be eliminated–but only later (Clements and Kockelman, 2017). In this case, the cost of the driver remains, which is one of the challenges with the current truck platooning concepts for efficient

Table 3
Digital servitization business models in the AVSs context.

Autonomous solution	Illustrative case	Digital servitization business model	Digital servitization focus/what is servitized through digitalization in the autonomous vehicle solution?	Value created through digital servitization business model
Advanced-data-assisted solutions (I)	Volvo Group (Case 1)	Safety as a service	Safety and flow improved by Advanced Driver Assistance Systems (ADASs) assisting the driver of the truck protecting the driver from harm in case driver attention is dropping, for example with collision warning and emergency braking. https://www.volvotrucks.com/en-en/news-stories/magazine-online/2017/jul/tech-focus-emergency-brake.html https://group.volvocars.com/company/innovation/autonomous-drive	Driving assistance, improved driving experience, traffic flow and safety, lower fuel consumption Implications for traffic safety, city planning and environmental footprint Lower rates on truck insurance premiums are possible through the automated braking system
Semiautonomous platooning solutions (II)	Scania (Case 2)	Efficiency as a service	Better flow and potential improvement of fuel and salary efficiency with connected systems with a lead vehicle and other vehicles where the other vehicles follow in the lead vehicle's aerodynamic drafting while their drivers are resting; later these systems could be totally automated. https://www.scania.com/group/en/home/newsroom/news/2018/automated-platooning-step-by-step.html#	Improved traffic flows, increased total efficiency, decreases in fuel consumption (less air resistance) with up to 10 %. Fully automated vehicles following the platoon leader. It would also be possible to reduce the driver costs, which are an estimated 26 % of the total annual costs for long haul in Europe. Fewer driver errors, fewer collisions, and lowered insurance premiums.
	Iveco (Case 3)	Efficiency as a service	Vehicles follow each other at close distance, using connectivity technology and automated driving support systems. https://www.thenewsmarket.com/news/iveco-deploys-semi-automated-trucks-for-world-s-first-ever-truck-platooning-challenge/s/cf1edfa6-b80e-4bec-88b6-fdfacde3205f https://www.iveco.com/sea/press-room/release/pages/ivecoplatooning.aspxL	Safer, cleaner, and more efficient transport, fuel consumption reduction; potential to CO_2 emission reduction (up to 10 %).
Autonomous demarcated solutions (III)	Rio Tinto (Case 4)	Capacity as a service	Better usage of capacity with mining trucks in a restricted area following a certain route and handling certain operations such as tipping, loading etc. https://www.riotinto.com/news/releases/Automated-truck-expansion-Pilbara	An improved flow in the mine leading to a larger mine throughput with more ore tons per hour produced due to a higher uptime. Better usage of capacity, as well as cost effectiveness, security, accuracy. Less need for personnel on site with the Pilbara case being remotely monitored from Perth 1400 km from Pilbara. Reduction of personnel on site also leads to increase of efficiency, such as decreased need for transport to the mine site, decreased need to ensure accommodation, hospital, restaurant, all allowing for reduction in personnel and personnel related costs. Less wear and tear on the equipment due to improved handling at given speeds leading to a decrease of cost for fuel, spare parts and maintenance.
	Komatsu (Case 5)	Capacity as a service	Better usage of capacity with unmanned hauling: Automated haul trucks have global navigation satellite positioning systems, advanced sensors, and integrated controllers. They are remotely controlled from a central control room, designed to be operated by a single operator for unmanned hauling. https://www.komatsuamerica.com/autonomous-haulage-system	Improved productivity, reduced costs, emissions, tire wear and fuel consumption, and reduced risk, moving workers to safer working environments.
Autonomous swarmed solutions (IV)	LoadRunner (Case 6)	Flexibility as a service	Autonomous vehicles can negotiate and fulfill orders individually, but also act cooperatively. Three use cases: parcel sorting, production supply, and baggage handling at airports. https://www.fraunhofer.de/en/press/research-news/2021/march-2021/an-autonomous-high-speed-transporter-for-tomorrows-logistics.html	Simulations show high potential for the (partial) replacement of current sorting systems.
	Uber for trucks (Case 7)	Flexibility as a service	On-demand trucks. Customers use a mobile app to access trucks and drivers who help them to move packages. Currently not for AVSs, but in the future, these systems can be developed for fully autonomous swarmed solutions. https://mobisoftinfotech.com/resources/blog/list-of-uber-for-trucks-startups-across-the-globe/	Optimized logistics with Uber for trucks making it possible to circumvent the large logistic planners, such as DB Schenker etc., whose main business model is logistics planning. With the equivalent of Uber combined with autonomous swarmed solutions, the platform business could optimize logistics routes, load factors on the fly in both inner-city distribution and long haul, and totally renew the future business models of trucking.

industrial use. Additional challenges are related to connectivity, multi-brands, and sensors, among others. Tests on trailer tractor combinations as described by Bergenhem et al. (2012a) and Bergenhem et al. (2012b) as well as in practical tests with different vehicle manufacturers such as in the 'European truck platooning challenge' have noted specific traits of platooning.[1] For example, there is communication between the vehicles in the platoon–a vehicle shares speed and sensor data directly with other vehicles in the platoon. The V2V platoon is a collaborative system where system sensing, control algorithms and activation is distributed among vehicles. Lateral control is important with avoidance of objects through radar and lidar technology. However, lane keeping is still challenging with today's technology in poor weather conditions such as fog, snow, and rain (Bergenhem et al., 2012a).

