# Unraveling paradoxical tensions in digital servitization ecosystems : an analysis of their interrelationships from the technology provider's perspective

**Reference:**

Smania Guilherme Sales, Osiro Lauro, Ayala Néstor Fabián, Coreynen Wim, Mendes Glauco H.S..- Unraveling paradoxical tensions in digital servitization ecosystems : an analysis of their interrelationships from the technology provider's perspective

Technovation / Union Carbide. Chemicals Division - ISSN 1879-2383 - 131(2024), 102957
Full text (Publisher's DOI): https://doi.org/10.1016/J.TECHNOVATION.2024.102957
To cite this reference: https://hdl.handle.net/10067/2030930151162165141

# Unraveling paradoxical tensions in digital servitization ecosystems: An analysis of their interrelationships from the technology provider's perspective

Guilherme Sales Smania[a]; Lauro Osiro[b]; Néstor Fabián Ayala[c]; Wim Coreynen[d,e]*; Glauco H. S. Mendes[a].

[a] *Department of Production Engineering, Federal University of São Carlos, Washington Luiz Road km 235, São Carlos, SP, 13565-905, Brazil*

[b] *Department of Production Engineering, Federal University of Triângulo Mineiro, 1250 Dr. Randolfo Borges Junior Avenue, Uberaba, MG, 38064-200, Brazil*

[c] *Organizational Engineering Group (Núcleo de Engenharia Organizacional – NEO), Department of Industrial Engineering, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil*

[d] *School of Management, Zhejiang University, Yuhangtang Road 866, Hangzhou, Zhejiang Province, China*

[e] *Faculty of Business and Economics, University of Antwerp, Prinsstraat 13, 2000 Antwerp, Belgium*

*Corresponding Author: Wim Coreynen. Address: Zhejiang University, Zijingang Campus, Yuhangtang Road 866, Hangzhou, Zhejiang Province, China. Telephone: + 86 19564132925. E-mail: wim.coreynen@zju.edu.cn

## Abstract

Effective collaboration between manufacturers, technology providers, and customers is an issue of critical importance in digital servitization ecosystems. Nevertheless, creating and implementing smart solutions is complex and instigates paradoxical tensions among ecosystem actors, often leading to hurdles and possibly failures. Though recent studies have focused on identifying these tensions, a comprehensive understanding of their interrelationships is necessary. This study aims to identify the paradoxical tensions that exist among companies in digital servitization ecosystems as well as unravel their interrelationships. To address these objectives, we apply a multi-method approach. First, a systematic review of the literature reveals 16 paradoxical tensions arising from inter-firm collaboration. Next, based on interviews with academic and industry experts, we assess the relationships among these tensions. In particular, we focus on the perspective of technology providers due to their importance in delivering smart solutions. Finally, we apply Interpretive Structural Modelling (ISM) and fuzzy *Matrices d'Impacts Croises Multiplication Appliqué a un Classement* (MICMAC) to the experts' responses to define the interrelationships between the identified tensions and cluster them based on their driving and dependence power. We adopt a paradox theory lens to classify the identified tensions into four categories—i.e., learning, belonging, organizing, and performing—and provide a conceptual framework showing their cause-and-effect relationships. We reveal that paradoxical tensions in digital servitization ecosystems do not exist in isolation; rather, they are interconnected. Furthermore, we provide practical recommendations for managers to cope with such tensions as well as suggestions for future research.

**Keywords:** Digital servitization; Digital servitization ecosystems; Inter-firm collaboration; Inter-organizational tensions; Agricultural machinery industry; Paradox lens.

## 1. Introduction

With advancements in digital technologies, many manufacturers are transforming towards offering smart solutions, i.e., packages or "bundles" of products, services, software, and intelligence (Favoretto *et al*., 2022; Frank *et al*., 2019). However, this transformation, known in the academic literature as digital servitization, goes beyond the manufacturer´s own organizational boundaries (Chen *et al*., 2021; Huikkola *et al*., 2022), as providing smart solutions requires effective collaboration between different ecosystem actors integrating technologies, capabilities, and processes (Dalenogare *et al*., 2023). On top of the opportunities provided by effective collaboration, digital servitization also create many challenges for companies (Favoretto *et al*., 2022; Frank *et al.,* 2022; Tronvoll *et al.,* 2020), some specifically referred to as paradoxical tensions (Tóth *et al*., 2022).

Tensions are contradictory and interrelated differences that exist within and between organizations, often caused by ambiguity from different sources, that reflect conflicting, non-combinable viewpoints or intentions (Fang *et al.*, 2011; Korkeamäki *et al.,* 2022; Raza-Ullah *et al.*, 2014). Moreover, tensions can include paradoxes (Smith and Lewis, 2011), which the literature refers to as persistent contradictions between interdependent elements (Smith and Lewis, 2011; Jarzabkowski *et al.*, 2013). For instance, Korkeamäki *et al*. (2022) recently discussed several paradoxical tensions when offering solutions, such as the need of industrial service providers to balance both formal and informal control mechanisms (e.g., contracts, trust), and of their customers to share knowledge with the provider while also preventing knowledge leakage. Hence, we use the term "paradoxical tensions" to refer to the discomfort and stress experienced by companies in digital servitization ecosystems that originate from the perception of contradictions (Raza-Ullah *et al.* 2014; Dmitrijeva *et al.,* 2022).

With this article, we aim to address three knowledge gaps in the current literature. First, we find that, so far, mainly *intra*-organizational tensions arising from digital servitization have received attention (e.g., Dmitrijeva *et al.,* 2022; Kohtamäki *et al*., 2019; Tóth *et al.,* 2022). Although valuable, this internal perspective does not consider *inter*-organizational tensions that emerge between ecosystem actors (Galvani and Bocconcelli, 2022). Similar to generative innovation ecosystems (Thomas and Tee, 2022), digital servitization ecosystems include actors with different goals, ambitions, and worldviews, which give rise to inter-organizational tensions (Cennamo and Santaló, 2019; Korkeamäki *et al.,* 2022) that can undermine their efforts towards digital servitization (Galvani and Bocconcelli, 2022). Moreover, studies that consider inter-organizational tensions often focus on specific relationships, such as the manufacturer-customer dyad (e.g., Eggert *et al.,* 2022; Korkeamäki *et al.,* 2022) and the manufacturerintermediary-customer triad (e.g., Burton *et al.,* 2016; Galvani and Bocconcelli, 2022). However, new technology companies that provide systems and tools for connectivity, artificial intelligence, and analytics, and which are continually joining digital servitization ecosystems (Hanelt *et al*., 2021; Jovanovic *et al*., 2021), have been largely neglected. Given the strategic and sensitive nature of their new technologies, technology providers face unique inter-organizational tensions that are different from those of more traditional servitization actors, such as manufacturers, service intermediaries, and customers (Miehé *et al*., 2023). To address this gap, we propose our first research question (RQ1)—*What paradoxical tensions arise from inter-firm collaboration in digital servitization ecosystems?*—and we aim to answer this question from the technology provider's perspective.

Second, prior studies have focused on paradoxical tensions in mostly a descriptive manner (e.g., Eggert *et al.,* 2022; Korkeamäki *et al.,* 2022). However, how certain tensions lead to new ones and also how they interact with others must be better understood (Tóth *et al*., 2022). For instance, Jarzabkowski *et al.* (2013) stated that tensions are generally unlikely to exist in isolation; rather, they influence each other. More recently, Visnjic *et al*. (2022) argued that existing tensions can lead to new ones, for example, the conflict of interest between manufacturers' product and service units creates internal power struggles for priority over selling new machines versus digital services. Hence, the interplay between paradoxical tensions means that one specific manifestation might escalate or evolve into another (Oliveira and Lumineau, 2019). Despite these insights, the process of how paradoxical tensions in digital servitization ecosystems influence each other remains unclear. To unravel these cause-and-effect relationships, we propose the second research question (RQ2): *How are paradoxical tensions in digital servitization ecosystems interrelated?*

Third, there still is a lack of understanding of the relative importance of paradoxical tensions and how to prioritize them in practice (Tóth *et al*., 2022). Identifying and prioritizing the most critical tensions is essential for companies to succeed in digital servitization, because it allows practitioners to redirect their attention from less urgent issues to more critical ones (Korkeamäki *et al*., 2022). One way to prioritize tensions is to classify them based on the extent to which they influence or drive others (Sandvik *et al*., 2022). Therefore, it is necessary to define their driving and dependence power: The former refers to the degree to which tensions influence other tensions, the latter represents the degree to which they are influenced by others (Muruganantham *et al*., 2018). Thus, tensions with a high driving power are considered the cause of other tensions; in turn, tensions showing a high dependence power are a result of other tensions (Bhosale and Kant, 2016). To move ahead in classifying paradoxical tensions in digital servitization, we propose the third and final research question (RQ3): *What are the most influential paradoxical tensions in digital servitization ecosystems?*

To answer these research questions, this study proposes a conceptual framework demonstrating the cause-and-effect interrelationships between inter-organizational, paradoxical tensions in digital servitization ecosystems from the technology provider's perspective. The framework is developed based on a multi-method research approach. First, a systematic review identifies a set of tensions related to digital servitization ecosystems. Second, Interpretive Structural Modelling (ISM) reveals the interrelationships among them. Third, fuzzy *Matrices d'Impacts Croises Multiplication Appliqué a un Classement* (MICMAC) analysis classifies them based on their driving and dependence powers. We employ paradox theory to discuss the ISM and fuzzy MICMAC results. As suggested by other studies (e.g., Dmitrijeva *et al*., 2022; Tóth *et al*., 2022), our framework evokes Smith and Lewis' (2011) conceptualization of different paradoxical tensions, specifically divided into learning, belonging, organizing, and performing tensions.

Specifically, we concentrate on the perspective of technology providers in the agricultural machinery industry. These companies are critical actors in providing smart solutions for precision agriculture, particularly as they have increasingly developed Industry 4.0 technologies for machinery manufacturers. Furthermore, the agricultural sector is an interesting setting for research into digital servitization ecosystems, since agricultural machinery manufacturers and technology providers have intensified their collaboration to deliver smart solutions to farmers (Smania *et al*., 2022). For instance, AGCO and John Deere have made considerable investments in technologies to connect their equipment to third-party systems (e.g., irrigation systems, weather stations, and telemetry systems) and provide agronomic solutions that optimize the overall performance of agricultural operations (Porter and Heppelmann, 2014).

This study extends the digital servitization literature and its exploration of tensions and paradoxes in ecosystems in five specific ways. First, we answer the calls for more investigation into the inter-organizational tensions related to digital servitization by expanding the range of tensions arising from inter-firm collaboration (Stegehuis *et al*., 2023; Tóth *et al*., 2022); specifically, this study identifies and discusses 16 tensions. Second, this study progresses prior digital servitization research based on paradox theory: Instead of using the paradox lens in the intra-organizational context, it investigates the paradoxical tensions in inter-organizational relationships in ecosystems. Third, it proposes a conceptual framework that provides insight into the cause-and-effect relationships of paradoxical tensions, organizing them into three clusters (i.e., independent, linkage, and dependent tensions) based on their driving and dependence power. Hence, we reveal that tensions in digital servitization ecosystems often do not arise in isolation but influence each other. Fourth, while previous digital servitization studies have focused mainly on investigating manufacturers (e.g., Chen *et al*., 2021; Sklyar *et al*., 2019) and customers (e.g., Kamalaldin *et al.,* 2021; Sjödin *et al.,* 2021), we bring the technology provider's perspective to the foreground. Finally, fifth, this study answers the call for more quantitative research on digital servitization (Favoretto *et al*., 2022) by using a multi-method approach based on a systematic literature review, ISM, and fuzzy MICMAC.