The illustrative cases denote efficiency by different means. Scania (Case 2) and Iveco (Case 3) focus on improving their efficiency with lower fuel consumption and increased safety as trucks are connected. These measures translate into fewer errors and reduced CO_2 emissions, and better traffic flow. AVS II illustrates the *Efficiency-as-a-service* digital servitization business model. The business model aims at improving and streamlining operations of companies, a notion brought forward also in prior servitization research (Fagnant and Kockelman, 2015; Sjödin et al., 2018; Leminen et al., 2018; Parida et al., 2019). For example, Leminen et al. (2018) documented how firms benefit from sensor data in their businesses by proposing four service business models. The underlying idea of sharing sensor data was to streamline and improve their businesses, but also build on new businesses above the shared data (ibid.). Like prior studies, the studied digital servitization business model relies on improving efficiency for the focal firms and their service ecosystem. In other words, the semiautonomous solution steps into the role of the operational staff by driving the platooning trucks (II). The role of operational staff is seen as supportive, as they are reacting to emerging unforeseen situations.

The efficiency of platooning has been identified in on-road tests with two platooning trucks, where the lead truck achieved fuel savings of 4–5 % and the second truck 10–14 % (Lu and Shladover, 2014). One should, however, keep in mind that in Europe and the US fuel stands for 26 % of the cost of a long-haul truck. The underlying thought of platooning is that trucks from different companies could platoon together in the future. A challenge resides in how to distribute efficiency gained when the following trucks save more fuel than the lead truck. Some tests display significantly less fuel savings (3–7 %) because of safety reasons; the distance between trucks must be higher than the optimal for platooning (cf. Engholm et al., 2020; Lopez, 2019). The cost of the business case for platooning is thus a challenge as it requires a human to take control over the truck when the system issues a warning. In a business such as long-haul trucking with margins at 2 % or lower, the cost for both the platooning system and the salary of the driver is steep.

To conclude, the analyzed cases Scania (Case 2) and Iveco (Case 3) provide multiple benefits. Among them, the main benefit of platooning is fuel cost reduction of a truck by 4–10 % and the truck annual cost reduction for fuel is an average 25 % of the total annual cost while the driver cost stands for another 26 %. Removing the drivers in the vehicles following the platoon but decreasing a 25 % fuel cost with only 10 % might not be the dealbreaker needed to invest in platooning systems. However, the improved efficiency would be found in driver cost reductions, fuel cost reductions and reductions in insurance premiums (Engholm et al., 2020; Lopez, 2019; Paddeu and Denby, 2021).

[1] Participants in the Truck Platooning Challenge in 2016 were the following automated trucks brands: DAF Trucks, Daimler Trucks, Iveco, MAN Truck & Bus, Scania, and Volvo Group. They have platooned on public roads from several European cities to the Netherlands. See e.g., https://connectedautomateddriving.eu/mediaroom/european-truck-platooning-challenge/.

5.3. Autonomous demarcated solutions and the 'capacity-as-a-service' business model

Autonomous demarcated solutions (III) provide autonomous transportation services for cargo or a carriage in a demarcated area. Autonomous demarcated solutions are driverless vehicles, where a driver is not responsible for intervening driving; rather, autonomous demarcated solutions may be operated externally. Contrary to semiautonomous solutions (I/II), no driver attention is needed for safety. Operation is restricted to geographically fenced areas such as mines or specific parts of a city. Previous literature (e.g., Shladover, 2018) has suggested autonomous buses, shuttles, and trucks restricted for use on special transitways, campus areas and zones, and dedicated lanes, pending some of the demarcated solutions that are likely to appear within a short period of time. Autonomous demarcated solutions (III) assume that a single vehicle autonomously moves in a certain predefined route. These solutions can be compared to continuous movement of objects on a conveyor belt and installing of single vehicles, which revolutionized the early manufacturing industry. These solutions emphasize the transition of operational staff, as they are no longer physically present in autonomous vehicles; rather, they may engage in the operation externally when needed. Thus, in contrast to prior research of digital business models, where conditions and locations data of the goods and material were communicated among different actors in ecosystems (Leminen et al., 2018) or there exist predictive approaches for vehicles (Parida et al., 2019; Leminen et al., 2020), the present study opens the diverse roles of autonomous systems to support decision making, and the semiautonomous and autonomous as part of digital servitization business models.

We estimate that such a revolution will occur as autonomous demarcated solutions enter more industries, such as mining and transportation. Examples are provided by Rio Tinto (Case 4) and Komatsu (Case 5), who deploy mining trucks in secluded areas with secured connectivity and without the requirement of a driver. In Rio Tinto's Pilbara mines (Case 4), haulers have moved a billion tons of iron ore and waste material since 2008 (McGagh, 2012; Rio Tinto, 2018). In 2017, the autonomous fleet in Rio Tinto's Pilbara site accounted for about a quarter of the total material moved. Each autonomous truck was estimated to have operated, on average, 700 h more than the conventional haul trucks during the same year, accounting for approximately 15 % lower load and haul unit costs. Safety has also increased on the mine site as pre-programmed autonomous trucks do not speed, take risks, or do unplanned manoeuvres.

The operation can then be seen as pre-programmed, following a certain route and handling certain operations, such as tipping and loading. In a mining context, a thorough analysis of the mine and blueprints of all components and the flow of a mine is required when autonomous operations begin. Mining customers seek multiple benefits by autonomous operations, such as cost-effectiveness, latency, security, accuracy, measurements, and local control solutions (McGagh, 2012). A mine is a production unit where connectivity requirements are affected by external network disturbances and should thus be built in a manner that can be regarded as impregnable. If one truck is disconnected, it will affect the other trucks in the mesh network, which has led to the development of private connectivity networks (e.g., LTE, 5G). Taking all into consideration and achieving a certain level of autonomous behavior and efficiency, significant company-level changes, and a supporting ecosystem of actors, such as legislators and regulators, are required. Also, telecommunications vendors and mobile operators are natural partners when building private or privately sliced networks such as WIFI 802.11P, LTE or 5G for secure wireless connectivity, as well as sensor consultants, such as Trimble, and EDGE gateway suppliers. Automated haul trucks consist of global navigation satellite positioning systems, advanced sensors, and integrated controllers, which are remotely controlled from a central control room, designed to be operated by a single operator for unmanned hauling. These improve the capacity of

autonomous operations as well as their cost efficiency, safety, security, and accuracy. Remotely operated trucks reduce risks, costs, emissions, tire wear and fuel consumption, and improve productivity, especially in terms of better usage of existing capacity. The autonomous demarcated solutions remove the safety risk of erratic behavior that leads to many mining accidents.