The remainder of the paper is organized as follows: Section 2 summarizes the literature on ecosystems and digital servitization, as well as tensions in inter-firm collaboration; section 3 outlines the research method; section 4 presents the study's objective results; section 5 discusses them in further detail; finally, section 6 sums up the study's theoretical contributions and offers extensive managerial implications as well as opportunities for further research.

## 2. Conceptual background

### *2.1 An ecosystem perspective on inter-firm collaboration in digital servitization*

Ecosystems have been defined as *"the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize"* (Adner, 2017, p. 40). Based on the ecosystem literature (e.g., Adner, 2017; Cennamo and Santaló, 2019; Gomes *et al*., 2021), we summarize that (i) ecosystems involve collective actions executed by a group of actors; (ii) they blur boundaries and alter established firm interdependencies and network positions; (iii) although ecosystems are not fully hierarchically controlled (e.g., formal mechanisms are often absent), their actors show high levels of hierarchical independence; and (iv) ecosystem actors share a specific system-level orientation or goal. Over the years, the ecosystem concept has been applied to different contexts, such as business ecosystems (Moore, 1993), platform ecosystems (Bonina *et al*., 2021; Kapoor *et al*., 2022), entrepreneurial ecosystems (Spigel *et al*., 2017), and knowledge ecosystems (Clarysse *et al*., 2014).

Since recently, the ecosystem perspective is also used by digital servitization[1] studies (e.g., Dalenogare *et al*., 2023; Kohtamäki *et al*., 2019; Sklyar *et al*., 2019). These studies have

---

[1] The concept of digital servitization originated from the convergence between digitalization and servitization (Frank *et al*., 2019). It refers to the use of digital technologies in the process of transforming manufacturers towards service-oriented business models (Kohtamäki *et al*., 2019; Sklyar *et al*., 2019). Recently, researchers question the use of the "digital" prefix: "servitization today is essentially all digital, driven or enabled by novel data and technological opportunities" (Kowalkowski *et al*., 2022, p. 60). In line with other recent studies (Chen *et al*., 2021; Dalenogare *et al*., 2023; Kolagar *et al*., 2022; Tronvoll *et al*.,

highlighted that manufacturers collaborate and integrate resources, capabilities, and activities with other actors in the ecosystem (e.g., service partners, technology providers) to overcome their own limitations in the provision of smart solutions (Chen *et al*., 2021; Kolagar *et al*., 2022). Such inter-organizational relationships are facilitated by digitalization, enabling new forms of interaction between ecosystem actors and creating new opportunities for value co-creation (Tronvoll *et al*., 2020). The ecosystem perspective has gained prominence in digital servitization, as inter-firm collaboration allows companies to access customer data (Vendrell-Herrero *et al*., 2017), share technologies and capabilities (Smania *et al*., 2022), and integrate different service functionalities into smart solutions (Ferreira and Lind, 2023).

Nevertheless, although companies in ecosystems ought to work together based on commitment, trust, and reciprocity to develop win-win inter-firm relationships, many resist sharing assets and information when creating and implementing smart solutions (Kamalaldin *et al*., 2021). Therefore, digital servitization ecosystems are often characterized by loosely coupled relationships wherein actors decide on their level of commitment without any form of hierarchical control from the ecosystem leader (Miehé *et al*., 2023). This triggers potential risks of ecosystem fragmentation. For example, when platform owners grant autonomy to module providers, the latter can unilaterally decide where to allocate the platform resources, which increases the challenges for the platform owner to ensure that quality standards are met and modules are properly integrated (Wei *et al*., 2022). Hence, although including new actors in the ecosystem contribute to generativity (i.e., the ecosystem's capacity to promote flexibility, openness, variability, and adaptability, resulting in more innovation and adaptation) (Thomas and Tee, 2022), the risk of unfiltered and uncoordinated contributions undermining digital servitization initiatives increases. Despite the general understanding that the nature of digital servitization ecosystems creates competitive tensions between companies (Sandvik *et al*., 2022), the literature still lacks a thorough investigation of tensions at the ecosystem-level when multiple actors collaborate to offer smart solutions (Tóth *et al*., 2022; Tronvoll *et al*., 2020).

### *2.2 A paradox perspective on tensions in digital servitization ecosystems*

Paradox theory provides a useful lens for understanding tensions arising from inter-firm collaboration in digital servitization ecosystems (Kohtamäki *et al*., 2020; Tóth *et al*., 2022). Paradoxes are "contradictory yet interrelated elements that exist simultaneously and persist

---

2020), this article still employs the full term "digital servitization", as it reinforces the role of digitalization in creating new services and transforming manufacturers' business models (Favoretto *et al*., 2022).

over time" (Smith and Lewis, 2011, p. 382). This definition highlights the two essential components of paradoxes: (i) their underlying tensions, and (ii) actors' responses that embrace these tensions simultaneously (Smith and Lewis, 2011). Thus, paradoxes advocate a dynamic equilibrium to manage tensions, meaning that contradictions are inherent and can be a powerful source of enhanced performance, if harnessed effectively (Tóth *et al*., 2022).

Research on digital servitization often uses paradox theory as lens to investigate tensions from different actors' viewpoints. For instance, some studies have used it to analyze firm-level tensions that manufacturers undergo when implementing servitization (e.g., Dmitrijeva *et al*., 2022; Kohtamäki *et al*., 2020), while other studies have used it to investigate inter-organizational tensions that digital servitization triggers at the ecosystem-level (e.g., Eggert *et al*., 2022; Galvani and Bocconcelli, 2022; Sandvik *et al*., 2022). However, some research gaps still need to be addressed for a more comprehensive understanding (Tóth *et al*., 2022). In particular, the literature so far has sought to identify and describe paradoxical tensions as well as appropriate actions to cope with them, though it has not yet explored how they are interrelated. Paradoxical tensions rarely appear in isolation and can even lead to new ones, if they are not treated appropriately (Jarzabkowski *et al*., 2013). Therefore, an analysis of the cause-and-effect relationships between paradoxical tensions is necessary. Such insights would allow for an early diagnosis of potential threats to successful collaborations in digital servitization ecosystems, providing insights for ecosystem actors to take appropriate preventive action to curb their influence and halt their evolution. Also, it would help decision-makers identify the most influential tensions to which greater importance should be assigned more urgently.

As previously suggested (e.g., Dmitrijeva *et al*., 2022; Tóth *et al*., 2022), we evoke Smith and Lewis' (2011) conceptualization of four different paradoxical tensions as foundations for our classification. First, learning tensions emerge when innovation transforms ecosystems and generates opposing demands on building new knowledge from exploiting pre-existing concepts and exploring new ideas (Clauss *et al*., 2021). Second, belonging tensions reflect identity-related issues that arise when actors aim to become influential while seeking to create interconnections with others (Kocabasoglu-Hillmer *et al*., 2023). Third, organizing tensions surface when collaboration requires conflicting processes, for instance, cooperation versus competition (Sandvik *et al*., 2022), control versus flexibility (Korkeamäki *et al*., 2022), and customization versus operational efficiency (Kohtamäki *et al*., 2020). Finally, fourth, performing tensions result from the divergence between actors' multiple goals, strategies, and interests, whereby one actor's gains may result in loss for another (Jarzabkowski *et al*., 2013).

## 3. Research method

To address the research questions, we adopted a multi-method approach. First, we conducted a systematic literature review to identify the paradoxical tensions resulting from inter-firm collaboration in digital servitization ecosystems. Second, we carried out expert interviews to validate the preliminary list of tensions and assess the relationships among them. Third, we applied the ISM technique to evaluate the experts' responses and analyze the interrelationships between each pair of tensions (Muruganantham *et al.*, 2018). Finally, we applied the fuzzy MICMAC technique to the responses obtained to evaluate each relationship's intensity and then classify each tension according to its driving and dependence powers (Bhosale and Kant, 2016).

The combination of ISM and fuzzy MICMAC techniques is a powerful way to unravel cause-and-effect relationships. ISM analyzes the interactions between the elements of a system and provides a structural model showing the hierarchical relationships between them (Muruganantham *et al.*, 2018). Therefore, it has been increasingly used to demonstrate how certain elements are interrelated and how they can evolve within a system (Kamble *et al.*, 2018). Fuzzy MICMAC, in turn, classifies these elements based on their driving and dependence power (Bhosale and Kant, 2016). It is a useful tool for analyzing a system's most critical elements based on the degree to which they affect other elements. The combination of these two techniques—ISM and fuzzy MICMAC—has gained prominence in the literature. Two examples are the studies by Sienkiewicz-Małyjurek (2022), which describes how collaboration risks in public safety networks can evolve, and Kamble *et al.* (2018), which investigated the adoption barriers of Industry 4.0 for manufacturers, revealing the most critical barriers that require urgent attention from firms' decision-makers. In the servitization field, Smania *et al.* (2022) applied these techniques to uncover the interrelationships between digitalization and ecosystem-related capabilities, proposing a pathway for manufacturers to develop innovative services through these capabilities. Therefore, we consider the combination of ISM and fuzzy MICMAC to be a good fit for investigating the interrelationships between paradoxical tensions in digital servitization ecosystems and for evaluating the most influential tensions. In the following subsections, we explain our methodological approach in further detail.

### *3.1 Systematic Literature Review*

A systematic literature review (Tranfield *et al.*, 2003) was conducted in order to identify a preliminary list of tensions. Initially, searches were carried out in the Scopus and Web of Science databases since they contain journals from leading publishers (e.g., Emerald, Elsevier, Taylor &

Francis) and are continuously updated (Alghababsheh and Gallear, 2020). The keywords were based on the digital servitization literature (Table 1), and the Boolean expression (AND) was used between the two sets of keywords. This string was searched in the articles' titles, abstracts, and keywords, returning an initial sample of 5,030 articles (3,196 in Scopus and 1,834 in Web of Science). We performed this search in December 2021.

**Table 1 - Keywords used in the search strings for titles, keywords, and abstracts**

| Terms | Keywords | Reference |
|---|---|---|
| Servitization | (serviti*ation OR "product-service system*" OR "integrated solution*" OR "smart service*" OR "service transformation" OR "service infusion" OR "advanced service" OR "service transition" OR "digital serviti*ation" OR "digital PSS" OR "smart product-service system*" OR "smart PSS" OR "smart serviti*ation") | (Baines *et al*., 2017; Paschou *et al*., 2020) |
| Digitalization | (digitali*ation OR digiti*ation OR "emerging technologies" OR ICT OR "big data" OR "cloud computing" OR "internet of things" OR IoT OR "remote control" OR "remote monitoring" OR "digital manufacturing" OR "digital technolog*" OR "digital transformation" OR "Industry 4.0" OR "predictive analytic*" OR "advanced manufacturing" OR "additive manufacturing" OR "augmented reality" OR "virtual reality" OR simulation OR cybersecurity OR "cyber-physical system*" OR RFID OR "automation and industrial robots" OR "3D printing" OR "smart data" OR smartization OR "smart manufacturing" OR "smart factory") | (Ardolino *et al*., 2018; Martín-Peña *et al*., 2018; Paschou *et al*., 2020) |

Next, we defined four eligibility criteria that allowed us to filter the initial sample. First, we adopted the following inclusion criteria: (i) document type ("articles" and "reviews") and (ii) language (English). Thus, given the absence of a more rigorous evaluation process, we excluded documents from the grey literature (e.g., conference papers and book chapters). This criterion reduced the initial sample to 2,134 articles (1,186 in Scopus and 948 in Web of Science). Second, we removed duplicate documents, which resulted in a sample of 1,371 articles. Third, a screening process was performed, in which we read the articles' titles, keywords, and abstracts. We selected articles that (i) are related to digital servitization, (ii) deal with product companies, and (iii) are empirical, as we are interested in practical evidence of tensions in collaboration. This screening process resulted in a sample of 246 articles. Fourth, a new screening process was carried out, in which we read the articles' introduction, research method, results, and contributions. We included in the sample only articles that address inter-firm collaboration and digital servitization ecosystems, excluding articles that either did not address these themes or merely mention them. As a result, a sample of 111 articles was obtained. After these procedures, we carried out a backward snowball process to overcome possible limitations in the research protocol (Wohlin, 2014) and included five new articles highly cited by the papers in the sample (e.g., Svahn *et al*., 2017). Therefore, the final sample consists of 116 focal articles.

To analyze the focal articles, we employed content analysis techniques. These techniques allowed us to categorize the textual data (Gioia *et al*., 2013). Supported by the NVivo 11 software, we read the articles in full and identified 502 text fragments referring to tensions and paradoxes. We then categorized these text fragments following an inductive-deductive approach and open coding system (Gioia *et al*., 2013). The categorization process resulted in 33 first-order codes. By grouping them, 16 second-order codes emerged that reflect tensions arising from the inter-firm collaboration. Two authors participated in this coding process, and the other authors were involved in the final categorization, thus ensuring reliability in the content analysis results (Archibald, 2016).

### *3.2 Expert interviews*

Initially, we invited two external researchers with extensive experience in digital servitization to assess the tensions identified in the previous stage. They provided insights and validated the preliminary list of tensions. We then developed the Structural Self-Interaction Matrix (SSIM) to evaluate the relationships among the investigated paradoxical tensions. Two other academics and two industry experts assessed the accuracy of the research instrument through a pre-test. They recommended minor modifications in the wording to facilitate filling out the matrix.

Once the final version of the research instrument was completed, we selected both academic and industry experts to participate in the study. We invited academic experts with extensive experience in digital servitization and precision agriculture research as well as experts from technology providers involved with smart product solutions for the agricultural machinery industry (e.g., services for managing agricultural processes, machine telemetry, meteorological services, and agronomic modelling). Though these ecosystems also include machinery manufacturers, input suppliers, service partners (e.g., dealerships), and farmers, we specifically focus on the technology providers´ point of view for this study. To be considered for participation, the experts should hold senior management positions within the company and be actively involved in relationships within the ecosystem.

The selected experts were then invited to participate through invitation e-mails, in which we explained the study’s objectives and asked for their contribution. If they agreed, we sent the research instrument, which is a document explaining each tension, and instructions for completing the matrix. As a result, we collected complete answers from 20 experts (see Table 2). According to Murry Jr. and Hammons (1995), a solid qualitative decision-making process can derive from a sample of 10 to 30 experts, which justifies our sample. Furthermore, our sample is consistent with recent studies using this research method (e.g., Chen *et al*., 2022; Kamble *et al*., 2018; Kumar *et al*., 2022; Smania *et al*., 2022). After collecting their answers and analyzing the results, we conducted in-depth interviews with four experts (e2, e7, e9, and e13) to better understand their experiences and opinions regarding the preliminary findings. These data were collected from September until December 2022.

**Table 2 - Details of the experts**

| Expert | Description |
|---|---|
| e1 | Head of agribusiness and partnerships at a provider of farm monitoring solutions with 15 years of experience. |
| e2 | Service and project manager for Latin America at a provider of monitoring and automation solutions for agricultural processes with seven years of experience. |
| e3 | CEO and founder of a provider of digital platforms for agronomic management with 11 years of experience. |
| e4 | Service manager at a provider of farm operations management and machine monitoring solutions with 30 years of experience. |
| e5 | Business manager at a provider of control systems for agricultural operations with 18 years of experience. |
| e6 | Product manager at a provider of control systems for agricultural operations with 20 years of experience. |
| e7 | Director and co-founder of a provider of platforms for monitoring agricultural machinery and assets with 30 years of experience. |
| e8 | Head of business and co-founder of a provider of agricultural diagnostic and weed identification solutions with 13 years of experience. |
| e9 | Business development manager for Latin America at a provider of platforms for managing agronomic data with four years of experience. |
| e10 | Commercial director at a provider of weed control solutions with 30 years of experience. |
| e11 | Head of product at a provider of agricultural diagnostic and weed identification solutions with 11 years of experience. |
| e12 | Sales director at a provider of crop protection solutions with 22 years of experience. |
| e13 | Head of agribusiness at a meteorological solutions provider with 25 years of experience. |
| e14 | IT manager and head of technology at a provider of agricultural diagnostic and weed identification solutions with five years of experience. |
| e15 | P&D manager at a provider of platforms for monitoring agricultural machinery and assets with 15 years of experience. |
| e16 | Regional operations manager at a provider of platforms for managing farm data with seven years of experience. |
| e17 | Commercial manager at a provider of agronomic modelling and artificial intelligence solutions with 21 years of experience. |
| e18 | Professor in Industrial Engineering with over 15 years of experience in Industry 4.0 and agro-industrial ecosystems research. |
| e19 | Assistant professor in Industrial Engineering with over ten years of experience in Industry 4.0 and digital servitization research. |
| e20 | Assistant professor in Industrial Engineering with over ten years of experience in Industry 4.0 and Agriculture 4.0 research. |

### *3.3 Interpretative structural modelling*

ISM is widely used to determine the hierarchical relationships among elements within a system, given its effectiveness in measuring their interrelationships (Warfield, 1974). In ISM, a finite set of *n* elements is represented by the system $S$ = $(s_1, \ldots, s_i, \ldots, s_n)$ and the SSIM analyzes the existing relationships between each pair of these *n* elements ($s_i$ and $s_j$). In this sense, it analyzes whether one element of the system leads to another. In this research, we identified 16 tensions and investigated their interrelationships through a 16*16 SSIM. Following Muruganantham *et al*. (2018), we conducted ISM in five steps. Firstly, we collected data from experts and asked them to fill in the SSIM according to the following codes:

*V: Tension i leads to Tension j;*

*A: Tension j leads to Tension i;*

*X: Tensions i and j lead to each other; and*

*O: Tensions i and j are unrelated.*

Secondly, we unified the 20 responses based on the most frequent codes for each SSIM entry. Thirdly, we converted the unified SSIM into the Initial Reachability Matrix. This matrix is binary and expresses whether or not there is a relationship between each pair of tensions. For this conversion, the following rules were used:

1. *If the entry (i, j) in SSIM is V, then the entries (i, j) and (j, i) in the reachability matrix are 1 and 0, respectively;*
2. *If the entry (i, j) in SSIM is A, then the entries (i, j) and (j, i) in the reachability matrix are 0 and 1, respectively;*
3. *If the entry (i, j) in SSIM is X, then both the entries (i, j) and (j, i) in the reachability matrix are 1; and*
4. *If the entry (i, j) in SSIM is O, then both the entries (i, j) and (j, i) in the reachability matrix are 0.*

Fourthly, the Initial Reachability Matrix was converted into the Final Reachability Matrix based on the transitivity condition. According to this condition, if Tension A leads to Tension B, for instance, and Tension B leads to Tension C, then Tension A also leads to Tension C. Finally, we partitioned each tension. Based on the Final Reachability Matrix entries, we defined the reachability, antecedent, and intersection sets for the 16 tensions. For each tension, the reachability set consists of the tensions driven by it, the antecedent set comprises the tensions that lead to it, and the intersection set includes the tensions that are simultaneously present in the two previous sets (Kamble *et al*., 2018). We compared the reachability and intersection sets for each one. When they were equal, the corresponding tension was placed at the top level of the ISM hierarchy. Then, this tension was removed from the system, and both sets were compared again. We repeated this process until we found the hierarchical level of all tensions in the system.

### *3.4 Fuzzy MICMAC analysis*

Fuzzy MICMAC was applied to cluster the tensions according to their driving and dependence powers, thus allowing us to evaluate which tensions most affect the others. This research method enables the fuzzification of the intensity of the relationship between two elements, so it is a highly appropriate method to complement the binary approach of the ISM (Bhosale and Kant, 2016). To apply fuzzy MICMAC in this research, we followed six steps. First, we converted the Initial Reachability Matrix into the Binary Direct Reachability Matrix (BDRM), replacing the values in the diagonal with zero. Second, we determined the Frequency Direct Relationship Matrix by counting how many experts responded that Tension *i* leads to Tension *j* and by multiplying the values in BDRM. Third, we examined the strength of each relationship based on the scale in Table 3. The assignment rules determined the strength of the relationships according to experts' response frequency. The fuzzy scale with five different degrees of intensity (i.e., no, weak, medium, strong, and very strong) was also applied by Kamble *et al*. (2018) and Smania *et al*. (2022).

**Table 3 - Fuzzy scale and assignment rules to define the strength of the relationships**

| Strength | Value assigned | Experts' response frequency |
|---|---|---|
| No | 0 | 0-7 |
| Weak | 0,25 | 8-10 |
| Medium | 0,5 | 11-13 |
| Strong | 0,75 | 14-16 |
| Very strong | 1 | 17-20 |

Fourth, we converted the Frequency Direct Relationship Matrix into the Fuzzy Direct Reachability Matrix (FDRM) based on the assignment rules in Table 3. For this, we replaced each entry in the matrix with the value assigned in the second column of Table 3. Fifth, we determined the Fuzzy MICMAC Stabilized Matrix. Supported by the MATLAB program, the FDRM was multiplied using the max-min function in Equation (1), proposed by Kandasamy *et al*. (2007). Although there are other fuzzy compositions to measure the strength of relationships (e.g., max-product, max-average), the max-min function is most appropriate for the present study, as it analyzes the maximum of all minimum impacts of Tension *i* on Tension *j* (Zimmermann, 2011). This procedure was performed repeatedly until the hierarchies of power and dependence stabilized, generating the Fuzzy MICMAC Stabilized Matrix.

$$T = U.V = \max n \, [\min(x_{in}, y_{nj})] \tag{1}$$

Here, $U = x_{in}$ and $V = y_{nj}$.