The *Capacity-as-a-service* digital servitization business model is associated with autonomous demarcated solutions (III), where, for example, mining trucks in a restricted area follow a certain predefined route and handle specific operations including tipping, loading, and so forth (Rio Tinto, 2018). The context has not been studied empirically to a large extent, but the role of continuous tracking production and data sharing for machineries have been discussed within prior literature of digital business models and servitization solutions (Spring and Araujo, 2017; Leminen et al., 2020). Spring and Araujo (2017) discuss continuous tracking of production by IoT solutions. Leminen et al. (2020) suggest sharing collected data for running trucks in the context of a mine site. This study, on the other hand, underlines that the *Capacity as a service* perspective should not solely be seen as tracking and moving raw material; rather, *Capacity as a service* indicates building up and developing versatile value adding service elements beyond 'outdoor operations'. This business model also includes the values offered in the previously described models 'Safety as a service' and 'Efficiency as a service'.

Our study explores the shift from monitoring to AVSs; that is, the value-adding elements of AVSs may include predictive maintenance and overall factory optimization. For instance, a drop in average speeds on some sites from 42 km/h to a recommended 30 km/h results in reduced wear and tear cost on the 300 Metric tons rigid haulers. A driver might exceed a selected operational speed, but a programmed computer will not. The *Capacity as a service* may be an important business model especially for optimizing different locations such as mine sites. Referring to Lovelock (1992), the capacity of a service can be understood as the highest output that may be obtained with a fixed level of staff, installations, and equipment. Relying on AVSs in *Capacity as a service* cases, better usage of capacity results from more hours per truck, less wear and tear leading to longer lifespan of equipment and vehicles, but also more efficient usage of staff resources. In the case of the Pilbara mine site with Komatsu and Caterpillar equipment (Rio Tinto, Case 6), the RTIO Operations Centre in Perth controls the mines from a geographical distance of 1400 km. Better usage of personnel capacity is realized, as on average, 1.5 operators are required to oversee the autonomous trucks, as opposed to normally having five operators overseeing each truck. Also, each autonomous truck operated, on average, 700 h more than a conventional haul truck in 2017.

5.4. Autonomous swarmed solutions and the 'flexibility-as-a-service' business model

Autonomous swarmed solutions (IV) are fully automated and function without a driver or an operator. Autonomous swarmed solutions operate autonomously to transport passengers or cargo in an open space or on a route, and thus provide autonomous (open) transportation services. Human intervention and planned routes are not required, and vehicles are organized in any form of group to fulfill their task in autonomous swarmed solutions. While autonomous demarcated solutions (III) assume single independently operating vehicles, in autonomous swarmed solutions (IV) vehicles operate together and react to forthcoming needs as a group or a swarm by reorganizing their operations. Hence, vehicles co-operate to decide the routes, structures, and tasks as well as adapt to the changes in the environment, including any objects on open routes. In semiautonomous platooning solutions (II), vehicles are connected in a platoon, which are determined and operated semi-autonomously by a driver, while autonomous swarmed solutions (IV) form fully automated fleets.

We were not able to identify fully functioning autonomous swarmed solutions in practice at this point of time. However, some illustrative cases draw partially on their potential; such autonomous vehicles may negotiate and fulfill orders individually and act cooperatively as a system (LoadRunner, Case 6). It can make the flow of traffic safe and smooth and avoid congestion. Another example is Uber for trucks (Case 7), that is, on-demand trucks that you can access with a mobile app. These solutions are currently not based on AVSs, but in the future, they could be developed for fully autonomous swarmed solutions. Such vehicles share data with surrounding vehicles and road infrastructure, and analyze lane changes, mimicking a swarm of fish. In the future, this could be connected to standard business models with swarming in platoons or more expensive business models for logistics, considering the speediness of the delivery and taking care of emergency transports, for instance, when production line seizures are a risk in the petrochemical or assembly industries. Ideally, autonomous swarmed solutions are self-driving vehicles that can work in all weather conditions, on several surface types, and all over the world. Such systems require advanced artificial intelligence, latency of less than one millisecond end to end, and lidar systems that work in heavy downfall of rain or snow. Severe shortcomings still exist regarding liability and technology.

While we are not yet able to observe autonomous swarmed solutions in practice, we were able to identify an on-going theoretical discussion and subsequent conceptual examples. Recently, Schranz et al. (2021) examined cyber–physical systems, such as robotics and swarm intelligence. Schranz et al. (2021) argue that there are far more experiments than functioning real-world applications of swarm systems, and that this particularly holds true for physical entities, such as swarm robotics. As reasons, the authors mention predictability and controllability, which are not easy to achieve in complex bottom-up systems, that rules are not easy to make for uncertain environments, and the difficulty in scaling proof-of-concepts to complex real-world tasks in a reliable, predictable, and efficient manner.

For example, there have been experiments of swarmed robotic solutions for indoor logistics, such as the LoadRunner (Case 6), developed and tested at The Fraunhofer Institute for Material Flow and Logistics. The LoadRunner builds on a collaborative logistics system based on high-speed automated guided vehicles (AGVs), autonomously acting elements that can negotiate and fulfill orders individually, but also act cooperatively. Such driving allows the transport of load objects of different measurements and weights. Three exemplary use cases, namely parcel sorting, production supply, and baggage handling at airports, are presented for the LoadRunner (ten Hompel et al., 2020).

Autonomous swarmed solutions give rise to the *Flexibility-as-a-service* digital servitization business model. Flexibility and self-organizing are sparsely discussed in literature on digital servitization or business models. Interestingly, Forkmann et al. (2017) study how a business model is reconfigured by capacity development of actors. Leminen et al. (2017), in turn, propose versatile actor roles and respective ecosystems when creating and reconfiguring new IoT business models. Acknowledging the need for reconfiguration of business models, our study suggests that the *Flexibility-as-a-service* digital servitization business model may configure itself autonomously, creating value based on customer needs. We thus emphasize that a digital servitization business model and its underlying ecosystem may compose and customize itself independently when autonomous vehicle swarms perform certain tasks. When such tasks have been performed, a reconfiguration of the business model reoccurs, as there are not necessarily any permanent structures of swarms to perform tasks. Following digital transformation of industrial firms towards servitization logic (Frank et al., 2019; Paiola and Gebauer, 2020), the present study proposes continuous transformation of digital servitization business models, particularly in a context of AVSs when a swarm makes autonomous decisions on how to organize itself. The *Flexibility-as-a-service* digital servitization business model thus entails continuous transformation in swarms according to customer needs. Being flexible and based on high-level automation, this model also includes all the values offered in the previously described models: Safety

as a service, Efficiency as a service and Capacity as a service.

6. Discussion and concluding remarks

In this study, we aimed to identify the types of AVS and their associated digital servitization business models in an emerging industry of autonomous vehicles to contribute specifically to the digital servitization research stream. Our first research question (RQ1), addressing the types of AVSs, was answered through an integrative review of previous literature on autonomous solutions and digital servitization, resulting in a conceptual framework for analyzing AVSs and four types of AVSs. Our second research question (RQ2), addressing the associated digital servitization business models of those AVS types, was addressed with cases illustrating what types of digital servitization business models AVSs give rise to. In so doing, the study contributes threefold to our scholarly understanding on both autonomous solutions and digital servitization. First, the study constructed a conceptual framework to analyze and categorize AVSs based on the autonomy and complexity of AVS technology. The study classified emerging AVSs into four distinct categories. Second, the study discussed digital servitization business models associated with the AVSs through illustrative case examples. The contributions are elaborated in the following subsections.

6.1. Conceptual framework for categorizing AVSs

This study developed a conceptual 2-by-2 matrix framework to categorize AVSs and their digital servitization business models that builds on two dimensions. The horizontal dimension in the framework, complexity, distinguishes between 'single vehicle' and 'fleet'. The vertical axis, autonomy, includes 'semiautonomous' and 'fully autonomous' solutions. The framework confirms the applicability of semiautonomous vis-à-vis fully autonomous as defining the nature of the solution and depicts whether an AVS is focused on individual vehicles or a group of vehicles (fleet) that collaborate in a complex service ecosystem to create, deliver, and capture value. Therefore, the framework not only allows for classifying AVSs, but also suggests how their business models rely on digital servitization. For instance, Thomson et al. (2021) regard AVSs as an extremely advanced form of digital servitization, which draws attention to the transportation and mobility industries as future empirical research contexts that show signs of potential revolution and disruption. While Thomson et al. (2021) focused on servitization in business models, we focused on digital servitization business models including individual vehicles vis-à-vis a group of vehicles (a fleet) operating together in semiautonomous and fully autonomous solutions.

The conceptual framework was created from an analysis of 48 relevant publications on AVSs and digital servitization and it is a step towards novel frameworks to understand digital servitization (e.g., Frank et al., 2019; Kohtamäki et al., 2020). The framework also highlights the importance of service ecosystems (Edvardsson et al., 2011; Tronvoll, 2017; Sklyar et al., 2019a; Makkonen et al., 2022) and the integration of service innovation in those ecosystems (Brax and Visintin, 2017). Thus, informing the areas of business model design and ecosystem orchestration, the conceptual framework provides a tool to structure research on these topics with servitization in focus.

Our study identified four AVSs: *advanced-data-assisted solutions, semiautonomous platooning solutions, autonomous demarcated solutions, and autonomous swarmed solutions.* The literature on AVSs to date describes individual AVSs (Kurczewski, 2020; Engholm et al., 2020; Shladover, 2018; Schranz et al., 2021) rather than drawing on several AVSs and comparing them. We contribute to recent research on autonomous solutions (e.g., Frandsen et al., 2022; Thomson et al., 2021; Makkonen et al., 2022) and research on service ecosystems by showcasing how AVSs may be classified to identify digital servitization business models, especially the enacted and emerging digital servitization business models. Thus, the conceptual framework goes beyond merely classifying AVSs by introducing two previously undisclosed AVSs (semiautonomous platooning solutions, autonomous swarmed solutions) to the servitization literature.

6.2. Digital servitization business models in the AVS context

AVSs being an emergent field, there can be various business model taxonomies related to vehicle ownership (Stocker and Shaheen, 2018; Beirigo et al., 2022; Monios and Bergqvist, 2020), network operations (Stocker and Shaheen, 2018; Monios and Bergqvist, 2020), as well as a company's role in logistics (Fritschy and Spinler, 2019) and maturity levels for digital business models and their ecosystems (Thomson et al., 2021). Several studies bring forth analyses on autonomous vehicles and solutions where the servitization perspective is increasingly included (Frandsen et al., 2022; Thomson et al., 2021; Makkonen et al., 2022). For example, Makkonen et al. (2022) explore the digital servitization process of a solution provider to exemplify its transformation. Thomson et al. (2021) develop a maturity model for commercialization of autonomous solutions. Building on the level of autonomy (semi-autonomous and fully autonomous levels) in the context of ecosystems (Thomson et al., 2021), we propose that the digitalized service ecosystem prompts distinct patterns for AVSs, namely four unique AVSs. These, subsequently, introduce digital servitization business models, the case companies have transitioned by means of disruptive technology. Based on seven illustrative cases, we conceptualize digital servitization business models in the context of AVSs and identify four distinct digital servitization business models: (i) Safety as a service, (ii) Efficiency as a service, (iii) Capacity as a service, and (iv) Flexibility as a service.