Finally, a cluster diagram was derived from each tension's driving and dependence powers. The driving and dependence powers were obtained by summing the entries in the rows and columns of the Fuzzy MICMAC Stabilized Matrix. Based on these values, tensions were positioned on the cluster diagram and classified into four types: independent, linkage, dependent, and autonomous tensions (Bhosale and Kant, 2016). First, independent tensions have high driving and low dependence power, strongly boosting other tensions and able to leverage new ones. Second, linkage tensions have simultaneously high driving and dependence powers. They are strongly interrelated within the system, since any change in one will quickly affect the others. Third, dependent tensions have low driving and high dependence powers, exhibiting characteristics of output variables within the system, so they are a consequence of independent and linkage tensions. Fourth, autonomous tensions have low driving and dependence powers, therefore they are considered as disconnected from the system (Kamble *et al.*, 2018; Muruganantham *et al.*, 2018). We adopted the value 14 for the limits of the diagram, because it was the closest integer to the maximum driving/dependence power.

## 4. Results

### 4.1 Paradoxical tensions in inter-firm collaboration in digital servitization ecosystems

The final list of paradoxical tensions was defined based on a review of the literature and the assessment of academic experts. The literature review identified 16 tensions arising from inter-firm collaboration in digital servitization ecosystems (Table 4). Two academic experts then validated this list and advised us to proceed with the ISM and Fuzzy MICMAC methods, without adding any tension to be analyzed. It is worth mentioning that industry experts could propose new tensions to be investigated (e.g., cultural differences) when we applied the SSIM. However, we did not include them in the final list, because they were suggested by only one expert and are not specific to the context of digital servitization ecosystems.

**Table 4 – Paradoxical tensions arising from inter-firm collaboration in digital servitization ecosystems**

| # | Tensions | Description | Key references |
|---|---|---|---|
| T1 | *Divergence of goals* | Tensions arising from actors pursuing different goals. | Altmann and Linder (2019); Bigdeli *et al.* (2021); Wagstaff *et al.* (2021a) |
| T2 | *Poorly defined responsibilities* | Tensions arising from the unclear definition of actors' responsibilities for providing smart solutions. | Grubic and Jennions (2018); Kamalaldin *et al.* (2021); Sayar and Er (2018) |

| | | | |
|---|---|---|---|
| T3 | *Lack of control over processes* | Tensions arising from the lack of control over the activities developed by complementors/contributors for providing digital solutions. | Bigdeli *et al*. (2021); Svahn *et al*. (2017) |
| T4 | *Multi-actor coordination* | Tensions between expanding or reducing the ecosystem based on decisions to increase or decrease the number of complementors/contributors. | Huikkola *et al*. (2020); Jovanovic *et al*. (2021); Kamalaldin *et al*. (2021) |
| T5 | *Collaboration governance* | Tensions between the use of contractual or trust-based agreements among ecosystem actors. | Kamalaldin *et al*. (2020); Sjödin *et al*. (2019); Svahn *et al*. (2017) |
| T6 | *Lack of commitment* | Tensions due to different levels of actors' commitment to collaboration and data/knowledge sharing. | Coreynen *et al*. (2017); Kamalaldin *et al*. (2021); Klein *et al*. (2018) |
| T7 | *Challenges for data analysis* | Tensions due to difficulties in analyzing and translating data collected from users and other actors into knowledge. | Altmann and Linder (2019); Grubic and Jennions (2018) |
| T8 | *Low innovation capability* | Tensions due to lack of flexibility and creativity to generate new knowledge when providing smart solutions. | Kamalaldin *et al*. (2020); Sjödin *et al*. (2019) |
| T9 | *Coopetition management* | Tensions between collaborating/sharing knowledge or competing/protecting knowledge when providing digital solutions. | Kamalaldin *et al*. (2021); Mosch *et al*. (2021); Sjödin *et al*. (2021) |
| T10 | *Complexity of processes* | Tensions between offering standardized or customized solutions. | Rajala *et al*. (2019); Sjödin *et al*. (2020) |
| T11 | *Power struggles* | Tensions due to actors seeking to expand their powers/importance to the detriment of others. | Huikkola *et al*. (2020); Mosch *et al*. (2021); Vendrell-Herrero *et al*. (2017) |
| T12 | *Manufacturer's loss of power* | Manufacturer's increased dependence on technology providers to offer smart solutions. | Bigdeli *et al*. (2021); Huikkola *et al*. (2020); Mosch *et al*. (2021) |
| T13 | *Customer's loss of power* | Customer's increased dependence on technology providers for the success of their operations. | Sjödin *et al*. (2019); Tronvoll *et al*. (2020) |
| T14 | *Technology provider's loss of power* | Technology provider's increased dependence on machinery manufacturers to provide smart solutions. | Linde *et al*. (2021); Mosch *et al*. (2021) |
| T15 | *Unequal value capture* | Tensions due to an imbalance in the returns obtained by the actors involved in providing digital solutions. | Huikkola *et al*. (2020); Vendrell-Herrero *et al*. (2017); Wagstaff *et al*. (2021a) |
| T16 | *Inappropriate use of data* | Tensions related to data access and misuse. | Coreynen *et al*. (2017); Paluch and Wünderlich (2016); Tronvoll *et al*. (2020) |

### *4.2 ISM results*

Applying the ISM analysis to the data collected according to the procedures explained in Section 3.3, we obtained the unified SSIM (Table A.1), the Initial Accessibility Matrix (Table A.2), the Final Accessibility Matrix (Table A.3), and the Level Partition (Table A.4). All tables related to the ISM results are provided in Appendix A. Based on these results, Figure 1 shows the ISM structural model that represents the interrelationships between the identified paradoxical tensions.

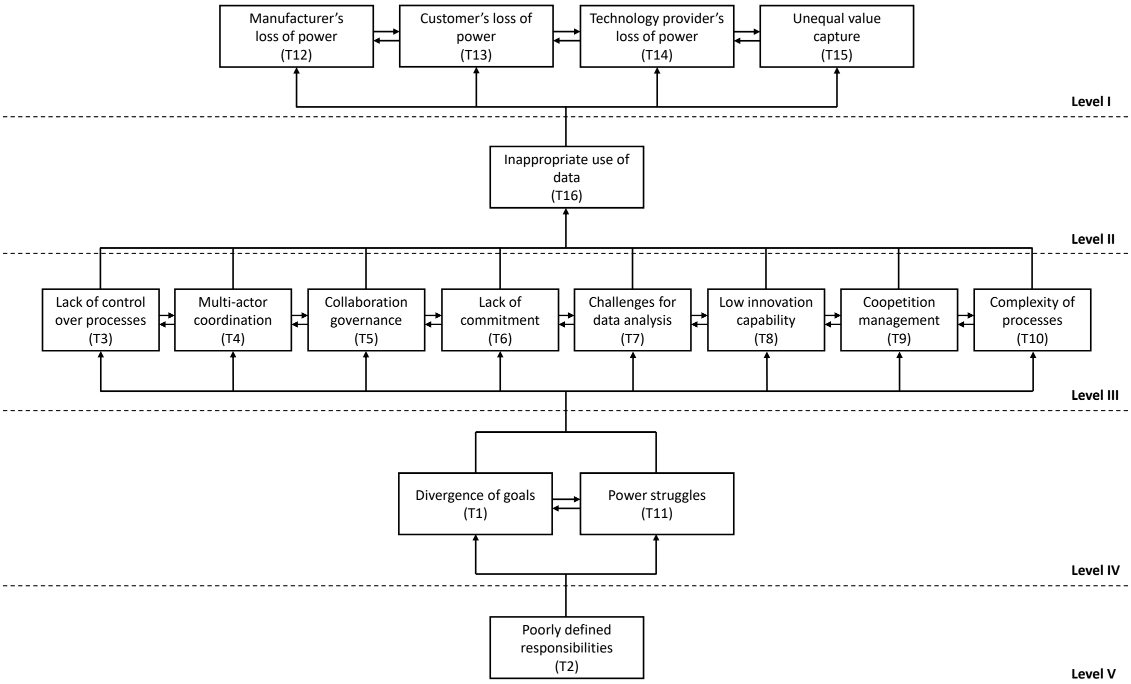


**Figure 1 – ISM structural model**

### *4.3 Fuzzy MICMAC results*

From the Fuzzy MICMAC analysis following the procedures of Section 3.4, we obtained the Binary Direct Reachability Matrix (Table B.1), the Frequency Direct Relationship Matrix (Table B.2), the Fuzzy Direct Reachability Matrix (Table B.3), and the Fuzzy MICMAC Stabilized Matrix (Table B.4). All tables related to the fuzzy MICMAC results are provided in Appendix B. From these matrices, we derived a cluster diagram (Figure 2) classifying the tensions based on their driving and dependence power.