- The *Safety-as-a-service* business model promotes safety in semi-autonomous and/or autonomous systems. More precisely, it utilizes safety as a value driver. The role of safety has been discussed extensively in prior AVS research (Cunningham et al., 2019; Lee et al., 2019; Martínez-Díaz and Soriguera, 2018; McCall et al., 2019; Osório and Pinto, 2019; Zhao et al., 2018).
- The *Efficiency-as-a-service* business model improves and streamlines business, focusing on effectivity and efficiency through digital servitization, which is also highlighted by servitization scholars (Fagnant and Kockelman, 2015; Kohtamäki et al., 2018; Sjödin et al., 2018; Leminen et al., 2018; Parida et al., 2019). The four digital servitization business models generally include a presumption of efficiency for the service ecosystems. However, efficiency was clearly identifiable in the illustrative cases related to the semiautonomous and fully autonomous solutions (AVS II and AVS III). In contrast to prior research on digital business models, where condition and location data of the goods and material are communicated among different actors in ecosystems (Leminen et al., 2018) or there exist predictive approaches for vehicles (Parida et al., 2019; Leminen et al., 2020), the present study explores the role of autonomous solutions in supporting human decision making as well as showcases the link between semiautonomous and autonomous solutions and digital servitization business models.
- The *Capacity-as-a-service* business model has been sparsely documented in the digital servitization literature. For example, prior literature discusses the role of continuous tracking of production in a factory but also shared data for machineries of digital business models and servitization solutions (Spring and Araujo, 2017; Leminen et al., 2020). Monios and Bergqvist (2020) suggest developing a business model for a transport service on a per km basis. Acknowledging prior contributions, we suggest that the *Capacity of a service* should not solely be seen as tracking moving raw material in a factory; rather, the *Capacity as a service* is building up and developing versatile value-adding service elements beyond 'outdoor operations'. The business model is based on a shift from mere monitoring to AVSs by including value-adding service elements, such as predictive maintenance and overall factory optimization, reaching for the highest output that may be obtained with a fixed level of staff,

installations, and equipment. Better usage of capacity results from more hours per vehicle, less wear and tear leading to longer lifespan of equipment and vehicles, but also more efficient and effective usage of staff resources.

- The *Flexibility-as-a-service* business model is sparsely discussed in the servitization and AVS literatures. For example, Monios and Bergqvist (2020) suggest utilizing an external pool of resources rather than managing and maintaining them. Forkmann et al. (2017), in turn, discuss reconfiguration of business models by capacity development of actors. Based on the illustrative case examples, we propose that the *Flexibility-as-a-service* digital servitization business model and its ecosystem may reconfigure itself independently when swarms of autonomous vehicles perform certain tasks. Sjödin et al. (2022) suggest an agile conceptualization and commercialization of new digital solutions with ecosystem partners. *Flexibility-as-a-service* extends the concept of agile conceptualization and commercialization towards autonomous reconfiguration (without formal decisions of ecosystem partners) of commercialized concepts in a context of AVS service ecosystem. Kohtamäki et al. (2019) define digital servitization business model as customization by tailoring solutions for customers. *Flexibility-as-a-service* thus advocates continuous, (hyper) rapid, and iterative reconfigurations of digital servitization business models, particularly in a context of AVSs, where autonomous vehicles in a swarm make autonomous decisions on how to organize themselves. The *Flexibility-as-a-service* – enabling *business model fluidity* – can meet the grand expectations embedded in the definition. Business model fluidity is not set in stone, but rather it assumes hyper-fast changes and reconfiguration of business models that are organized and implemented automatically by a swarm. In an extreme situation each customer and task may demand a different business model. The swarm automatically organizes, reconfigures, and optimizes itself and the business model depending on an active customer base and tasks that need to be fulfilled. The underlying value proposition of business model remains same, i.e., a company delivers, but everything else may change within a business model. Of note, we perceive that business model fluidity, due to its rapid and autonomous nature, is different from the more traditional concept of business model transformation that describes a slower change in value creation and appropriation. That is, both business model transformation and business model fluidity include changes of business models, but business model transformation assumes a starting point of a business model and its relatively slow emergence of business models towards targeted solutions (cf. Frank et al., 2019; Leminen et al., 2018).

6.3. Key theoretical contributions

The key theoretical contributions of the study are: (i) a conceptual framework for identification and classification of AVSs and their digital servitization business models, including a detailed methodological elaboration for replication and further development by scholars of digital servitization and autonomous solutions, (ii) through application of the framework, a taxonomy of four current AVS types and the identification of four enacted and emerging digital servitization business models regarding those AVS types, and (iii) an idea of fluidity of digital servitization business models when a swarm of autonomous vehicles make autonomous decisions on how to organize themselves and rapidly adapt the business model to a particular situation and customer needs. Our study shows how to merge established research fields (digital servitization and business models) with new contexts and emerging research (autonomous solutions) with the goal of disclosing new aspects and introducing nuances to established research, in addition to advancing knowledge of how digital servitization drives business model development in a specific context (autonomous solutions). We contribute firstly to research on digital servitization and business models (Kohtamäki et al., 2019; Parida et al., 2019; Sklyar et al., 2019a, 2019b; Eloranta et al., 2021), and secondly to research on autonomous solutions (Merfeld et al., 2019; Liu and Xu, 2020; Thomson et al., 2021).

Previous studies on business models offer conceptualizations for understanding digitalization and servitization. However, they often focus on utilizing various technologies in a variety of business areas (Paiola and Gebauer, 2020; Ritter and Pedersen, 2020; Leminen et al., 2018), while digital servitization literature is typically associated with understanding digitalization and ecosystems (Cenamor et al., 2017; Kohtamäki et al., 2019; Palo et al., 2019). Similarly, our study attempts to conceptualize digital servitization of AVSs in a B2B context and offer definitions for the needs, purposes, and uses of future scholarly research on digital servitization business models.

Frandsen et al. (2022) argue that there is a need for spatial understanding for the development and coevolution of business ecosystems in autonomous solutions. Accordingly, we emphasize the interplay between digital servitization business models and the context, i.e., autonomous solutions and AVSs. Hence, studying digital servitization business models 'in their context' and 'as they unfold' is an important contribution to the servitization literature. If the research is conducted when the context is early in its development, the theoretical approach used to explain the phenomenon should be robust. Therefore, combining theoretical dimensions and research streams may provide interesting new insights on how disruptive technologies affect ecosystems, business models, and servitization processes. In this study, combining the research streams of AVSs and digital servitization allowed for novel conceptual tools for scholars to understand the business of autonomous solutions and AVSs, along with associated servitization models driven by digitalization and digital technology. Also, the study suggested the concept of 'business model fluidity', reflecting rapid and autonomous business model changes and adaptation to various use and customer contexts.

6.4. Managerial implications

The present study suggests a conceptual framework for managers to analyze and categorize AVSs and their digital servitization business models in the B2B context. This framework enables managers and other practitioners to better comprehend the emerging landscape of AVSs and build their business models based on digital servitization in this context, especially in the transportation of goods and raw materials. *Advanced-data-assisted solutions* focus on assisting drivers. Its digital servitization business model *Safety as a service* indirectly impacts costs, e.g., operating costs, potentially lowering insurance premiums, and leading fleet owners to invest in equipment of safety systems. They are linked to risk management costs benefitting servitization models. For instance, in the case of an automatically sent emergency call eCall (https://digital-strategy.ec.europa.eu/en/news/ecall-all-new-cars-april-2018), the service enables quick reaction to accidents and incidents; the *Safety as a service* automatically launches emergency services to save lives. A vehicle manufacturer-based *Safety as a service* may be alerted regarding the accident and haul damaged equipment, locate the nearest workshops, repair the damaged vehicle as fast as possible and enable the vehicle operator to quickly return to tasks. Also, the *Safety as service* digital assistance systems enable tracking of causes for an accident by pooling different sources of information from legal and insurance standpoints. For managers, exploring the *Safety-as-a-service* digital servitization business model thus indicates not only added value to customers, but also reduced operating and risk management costs.

The *semiautonomous platooning solution* and its associated digital servitization business model focuses on *Efficiency as a service* and relies on several autonomous vehicles driving in a platoon to transport large amounts of goods. This study proposes that such solutions may be particularly beneficial for a carrier, who faces fierce cost competition. A semiautonomous platooning solution focuses on optimizing fuel consumption across the platoon and monitoring each individual vehicle in the platoon. Reduction of full time equivalent (FTE) of drivers in the

trucks leads to efficiency in semiautonomous platooning solutions. For example, the solution of an oil and gas software company (www.Peloton.com, multi-brand) was to add sensors (at a cost of approximately 15–20 thousand USD) to all trucks in a platoon utilizing platooning software other than from the original equipment manufacturer (OEM). However, given that the long-haul industry often has an average 2 % margin, it may be difficult to justify investments that include both the cost for the driver and the platooning solution.

Autonomous demarcated solutions are associated with the *Capacity-as-a-service* digital servitization business model. Our study proposes that such a solution may for example be beneficial for large industrial plants operating 24/7 in restricted areas, where managers face challenges in finding a skilled workforce. The business model is based on vehicles operating around the clock according to a desired speed, and there are no humans in the cabin of the vehicle. The business model enables the increase in machine availability and to develop maintenance services. The *Capacity-as-a-service* digital servitization business model has so far been successful (Rio Tinto, 2018); flow optimization of minitrucks at the Pilbarra and at other mine sites enable improvement of the flow of the mines and the output of the production at a lower cost. There are obvious benefits of better usage of capacity, leading to reductions of manpower cost, and a reduction down to 1.5 FTEs (compared with 5 FTEs on average), as well as great potential for on-site efficiency regarding personnel logistics, accommodation, insurance premiums, restaurants, medical services etc. (see Table 2). The digital servitization business model optimizes the flow of crossing traffic in mines and decreases idle time costs in tipping queues to crushers or loading stations etc. Hence, the constant flow and better usage of the capacity is achieved in the business model.

Finally, *autonomous swarmed solutions* and its *Flexibility-as-a-service* digital servitization business model is not yet fully operationalized. Our study proposes that new types of flexible swarm constructions or structure will be realized with service offerings. The service may be visualized by the example of Uber-comparable solutions (in B2C markets) for logistics. Such solution(s) enables new and agile players to challenge extant and well-established carriers also beyond their boundaries. The business model could potentially terminate businesses of carriers such as DB Schenker; their business model is to book a third-party logistics service provider at a relatively low income for the service provider but at a relatively high income for the logistic planner. Our study proposes that (in the future) logistics could be planned to use a platform(s) and thus revolutionize inner city distribution and long haul. The *Flexibility-as-a-service* digital servitization business model could bundle the logistics needs in lieu of the logistics planning company. With the promise of automatically adapting and fluid digital servitization business models, it would enable data-driven logistics planning with lower CO_2 emissions due to improved bundling of freight implemented by swarms of AVS, by lower price for the customer and a potentially higher income for the performer of the transport. In summary, our study suggests that AVSs offer multiple opportunities to industries.