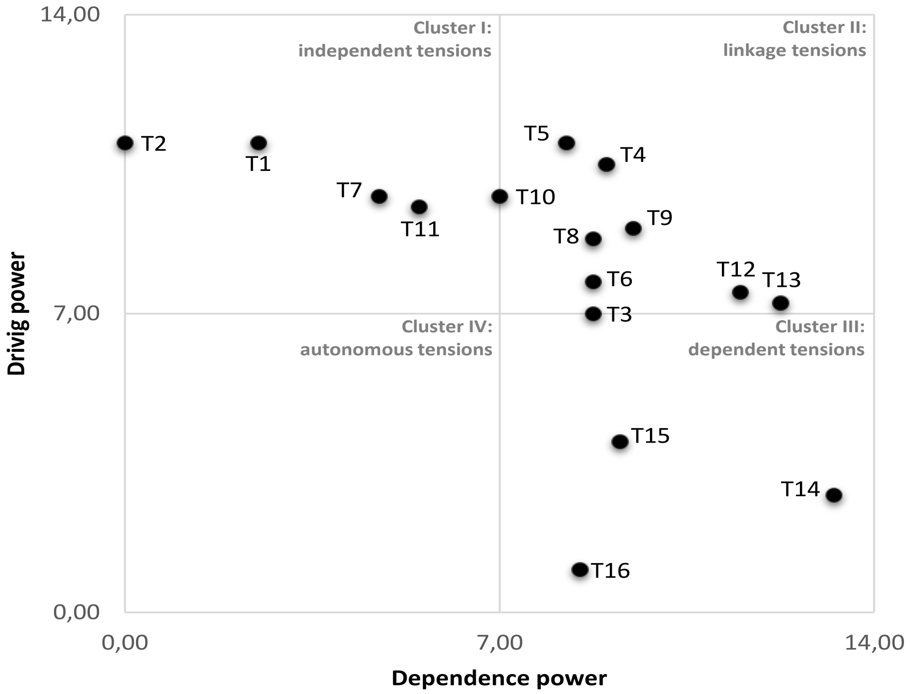
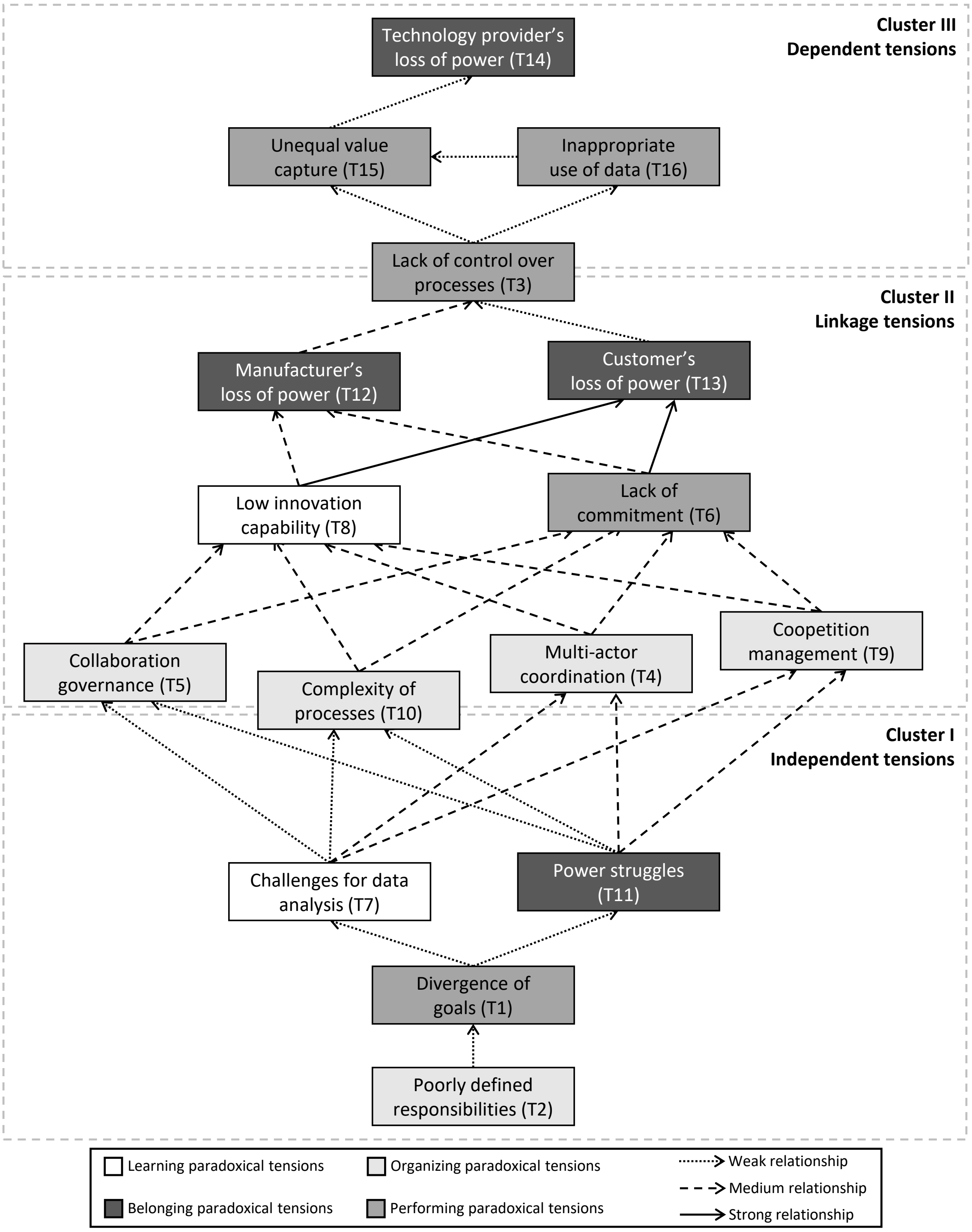


**Figure 2 – Cluster diagram of the tensions**

## 5. Discussion

Combining the ISM model (Figure 1) with the fuzzy MICMAC cluster diagram (Figure 2), we present the conceptual framework showing the cause-and-effect interrelationships between the paradoxical tensions in digital servitization ecosystems (Figure 3). In the following subsections, we discuss this framework in further detail.



Notes: (1) The boxes represent the identified tensions (see Table 4); (2) They are placed according to their positions in the cluster diagram, considering the quadrants and distance among them (see Figure 2). For instance, the tensions in the independent quadrant (i.e., lower dependence and higher driving power) are placed at the bottom of the framework, meaning they cause other tensions; (3) The boxes are colored in a grayscale, representing their associations with learning, belonging, organizing, and performing paradoxical tensions; (4) The arrows represent the cause-and-effect chain directions; and (5) The different type of arrows (i.e., dotted, dashed, full) represents each relationship's strength in the Fuzzy MICMAC Stabilized Matrix (see Table B.4).

**Figure 3 – Conceptual framework of the paradoxical tensions in digital servitization ecosystems**

### *5.1 Cluster I – Independent tensions*

Cluster I groups four paradoxical tensions: *Poorly defined responsibilities (T2)*, *Divergence of goals (T1)*, *Challenges for data analysis (T7)*, and *Power struggles (T11)*. These tensions show high driving power and low dependence power (see Figure 2), so they are considered the primary causes of other tensions. In short, they are independent tensions. Interestingly, three of these tensions (i.e., T2, T1, and T11) are also positioned in the bottom layers of the ISM model (see Figure 1), which confirms that they are predictors of other tensions. As a result, we consider them as critical paradoxical tensions in digital servitization ecosystems, and they must therefore be treated as top priorities.

Poorly defined responsibilities (T2) appear to be the most critical tension for technology providers. Concerning this, expert e7 stated: *"Most of the failures and tensions [in collaboration], I believe, are caused by the lack of clarity on the part of the technology provider, the manufacturer, and the customer. It is always difficult to clearly define the roles. Eventually, even the goals that can or should be achieved with technology adoption."* Machinery manufacturers must therefore properly orchestrate the ecosystem and clearly define the roles of technology providers (as complementors or contributors) to ensure a well-functioning collaboration and successful provision of smart solutions (Sayar and Er, 2018). Otherwise, service performance may be impaired due to the plurality of (conflicting) processes (Kamalaldin *et al*., 2021). For instance, technology providers must agree with manufacturers on who is responsible for providing technical support to customers (Sayar and Er, 2018). They must also define customers' responsibilities regarding the technological infrastructure necessary to offer digital services. Otherwise, the end-user cannot exercise their role as data provider, and they may also have unreachable expectations about the service (Grubic and Jennions, 2018; Paluch and Wünderlich, 2016). On this, expert e13 reinforced: *"Farmers often lack a clear awareness of their technology readiness level […] They should not set high expectations and goals to implement technologies if they do not have a minimum preparation condition for processes and labor."* As this tension relates to the issue of organization, we classify it as an organizing paradoxical tension (Smith and Lewis, 2011).

The lack of a clear definition of actors' roles and responsibilities can lead to a divergence of goals (T1). Ecosystem actors are more likely to act according to their own interests when they are unaware of their responsibilities (Kamalaldin *et al*., 2021). This tension is even more evident when orchestrators and complementors (or contributors) fail to balance contrasting interests, and one actor's efforts to capture value undermine another's efforts, which is reflective of a generativity tension (Bigdeli *et al*., 2021). In our study, technology providers and manufacturers may have different expectations of the newly implemented technology (Altmann and Linder, 2019). For example, machinery manufacturers, which are focused on selling farming equipment and services already included in their own digital platforms, may not be as interested in selling technologies that can provide additional services (e.g., drone systems for agronomic monitoring, sensors for soil mapping). Consequently, technology implementation goals may differ between manufacturers and technology providers, triggering conflicts when they try to balance these competitive interests. This tension is thus associated with the performing paradox, as conflicting stakeholder demands can lead to divergent measures for assessing digital servitization success.

Next, a divergence of goals causes two other tensions: challenges for data analysis (T7) and power struggles (T11). First, data analysis is critical to provide significant information for decision-making in digital servitization ecosystems (Favoretto *et al.*, 2022; Kolagar *et al.,* 2022). The lack of common goals among ecosystem actors can therefore mislead data generation and analysis activities (Grubic, 2018). For instance, while technology providers are interested in collecting data to improve their own algorithms, machinery manufacturers seek to extract insights from data to improve their own equipment. This makes it difficult to agree on which technology to implement to process the data (Altmann and Linder, 2019). Similarly, challenges may arise due to a poor understanding of the data capabilities necessary to explore data from multiple actors´ perspectives (Favoretto *et al.*, 2022). This can create tensions between the choice to employ existing capabilities while also developing new ones (Tóth *et al.*, 2022). Expert e7 remarked how users might experience this paradoxical tension: *“Sometimes the customer wants a very sophisticated technological solution, eventually even with a resolved connectivity structure. However, its operator is not current with the new capabilities to receive this level of technology being implemented. These gaps appear and sometimes frustrate the project a lot.”* Hence, we argue that this tension reflects a learning paradox.

Second, when actors pursue different goals, power struggles (T11) will often follow, whereby conflicting actors fight to control and establish their influence in the ecosystem (Huikkola *et al.*, 2020; Mosch *et al.*, 2021). This finding is also exemplified in the study by Vendrell-Herrero *et al.* (2017), which explains how companies seek to control resources, take advantage of end-users, and use their influence to consolidate their positions to maximize their own benefits. In this case, complementors and contributors (i.e., technology providers) see their power undermined when orchestrators (i.e., equipment manufacturers) tend to exploit the power of their brand and network to consolidate their business model, creating barriers to add-on digital services (Gaiardelli *et al*., 2020). Thus, power asymmetries can negatively affect “weaker” actors and may intensify opportunism perceptions (Grewal *et al*., 2021; Kamalaldin *et al*., 2021; Mosch *et al*., 2021). As expert e9 stated: *“The machinery manufacturer is much bigger than us [technology providers]. We are not asking a favor but waiting for an opportunity to enter the market [...] The manufacturer articulates everything [in the ecosystem]. If our technology pleases it, the manufacturer scales it to the brand’s customers and its dealers. Otherwise, it blocks us.”* We therefore consider this tension to be associated with the belonging paradox, which asserts that power asymmetries and distinctive interests in collaboration fuel struggles among actors for increased influence over others (Lewis, 2000).

### *5.2 Cluster II – Linkage tensions*

Cluster II consists of eight tensions: *Complexity of processes (T10)*, *Collaboration governance (T5)*, *Multi-actor coordination (T4)*, *Coopetition management (T9)*, *Low innovation capability (T8)*, *Lack of commitment (T6)*, *Manufacturer’s loss of power (T12)*, and *Customer’s loss of power (T13)*. Most of these paradoxical tensions are positioned at level III of the ISM model (see Figure 1), which means that they are strongly interconnected. The exceptions are T12 and T13, which are placed at level I due to their higher dependence power (see Figure 2). Tensions in this quadrant display the characteristics of strong driving and dependence power. Moreover, they are strongly linked, meaning that changes occurring to these tensions affect others.

As shown in Figure 3, challenges for data analysis (T17) and power struggles (T11) contribute to four tensions associated with the organizing paradox. In particular, they influence decisions to offer either customized or standardized solutions, leading to tensions related to the complexity of processes (T10). When customizing services, complementors increase user value, which contributes to leveraging their influence as the solution becomes more unique (Kohtamäki *et al*., 2020). In the agricultural machinery sector, many solutions require customization, because they are based on projects that depend on individual farms’ peculiarities, such as soil, water, and planting characteristics. Technology providers that are capable of providing flexible solutions therefore enjoy greater bargaining power. However, these solutions require highly flexible procedures to process data in a customized way (e.g., individual reports), which increases operational costs, extends the delivery time, and reduces profitability (Rajala *et al*., 2019). Balancing customization and standardization therefore represents an organizing paradoxical tension that is not easily resolved (Korkeamäki *et al.,* 2022; Sandvik *et al.,* 2022).

Collaboration governance (T5), multi-actor coordination (T4), and coopetition management (T9) involve relational and orchestration processes necessary to build trust, manage collaborations, share knowledge, and create value within digital servitization ecosystems (Sjödin *et al.,* 2019;

Korkeamäki *et al.,* 2022; Tóth et al., 2022). Tensions concerning collaboration governance (T5) arise when defining the use of structural (i.e., formal arrangements, explicit contracts) and social mechanisms (Svahn *et al*., 2017). Hence, they stem from balancing control and autonomy in inter-firm collaboration, a paradoxical tension typical of generativity (Wei *et al*., 2022). As shown in Figure 3, challenges in data analysis procedures (T7) and inter-organizational struggles for power (T11) influence actors' decisions regarding governance mechanisms. Actors therefore often prefer explicit contracts to align data processing activities and control partners' behavior, despite their inherent rigidity (Sjödin *et al*., 2019). The interviewed technology providers often apply a set of formal mechanisms to mitigate opportunistic behavior (e.g., source code leak) and prevent partners from taking control over their technologies, but that is not always possible. According to expert e9: *"We try to protect ourselves with NDAs (Non-Disclosure Agreements). But it's a real danger [code leak]. As our business is based on micro-services, the partner would be able to take a module away and attach it to its solution. That worries me."*

Furthermore, the multi-actor coordination tension (T4) relates to ecosystems' expansion or retraction, implying strategic decisions regarding the number of complementors and contributors that orchestrators allow to join (Jovanovic *et al.,* 2021). In particular, expanding the ecosystem triggers greater competition among external providers, allowing the orchestrator to offer users a wider range of services (Wei *et al*., 2019). Nevertheless, it implies challenges in managing multiple agreements, harmonizing different interests, processing a high volume of data on a platform, and ensuring compliance with quality standards (Kamalaldin *et al.,* 2021). Conversely, when retracting the ecosystem, the orchestrator has greater control over inter-firm collaboration, but it also increases the bargaining power of complementors and contributors (Huikkola et al., 2020). Power disputes and challenges in data processing therefore often influence the orchestrater's decision to expand or retract the ecosystem.

The coopetition management tension (T9) deals with balancing cooperation and competition, which is critical for innovation and collective progress in generative ecosystems (Sandvik *et al.,* 2022). Figure 3 indicates that indecisions regarding cooperating or competing may also derive from power struggles and problems in data analysis. An example is when a manufacturer does not share all the data collected from their equipment with the technology provider in order to protect its own competitive advantage. As remarked by one expert (e2): *"Currently, there is a limitation on how open communication protocols are. For example, 30% [of them] are open, and 70% are closed. Manufacturers do not share 100% of their data with us, as they do not want another company growing in this segment."* Conflicts whereby technology providers need more data access while manufacturers decide to protect their data, may therefore arise, as also described in other studies (Kamalaldin *et al.,* 2021; Sjödin *et al.,* 2021). The lack of data transparency also prevents complementors from customizing their technologies and delivering unique value propositions. Ample studies (e.g., Bengtsson *et al*., 2016; Sandvik *et al*., 2022) have described this tension as a manifestation of the coopetition paradox. It can also be associated with the organizing paradox, since complex systems can support or hinder knowledge sharing among ecosystem actors.

The results show that these organizing paradoxical tensions (i.e., T5, T10, T4, and T9) undermine actors' innovation capability (T8) and commitment (T6). Concerning innovation, companies that do not cooperate well may not benefit from jointly generating innovations that neither firm could achieve in isolation (Kohtamäki *et al*., 2019; Tronvoll *et al.,* 2020). Moreover, from the technology provider's perspective, manufacturers are often large companies with rigid and unreactive structures that hinder change and innovation, which differs from the flexibility and agility of associated with technology providers. This limits their ability to collaborate on innovation and create new digital solutions (Sjödin *et al*., 2019). According to one expert´s opinion (e2): *"For large manufacturers, strategic decisions must be escalated to the highest level [of the firm], where there is a person with the decision-making power. If no person at the top level sees what is happening in the market, the company will not be able to keep up with the speed of the market. And the technology provider will start developing solutions in the field."* We therefore consider actors' innovation capability a learning paradoxical tension.

In turn, a lack of commitment (T6) follows from a plurality of goals, which relates to the performing paradox (Tóth *et al*., 2022). When distrust and competitive reasons raise tensions in the collaboration, actors will not share operational data and strategic knowledge (Kamalaldin *et al*., 2021). Complementors commonly face this tension when users consider their (internal) data to be critical to their business, and they oppose data sharing because they think it could threaten their competitive advantage (Mosch *et al*., 2021). The identified organizing paradoxical tensions (i.e., T5, T10, T4, and T9) may thus trigger a lack of commitment. For example, a lack of contractual agreements (with explicit rules on data access and data use) increases customers' distrust in technology providers, which causes them to resist sharing business information (Chávez *et al*., 2023). Traditionally, customers in the agricultural machinery industry have shown this type of behavior, though recently they are considered to be more inclined to share data. On this, expert e7 stated: *"In precision agriculture projects, sometimes you need a customer map that shows where their production is. This way, you will know how much they produce. And sometimes [this information] is strategic. However, this has no going back: At first, farmers were resistant [to sharing the data], but today they provide the data, believing that the company will* *not disclose it to anyone."* In short, a lack of commitment can generate information asymmetry and limit service provision, leading to tensions (Huikkola *et al*., 2020).

The last two tensions of the linkage tensions cluster—the manufacturer's loss of power (T12) and customer's loss of power (T13)—show higher dependence power, which means that they are more influenced by other tensions, particularly by low innovation capability and lack of commitment. Both tensions are associated with the belonging paradox, reinforcing our observation that power discrepancies occur when ecosystem actors have opposing values and seek to increase their influence over others (Kocabasoglu-Hillmer *et al*., 2023; Lewis, 2000). Manufacturers lose power when they cannot keep up with the latest technological advances and, consequently, have reduced innovation capability to develop new machines with embedded technology (e.g., automation and robotics) to address customer needs (Ferreira and Lind, 2023). Conversely, complementors and contributors are often more agile and capable of developing innovative, digital solutions (Genzlinger *et al*., 2020). On this, expert e9 commented: *"There will come a time when the farmer will say: 'I no longer need a sprayer from the Manufacturer X. I can buy a robot that makes the application 24 hours a day without an employee [to drive it]'. Because several technology companies are already managing to perform optimized operations more efficiently, without large volumes of machinery."* As digital servitization progresses, manufacturers' power in the ecosystem may therefore diminish when they fail to invest in new service and digitalization capabilities (Bigdeli *et al*., 2021; Ferreira and Lind, 2023).

Concerning the customer's loss of power (T13), creating efficiency by improving farmers' productivity is essential in precision agriculture (Smania *et al*., 2022; Vidickiene and Gedminaite-Raudone, 2018). Small gains in operating time and use of inputs can greatly benefit sales of agricultural products. As explained by one expert (e2): *"With precision agriculture, farmers can produce more at a lower cost. As the world is globalized and agricultural products are commodities, farmers must make their merchandise cheaper to compete globally. Therefore, they increase their commercial power with technologies that generate gains in seconds of operation or millimeters of agrochemical application."* This observation together with the interrelationships shown in Figure 3 indicate that service providers' commitment to sharing knowledge strongly influences farmers' operational performance. Consequently, farmers increase their dependence on equipment manufacturers and technology companies that provide precision agriculture solutions (Vidickiene and Gedminaite-Raudone, 2018), which also decreases their bargaining power towards these providers.

### *5.3 Cluster III – Dependent tensions*

Cluster III covers four tensions: *Lack of control over processes (T3)*, *Unequal value capture (T15)*, *Inappropriate use of data (T16)*, and *Technology provider's loss of power (T14)*. These paradoxical tensions are characterized as having a low driving and high dependence power, meaning that they are dependent on (or result from) the previous identified tensions. Consequently, their manifestation indicates that the previous tensions have not been appropriately managed and may increasingly strain ecosystem collaboration.

Figure 3 shows that the loss of power of manufacturers and customers towards technology providers implies a reduction of control over processes (T3). First, when machinery manufacturers do not develop the necessary capabilities to deliver digital services and outsource these activities to complementors, they cannot fully control the solution being provided to the end-user (Bigdeli *et al*., 2021; Svahn *et al*., 2017). Second, when technology providers (as complementors) take over some of the customer's business functions (e.g., providing fertilizer application services by robots on the farmer's property), customers also lose control over the performance and thus productivity of their own operations (Sjödin *et al*., 2019). This tension is therefore associated with the performing paradox, as actors might be motivated by conflicting goals and measures to assess organizational success in service provision.

The lack of control over processes can fuel tensions related to unequal value capture (T15) and inappropriate use of data (T16). When manufacturers delegate digital services to technology providers, they can hardly control what information the provider is collecting from customers' machines (Paluch and Wünderlich, 2016; Rymaszewsk *et al*., 2017). Complementors may have access to information that is outside the scope of their service contracts, creating new opportunities to capture value by monetizing data or generating new business intelligence (Klein *et al*., 2018). Such opportunistic behavior may undermine the trust developed between ecosystem actors and damage their long-term collaboration (Huikkola *et al*., 2020). These tensions therefore are also considered as performing paradoxical tensions, which emerge from actors' conflicting goals regarding data use and value distribution.

A direct consequence of unequal value capture is manufacturers' attempt to limit technology providers' bargaining power (T14). This tension is therefore associated with the belonging paradox. When technology providers extract most of the benefits generated by the ecosystem, manufacturers tend to use their power to limit their influence over other actors. A common practice is to promote competition and restrict complementors' access to the end-user, making it difficult for them to offer digital services (Mosch *et al*., 2021). Given their long-standing relationships with customers, machinery manufacturers usually dictate the rules, and they can cut off technology providers' access to customers when they become too important (Kamalaldin *et al*., 2021). Expert e2 illustrates this situation: *"When the technology provider grows and makes a lot of money, the manufacturer tries to acquire it. As soon as the manufacturer realizes it cannot, it starts to challenge the technology provider in the market. So, it encourages the development of a competitor, invests in new solutions based on experience with the provider and ends the relationship."*

Ultimately, when dependent paradoxical tensions prevail, there is no synergy among actors, and strategies are not shared equally, the new value generated from the solution will not be distributed fairly (Wagstaff *et al*., 2021a). Actors will seek to maximize their own benefits, creating adversarial relationships with others characterized by a "zero-sum" logic (Huikkola *et al*., 2020; Vendrell-Herrero *et al*., 2017). Consequently, some actors are no longer able extract value from the collaboration, and many relationships are at risk of breaking up or dissolving (Mosch *et al.,* 2021).