6.5. Limitations and future research

Our study identified several illustrative case examples of the rapidly expanding AVS landscape. The extant body of AVSs literature has not focused on autonomous swarmed solutions. We were unable to find the entire operating case examples of the fourth AVS fully in operation. Rather, we identified bits and pieces associated with its digital servitization business model. Therefore, we attempted to explore the solutions in accordance with the literature, but also inspired by examples found in nature, especially regarding labeling and describing the models. We adopt a flock of birds and a swarm of insects such as bees and ants as metaphors to provide us with further understanding of the identified fourth AVS and its business model(s). Therefore, we call for more research on AVSs, particularly from the perspective of autonomous swarmed solutions and their digitalized servitization business models. Further, our study focused on categorizing and understanding AVSs and digital servitization business models associated with them rather than providing detailed measurements to assess the efficiency of such models. We suggest that future studies could further analyze the efficiency of the business models within the AVS industry but also adopt them horizontally across other industries. Also, we do not detail the digital servitization processes, how they unfold, and what they look like. Therefore, we call for more process-based studies on AVSs to understand the dynamics involved both at the level of the focal firm and the service ecosystem. Also, we call for more research on how to implement AVSs and under which contexts they might (not) be valuable for practitioners. Finally, we call for research on AVSs in diverse industries, as well as further exploration of the AVSs and their digital servitization business models in B2B settings, along with business model fluidity.

CRediT authorship contribution statement

Conceptualization, S.L., M.R., R.W., M.W., & AG.N; methodology, S.L., M.R., M.W., & AG.N software, S.L., M.R., M.W., & AG.N.; formal analysis, S.L., M.R., R.W., M.W., & AG.N.; investigation, S.L., M.R., R.W., M.W., & AG.N.; resources, S.L., M.R., R.W., M.W., & AG.N.; data curation, S.L., M.R., R.W., M.W., & AG.N.; writing—original draft S.L., M.R., R.W., M.W., & AG.N.; preparation, S.L., M.R. & M.W.; writing—review and editing, S.L., M.R., R.W., M.W., & AG.N; visualization, S.L., M.R., R.W., M.W., & AG.N.; supervision S.L.; project administration. S.L.; funding acquisition; S.L., M.R., R.W., M.W., & AG.N (all their own parts).

Data availability

Data will be made available on request.

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Appendix A. Key concepts related to autonomous vehicle solutions

AVS concept	Characteristics	Synonyms	Literature
Autonomous vehicle solution (AVS)	(i) senses its locations and spaces, (ii) has a capability to move and interact with its surroundings to fulfill value-producing activities, and (iii) includes digitally enabled services in autonomous operations		Broggi et al., 2013 Seo et al., 2016 Van Brummelen et al., 2018 Thomson et al., 2021
Autonomous vehicle	A vehicle capable of sensing its environment and moving safely with little or no human input		

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AVS concept	Characteristics	Synonyms	Literature
		Autonomous car, autonomous bus, autonomous truck, self-driving car, driverless car, robo-car	Gehrig and Stein, 1999 Hu et al., 2020
Autonomous solution	An advanced form of digital servitization. Three maturity levels: Level 1: operator assistance Level 2: semiautonomous operation Level 3: fully autonomous operation		Parida et al., 2019 Thomson et al., 2021
Autonomous system	(i) Utilizes information taken from its environment, (ii) analyzes outcomes, (iii) generates alternatives, and (iv) makes decisions in uncertainty		Pak et al., 2019
Servitization	Combining products and related services into a solution that provides a full continuum of products and services		Kuijken et al., 2017 Baines and Lightfoot, 2013
Digital servitization	Servitization solutions that use digital technologies		Kohtamäki et al., 2019 Sklyar et al., 2019a

Appendix B. Literature search result

#	Author(s)	Article title	Year	Journal
1	Thomson, Kamalaldin, Sjodin and Parida	A maturity framework for autonomous solutions in manufacturing firms: The interplay of technology, ecosystem, and business model	2021	*International Entrepreneurship and Management Journal*
2	Vendrell-Herrero, Bustinza and Vaillant	Adoption and optimal configuration of smart products: The role of firm internationalization and offer hybridization	2021	*Industrial Marketing Management*
3	Simonsson and Agarwal	Perception of value delivered in digital servitization	2021	*Industrial Marketing Management*
4	Paiola, Schiavone, Khvatova and Grandinetti	Prior knowledge, industry 4.0 and digital servitization. An inductive framework	2021	*Technological Forecasting and Social Change*
5	Paiola, Schiavone, Grandinetti and Chen	Digital servitization and sustainability through networking: Some evidence from IoT-based business models	2021	*Journal of Business Research*
6	Gaiardelli, Pezzotta, Rondini, Romero, Jarrahi, Bertoni, Wiesner, Wuest, Larsson, Zaki, Jussen, Boucher, Bigdeli and Cavalieri	Product-service systems evolution in the era of Industry 4.0	2021	*Service Business*
7	Chen, Visnjic, Parida and Zhang	On the road to digital servitization – The (dis)continuous interplay between business model and digital technology	2021	*International Journal of Operations and Production Management*
8	Hsuan, Jovanovic and Clemente	Exploring digital servitization trajectories within product–service–software space	2021	*International Journal of Operations and Production Management*
9	Linde, Frishammar and Parida	Revenue Models for Digital Servitization: A Value Capture Framework for Designing, Developing, and Scaling Digital Services	2021	*IEEE Transactions on Engineering Management*
10	Tian, Coreynen, Matthyssens and Shen	Platform-based servitization and business model adaptation by established manufacturers	2021	*Technovation*
11	Schrantz, Di Caro, Schmickl, Elmenreich, Arvin, Şekercioğlu and Sende	Swarm Intelligence and cyber-physical systems: Concepts, challenges and future trends	2021	*Swarm and Evolutionary Computation*
12	Ghosal, Sagong, Halder, Sahabandu, Conti, Poovendran and Bushnell	Truck platoon security: State-of-the-art and road ahead	2021	*Computer Networks*
13	Solem, Kohtamaki, Parida and Brekkev	Untangling service design routines for digital servitization: empirical insights of smart PSS in maritime industry	2022	*Journal of Manufacturing Technology Management*
14	Liu, Nikitas and Parkinson	Exploring expert perceptions about the cyber security and privacy of Connected and Autonomous Vehicles: A thematic analysis approach	2020	*Transportation Research Part F: Traffic Psychology and Behavior*
15	Berrada, Mouhoubi and Christoforou	Factors of successful implementation and diffusion of services based on autonomous vehicles: users' acceptance and operators' profitability	2020	*Research in Transportation Economics*
16	Lê and Nguyen	Digitizing Service Level Agreements in Service-Oriented Enterprise Architecture: Relevance of the Multi-perspective Approach	2020	*SN Computer Science*
17	Paiola and Gebauer	Internet of things technologies, digital servitization and business model innovation in BtoB manufacturing firms	2020	*Industrial Marketing Management*
18	Kamalaldin, Linde, Sjödin and Parida	Transforming provider-customer relationships in digital servitization: A relational view on digitalization	2020	*Industrial Marketing Management*
19	Tronvoll, Sklyar, Sörhammar and Kowalkowski	Transformational shifts through digital servitization	2020	*Industrial Marketing Management*
20	Kohtamäki, Parida, Patel and Gebauer	The relationship between digitalization and servitization: The role of servitization in capturing the financial potential of digitalization	2020a	*Technological Forecasting and Social Change*
21	Linde, Sjödin, Parida & Gebauer	Evaluation of Digital Business Model Opportunities: A Framework for Avoiding Digitalization Traps	2020	*Research Technology Management*
22	Qvist-Sørensen	Applying IoT and AI - Opportunities, requirements and challenges for industrial machine and equipment manufacturers to expand their services	2020	*Central European Business Review*
23	Simonsson, Magnusson & Johanson	Organizing the development of digital product-service platforms	2020	*Technology Innovation Management Review*
24	Gurumurthy and Kockelman	Modelling Americans' autonomous vehicle preferences: A focus on dynamic ride-sharing, privacy & long-distance mode choices	2020	*Technological Forecasting and Social Change*