## 6. Conclusions

### *6.1 Theoretical contributions*

This study contributes to the digital servitization literature in five ways. First, the ecosystem perspective is widely acknowledged as a critical element for providing smart solutions. Through collaboration, different ecosystem actors (e.g., manufacturers, technology providers, customers) integrate resources and capabilities to build new value propositions (e.g., smart solutions). Nevertheless, collaboration has a dark side that prevents them from achieving the expected results. This study thus contributes to the investigation of the dark side of digital servitization by expanding the range of tensions that affect collaboration in digital servitization ecosystems. In particular, it complements other studies (e.g., Korkeamäki *et al.,* 2022; Tóth *et al*., 2022) by identifying ecosystem behaviors that prevent actors from collaborating successfully, which can ultimately lead to value destruction.

Second, paradox theory provides a powerful theoretical lens for understanding tensions that surface from competitive demands in digital servitization. Recently, studies have used this lens to identify the tensions that manufacturers face when moving towards servitization (e.g., Dmitrijeva *et al*., 2022; Kohtamäki *et al*., 2020). Rather than applying the paradox lens to the intra-organizational context, we employed it to investigate inter-organizational tensions that exist in ecosystems. This research therefore advances the literature on digital servitization ecosystems by interpreting different paradoxical tensions (i.e., related to learning, belonging, organizing, and performing) that emerge from competing demands in inter-firm collaboration.

Third, this study introduces a cause-and-effect perspective to paradoxical tensions. Although recent servitization studies have started to explore this phenomenon (e.g., Stegehuis *et al*., 2023; Wagstaff *et al*., 2021b), the literature so far has mainly focused on identifying tensions and their associated coping actions. Hence, an in-depth analysis of the interrelationships of paradoxical tensions remains a fruitful area of investigation (Tóth *et al*., 2022). Our findings reveal that tensions in inter-firm collaboration do not surface in isolation; rather, they can strongly boost other tensions and even generate new ones. A better understanding of these relationships is crucial for effective collaboration in digital servitization ecosystems. In this study, we propose a conceptual framework that unravels the cause-and-effect relationships of paradoxical tensions and organizes them into different clusters (i.e., independent, linkage, and dependent clusters) based on their driving and dependence power. Thereby, we reveal how paradoxical tensions are interrelated. Furthermore, this classification allows us to identify the most influential paradoxical tensions, which represent the greatest potential threat to digital servitization ecosystems and should be treated as a priority by ecosystem actors.

Fourth, studies on digital servitization mainly focus on more traditional actors, such as manufacturing companies (e.g., Chen *et al*., 2021; Sklyar *et al*., 2019) and customers (e.g., Kamalaldin *et al.,* 2021; Sjödin *et al.,* 2021), neglecting the critical role of technology providers that develop Industry 4.0 technologies for smart solutions. This study expands the digital servitization literature by considering paradoxical tensions from the perspective of technology providers. Moreover, to the best of our knowledge, it is one of the first studies to emphasize the role of technology providers in ecosystems, specifically focusing on their collaborative relationships with machinery manufacturers and customers.

Finally, studies exploring tensions and paradoxes in digital servitization have so far mainly used qualitative approaches (e.g., Galvani and Bocconcelli, 2022; Sandvik *et al.,* 2022), raising the call for more quantitative research in this area (Favoretto *et al*., 2022). For this study, we have investigated the cause-and-effect interrelationships of paradoxical tensions through a multi-method approach, mixing both qualitative and quantitative procedures. As far as we know, this work is a pioneer in combining a systematic literature review, ISM, and fuzzy MICMAC to assess this topic, which may serve as an example to future research.

### *6.2 Managerial implications*

A better understanding of the interrelationships between paradoxical tensions in digital servitization ecosystems supports the formulation of preventive strategies to mitigate and them. Following the conceptual framework on paradoxical tensions presented in Figure 3, we provide specific suggestions for managers working on smart solutions to cope with paradoxical tensions in digital servitization ecosystems (categorized per cluster). Table 5 summarizes the following discussion.

In the first cluster, tensions follow mainly from the lack of alignment and plurality of goals when actors collaborate to provide smart solutions. When roles are poorly defined, actors tend to behave according to their own goals and strategies. Our first suggestion therefore is to clearly define the responsibilities of each actor, thus mitigating the risk of individual interests prevailing over the collective objective. In addition, the multiplicity of goals can trigger challenges for actors to create value from data in digital services and instigate disputes for control and dominance. As a second coping action, we recommend that managers strive to share strategies across the ecosystem, so that providing smart solutions benefits all parties. Aligning purposes and strategies contributes to harmonizing actors in value cocreation, and it reduces the threat of some parties exploiting their influence to benefit only their goals. In short, aligning interests, goals, and responsibilities is a prerequisite for successful inter-firm collaboration and should be a top priority for managers when orchestrating relationships in digital servitization ecosystems.

In the second cluster, misalignment among actors raises questions about how to orchestrate the ecosystem. For example, actors may have doubts about whether to establish more flexible agreements with their partners or impose stricter contractual mechanisms, or whether to share information or protect strategic knowledge. These indecisions can affect actors' commitment to the relationship, gradually undermining inter-firm collaboration. Hence, as a third coping action, we suggest that managers promote open communication channels across the ecosystem regarding the benefits of smart solutions. This strategy can motivate actors to collaborate and avoid opportunistic behavior. Furthermore, providing smart solutions can create interdependence among actors, triggering power imbalances in the ecosystem due to the new resources and capabilities required. For this reason, our fourth suggested action recommends managers to build trust across the ecosystem to prevent their partners from exploiting their expertise and consolidate their own control over the ecosystem.

In the third cluster, inter-firm collaboration can be characterized by opportunistic behavior, whereby some actors misuse data to create additional benefits for themselves and seek to maximize their own value extracted from the collaboration, even at the expense of their partners. Consequently, the provision of smart solutions may undermine some actors' business outcomes. As a fifth and final coping action, we suggest that managers promote transparency to make the use of data and partners' behavior visible to all ecosystem actors. Such transparency would help ensure that inappropriate behavior is quickly identified and controlled. As a result, managers can better monitor data usage and ensure that value is distributed fairly across the ecosystem.

**Table 5 – Coping actions for paradoxical tensions**

| Clusters | Paradoxical tensions | Coping actions |
|---|---|---|
| I – Independent tensions | T2 – Poorly defined responsibilities<br>T1 – Divergence of goals | 1. Clearly defining the responsibilities of each actor in digital servitization, encouraging collaboration towards a common goal, and the prevalence of collective objectives over individual interests. |
| | T7 – Challenges for data analysis<br>T11 – Power struggles | 2. Sharing strategies across the ecosystem to benefit all stakeholders through digital servitization. |
| II – Linkage tensions | T8 – Low innovation capability<br>T6 – Lack of commitment | 3. Promoting open communication across the ecosystem concerning the benefits of smart solutions to stimulate actors' interest in collaboration and mitigate opportunistic behavior. |
| | T12 – Manufacturer's loss of power<br>T13 – Customer's loss of power | 4. Building trust in inter-organizational relationships to prevent actors from exploiting their influence and controlling the ecosystem. |
| III – Dependent tensions | T15 – Unequal value capture<br>T16 – Inappropriate use of data<br>T14 – Technology provider's loss of power | 5. Promoting transparency in inter-organizational relationships and revealing the partners' behavior in the collaboration to other actors in the ecosystem. |

### *6.3 Limitations and further research*

Despite its contributions, this study has limitations that open avenues for future research. First, our study identified 16 paradoxical tensions based on a systematic review of the literature, potentially missing other important tensions. We therefore recommend researchers to use other methods (e.g., case-based research) to uncover more inter-organizational tensions and assess their relationships. Furthermore, researchers can also employ the paradox lens to provide in-depth accounts of tensions emerging digital servitization specifically, such as tensions related to data. Hence, we invite researchers to zoom in on and deepen our understanding of these servitization specific paradoxical tensions.

Second, our study's findings are derived from the technology providers' perspective. However, focusing only on one type of actor's perspective may limit our understanding of paradoxical tensions in inter-firm collaboration, since their cause-and-effect relationships and prioritization decisions are based on their individual interpretations. Future studies can thus consider other actors (e.g., manufacturers, customers, suppliers, etc.) or a apply multi-actor perspective, which would provide a broader view of these paradoxical tensions. We argue that it is important to investigate tensions from other actors' viewpoints, understand their key drivers, and find out how they resolve them through other coping actions.

Third, our results are based on the subjective judgment of academics and industry experts. Although we judiciously selected experts with experience in the chosen sector, our results are not free from expert bias. Hence, we suggest using other quantitative techniques (e.g., partial least squares) to assess the interactions among tensions. Specifically, we encourage future studies on digital servitization to analyze the interaction between tensions in more detail, for instance, by investigating how the ownership of critical resources and capabilities can lead to power asymmetries.

Fourth, we focused on the agricultural machinery industry where digital servitization platforms have rather progressed over recent years, unraveling tensions that are specific to this particular context. For instance, we found that technology providers offering autonomous robot services to fertilize the soil, undermine the manufacturers' bargaining power. This led us to conclude that, while ecosystem openness is critical for new value creation, it also changes the digital servitization ecosystem's competitive dynamics. However, investigating tensions in other settings may uncover different findings. Scholars can thus expand this research by exploring paradoxical tensions in different contexts, such as the mobility and logistics sectors.

Fifth, the coping actions suggested here are not meant to be exhaustive. Instead, they represent potential strategies derived from the study's findings. Thus, more qualitative research is required to verify their effectiveness in dealing with paradoxical tensions in digital servitization ecosystems. For example, a customers' reluctance to grant technology providers access to their strategic data warrants further investigation of the actions to promote data sharing while ensuring customer control over critical information.

Finally, the negative outcomes of the paradoxical tensions require further research. Paradoxical tensions are expected to generate information asymmetry, low service quality, and high costs for delivering smart solutions. As a result, companies implementing digital servitization often perform below their initial expectations. We therefore invite researchers to test the influence of paradoxical tensions on the performance of ecosystem partnerships. Quantitative studies could, for instance, bring valuable insights regarding the moderating effect of paradoxical tensions on the relationship between inter-firm collaboration and specific digital servitization outcomes.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## References

Aarikka-Stenroos, L., Ritala, P., 2017. Network management in the era of ecosystems: Systematic review and management framework. Industrial Marketing Management 67, 23-36.

Adner, R., 2017. Ecosystem as structure: An actionable construct for strategy. Journal of Management 43 (1), 39-58.

Alghababsheh, M., Gallear, D., 2020. Social capital in buyer-supplier relationships: A review of antecedents, benefits, risks, and boundary conditions. Industrial Marketing Management 91, 338-361.

Altmann, P., Linder, M., 2019. Managing emerging (Mis) alignments in data-driven servitization. Research-Technology Management 62 (4), 37-45.

Archibald, M.M., 2016. Investigator triangulation: A collaborative strategy with potential for mixed methods research. Journal of Mixed Methods Research 10 (3), 228-250.

Ardolino, M., Rapaccini, M., Saccani, N., Gaiardelli, P., Crespi, G., Ruggeri, C., 2018. The role of digital technologies for the service transformation of industrial companies. International Journal of Production Research 56 (6), 2116-2132.

Bengtsson, M., Raza-Ullah, T., Vanyushyn, V., 2016. The coopetition paradox and tension: The moderating role of coopetition capability. Industrial Marketing Management 53, 19-30.