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#	Author(s)	Article title	Year	Journal
25	Shit	Crowd intelligence for sustainable futuristic intelligent transportation system: a review.	2020	*IET Intelligent Transport System*
26	Liu and Xu	Public attitude towards self-driving vehicles on public roads: Direct experience changed ambivalent people to be more positive	2020	*Technological Forecasting and Social Change*
27	Pucihar, Zajc, Sernec and Lenart	Living lab as an ecosystem for development, demonstration and assessment of autonomous mobility solutions	2019	*Sustainability*
28	Kohtamäki, Parida, Oghazi, Gebauer and Baines	Digital servitization business models in ecosystems: A theory of the firm	2019	*Journal of Business Research*
29	Zheng, Wang, Chen and Pheng Khoo	A survey of smart product-service systems: Key aspects, challenges and future perspectives	2019	*Advanced Engineering Informatics*
30	Basirati, Weking, Hermes, Böhm and Krcmar	Exploring opportunities of ioT for product-service system conceptualization and implementation	2019	*Asia Pacific Journal of Information Systems*
31	Hudson, Orviska and Hunady	People's attitudes to autonomous vehicles	2019	*Transportation Research Part A: Policy and Practice*
32	Lee, Lee, Park, Lee and Ha	Autonomous vehicles can be shared, but a feeling of ownership is important: Examination of the influential factors for intention to use autonomous vehicles	2019	*Transportation Research Part C: Emerging Technologies*
33	Penmetsa, Adanu, Wood, Wang and Jones	Perceptions and expectations of autonomous vehicles – A snapshot of vulnerable road user opinion	2019	*Technological Forecasting and Social Change*
34	Li, Garces and Daim	Technology forecasting by analogy-based on social network analysis: The case of autonomous vehicles	2019	*Technological Forecasting and Social Change*
35	Osorio and Pinto	Information, uncertainty and the manipulability of artificial intelligence autonomous vehicles systems	2019	*International Journal of Human-Computer Studies*
36	McCall, McGee, Mirnig, Meschtscherjakov, Louveton, Engel and Tscheligi	A taxonomy of autonomous vehicle handover situations.	2019	*Transportation Research Part A: Policy and Practice*
37	Merfeld, Wilhelms, Henkel & Kreutzer	Carsharing with shared autonomous vehicles: Uncovering drivers, barriers and future developments – A four-stage Delphi study	2019	*Technological Forecasting and Social Change*
38	Wang, Wang, Ma and Liu	Demystifying the crowd intelligence in last mile parcel delivery for smart cities	2019	*IEEE Network*
39	Kaur and Rampersad	Trust in driverless cars: Investigating key factors influencing the adoption of driverless cars	2018	*Journal of Engineering and Technology Management*
40	Schladover	Connected and automated vehicle systems: Introduction and overview	2018	*Journal of Intelligent Transportation Systems*
41	Mommens, Lebeau, Verlinde, van Lier and Macharis	Evaluating the impact of off-hour deliveries: An application of the TRansport Agent-BAsed model	2018	*Transportation Research Part D: Transport and Environment*
42	Hulse, Xie and Galea	Perceptions of autonomous vehicles: Relationships with road users, risk, gender and age	2018	*Safety Science*
43	Van Brummelen, O'Brien, Gruyer and Najjarana	Autonomous vehicle perception: The technology of today and tomorrow	2018	*Transportation Research Part C: Emerging Technologies*
44	Martínez-Díaz and Soriguera	Autonomous vehicles: theoretical and practical challenges.	2018	*Transportation Research Procedia*
45	Rondini, Tornese, Gnoni, Pezzotta and Pinto	Hybrid simulation modelling as a supporting tool for sustainable product service systems: a critical analysis	2017	*International Journal of Production Research*
46	Cassetta, Marra, Pozzi and Antonelli	Emerging technological trajectories and new mobility solutions. A large-scale investigation on transport-related innovative start-ups and implications for policy	2017	*Transportation Research Part A: Policy and Practice*
47	Vendrell-Herrero, Bustinza, Parry and Georgantzis	Servitization, digitization and supply chain interdependency	2017	*Industrial Marketing Management*
48	Hu, Lu and Zhang	TPSQ: Trust-based platoon service query via vehicular communications	2017	*Peer-to-Peer Networking and Applications*

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