Bhosale, V.A., Kant, R., 2016. An integrated ISM fuzzy MICMAC approach for modelling the supply chain knowledge flow enablers. International Journal of Production Research 54 (24), 7374-7399.

Bigdeli, A.Z., Kapoor, K., Schroeder, A., Omidvar, O., 2021. Exploring the root causes of servitization challenges: an organisational boundary perspective. International Journal of Operations & Production Management 41 (5), 547-573.

Bonina, C., Koskinen, K., Eaton, B., Gawer, A., 2021. Digital platforms for development: Foundations and research agenda. Information Systems Journal 31 (6), 869-902.

Burton, J., Story, V., Zolkiewski, J., Raddats, C., Baines, T. S., Medway, D., 2016. Identifying tensions in the servitized value chain. Research-Technology Management 59 (5), 38-47.

Cennamo, C., Santaló, J., 2019. Generativity tension and value creation in platform ecosystems. Organization Science 30 (3), 617-641.

Chávez, C. A. G., Unamuno, G., Despeisse, M., Johansson, B., Romero, D., Stahre, J., 2023. Analyzing the risks of digital servitization in the machine tool industry. Robotics and Computer-Integrated Manufacturing 82, 102520.

Chen, X., Locatelli, G., Zhang, X., Gong, Y., He, Q., 2022. Firm and project innovation outcome measures in infrastructure megaprojects: An interpretive structural modelling approach. Technovation 109, 102349.

Chen, Y., Visnjic, I., Parida, V., Zhang, Z., 2021. On the road to digital servitization–The (dis) continuous interplay between business model and digital technology. International Journal of Operations & Production Management 41 (5), 694-722.

Clarysse, B., Wright, M., Bruneel, J., Mahajan, A., 2014. Creating value in ecosystems: Crossing the chasm between knowledge and business ecosystems. Research Policy 43 (7), 1164-1176.

Clauss, T., Kraus, S., Kallinger, F.L., Bican, P.M., Brem, A., Kailer, N., 2021. Organizational ambidexterity and competitive advantage: The role of strategic agility in the exploration-exploitation paradox. Journal of Innovation & Knowledge 6 (4), 203-213.

Coreynen, W., Matthyssens, P., Van Bockhaven, W., 2017. Boosting servitization through digitization: Pathways and dynamic resource configurations for manufacturers. Industrial Marketing Management 60, 42-53.

Dalenogare, L.S., Le Dain, M.A., Ayala, N.F., Pezzotta, G., Frank, A.G., 2023. Building digital servitization ecosystems: An analysis of inter-firm collaboration types and social exchange mechanisms among actors. Technovation 124, 102756.

De Reuver, M., Sørensen, C., Basole, R. C., 2018. The digital platform: a research agenda. Journal of Information Technology 33 (2), 124-135.

Dmitrijeva, J., Schroeder, A., Bigdeli, A.Z., Baines, T., 2022. Paradoxes in servitization: A processual perspective. Industrial Marketing Management 101, 141-152.

Eggert, C.G., Winkler, C., Volkmann, A., Schumann, J.H., Wünderlich, N. V., 2022. Understanding intra-and interorganizational paradoxes inhibiting data access in digital servitization. Industrial Marketing Management 105, 404-421.

Fang, S. R., Chang, Y. S., Peng, Y. C., 2011. Dark side of relationships: A tensions-based view. Industrial Marketing Management 40 (5), 774-784.

Favoretto, C., Mendes, G.H.S., Oliveira, M.G., Cauchick-Miguel, P.A., Coreynen, W., 2022. From servitization to digital servitization: How digitalization transforms companies' transition towards services. Industrial Marketing Management 102, 104-121.

Ferreira, C. C., Lind, F., 2023. Supplier interfaces in digital transformation: an exploratory case study of a manufacturing firm and IoT suppliers. Journal of Business & Industrial Marketing 38 (6), 1332-1344.

Frank, A.G., Mendes, G.H.S., Ayala, N.F., Ghezzi, A., 2019. Servitization and Industry 4.0 convergence in the digital transformation of product firms: A business model innovation perspective. Technological Forecasting and Social Change 141, 341-351.

Frank, A.G., Mendes, G.H.S., Benitez, G.B., Ayala, N.F., 2022. Service customization in turbulent environments: service business models and knowledge integration to create capability-based switching costs. Industrial Marketing Management 100, 1-18.

Gaiardelli, P., Pezzotta, G., Rondini, A., Romero, D., Jarrahi, F., Bertoni, M., ... Cavalieri, S., 2021. Product-service systems evolution in the era of Industry 4.0. Service Business 15 (1), 177-207.

Galvani, S., Bocconcelli, R., 2022. Intra- and inter-organizational tensions of a digital servitization strategy. Evidence from the mechatronic sector in Italy. Journal of Business & Industrial Marketing 37 (13), 1-18.

Genzlinger, F., Zejnilovic, L., Bustinza, O.F., 2020. Servitization in the automotive industry: How car manufacturers become mobility service providers. Strategic Change 29 (2), 215-226.

Gioia, D.A., Corley, K.G., Hamilton, A.L., 2013. Seeking qualitative rigor in inductive research: Notes on the Gioia methodology. Organizational Research Methods 16 (1), 15-31.

Gomes, L.A.V., Flechas, X.A., Facin, A.L.F., Borini, F.M., 2021. Ecosystem management: Past achievements and future promises. Technological Forecasting and Social Change 171, 120950.

Grewal, D., Guha, A., Satornino, C.B., Schweiger, E.B., 2021. Artificial intelligence: The light and the darkness. Journal of Business Research 136, 229-236.

Grubic, T., 2018. Remote monitoring technology and servitization: Exploring the relationship. Computers in Industry 100, 148-158.

Grubic, T., Jennions, I., 2018. Remote monitoring technology and servitised strategies–factors characterising the organisational application. International Journal of Production Research 56 (6), 2133-2149.

Hanelt, A., Bohnsack, R., Marz, D., Antunes Marante, C., 2021. A systematic review of the literature on digital transformation: Insights and implications for strategy and organizational change. Journal of Management Studies 58 (5), 1159-1197.

Huikkola, T., Kohtamäki, M., Ylimäki, J., 2022. Becoming a smart solution provider: Reconfiguring a product manufacturer's strategic capabilities and processes to facilitate business model innovation. Technovation 118, 102498.

Huikkola, T., Rabetino, R., Kohtamäki, M., Gebauer, H., 2020. Firm boundaries in servitization: Interplay and repositioning practices. Industrial Marketing Management 90, 90-105.

Jarzabkowski, P., Lê, J.K., Van de Ven, A.H., 2013. Responding to competing strategic demands: How organizing, belonging, and performing paradoxes coevolve. Strategic Organization 11 (3), 245-280.

Jovanovic, M., Sjödin, D., Parida, V., 2021. Co-evolution of platform architecture, platform services, and platform governance: Expanding the platform value of industrial digital platforms. Technovation 118, 102218.

Kamalaldin, A., Linde, L., Sjödin, D., Parida, V., 2020. Transforming provider-customer relationships in digital servitization: A relational view on digitalization. Industrial Marketing Management 89, 306-325.

Kamalaldin, A., Sjödin, D., Hullova, D., Parida, V., 2021. Configuring ecosystem strategies for digitally enabled process innovation: A framework for equipment suppliers in the process industries. Technovation 105, 102250.

Kamble, S.S., Gunasekaran, A., Sharma, R., 2018. Analysis of the driving and dependence power of barriers to adopt industry 4.0 in Indian manufacturing industry. Computers in Industry 101, 107-119.

Kandasamy, W.V., Smarandache, F., Ilanthenral, K., 2007. Elementary fuzzy matrix theory and fuzzy models for social scientists. Automaton, Los Angeles.

Kapoor, K., Bigdeli, A.Z., Schroeder, A., Baines, T., 2022. A platform ecosystem view of servitization in manufacturing. Technovation 118, 102248.

Klein, M.M., Biehl, S.S., Friedli, T., 2018. Barriers to smart services for manufacturing companies–

an exploratory study in the capital goods industry. Journal of Business & Industrial Marketing 33 (6), 846-856.

Kocabasoglu-Hillmer, C., Roden, S., Vanpoucke, E., Son, B. G., Lewis, M. W., 2023. Radical innovations as supply chain disruptions? A paradox between change and stability. Journal of Supply Chain Management 59 (3), 3-19.

Kohtamäki, M., Einola, S., Rabetino, R., 2020. Exploring servitization through the paradox lens: Coping practices in servitization. International Journal of Production Economics 226, 107619.

Kohtamäki, M., Parida, V., Oghazi, P., Gebauer, H., Baines, T., 2019. Digital servitization business models in ecosystems: A theory of the firm. Journal of Business Research 104, 380-392.

Kolagar, M., Parida, V., Sjödin, D., 2022. Ecosystem transformation for digital servitization: A systematic review, integrative framework, and future research agenda. Journal of Business Research 146, 176-200.

Korkeamäki, L., Sjödin, D., Kohtamäki, M., Parida, V., 2022. Coping with the relational paradoxes of outcome-based services. Industrial Marketing Management 104, 14-27.

Kowalkowski, C., Bigdeli, A. Z., Baines, T., 2022. Guest editorial: the future of servitization in a digital era. Journal of Service Management 33 (1), 59-69.

Kumar, S., Raut, R.D., Agrawal, N., Cheikhrouhou, N., Sharma, M., Daim, T., 2022. Integrated blockchain and internet of things in the food supply chain: Adoption barriers. Technovation 118, 102589.

Lewis, M.W., 2000. Exploring paradox: Toward a more comprehensive guide. Academy of Management Review 25 (4), 760-776.

Linde, L., Sjödin, D., Parida, V., Wincent, J., 2021. Dynamic capabilities for ecosystem orchestration A capability-based framework for smart city innovation initiatives. Technological Forecasting and Social Change 166, 120614.

Martín-Peña, M.L., Díaz-Garrido, E., Sánchez-López, J.M., 2018. The digitalization and servitization of manufacturing: A review on digital business models. Strategic Change 27 (2), 91-99.

Miehé, L., Palmié, M., Oghazi, P., 2023. Connection successfully established: How complementors use connectivity technologies to join existing ecosystems–Four archetype strategies from the mobility sector. Technovation 122, 102660.

Moore, J. F., 1993. Predators and prey: a new ecology of competition. Harvard Business Review 71 (3), 75-86.

Mosch, P., Schweikl, S., Obermaier, R., 2021. Trapped in the supply chain? Digital servitization strategies and power relations in the case of an industrial technology supplier. International Journal of Production Economics 236, 108141.

Murry Jr., J.W., Hammons, J.O., 1995. Delphi: A versatile methodology for conducting qualitative research. The Review of Higher Education 18 (4), 423-436.

Muruganantham, G., Vinodh, S., Arun, C.S., Ramesh, K., 2018. Application of interpretive structural modelling for analysing barriers to total quality management practices implementation in the automotive sector. Total Quality Management & Business Excellence 29 (5-6), 524-545.

Oliveira, N., Lumineau, F., 2019. The dark side of interorganizational relationships: An integrative review and research agenda. Journal of Management 45 (1), 231-261.

Paluch, S., Wünderlich, N.V., 2016. Contrasting risk perceptions of technology-based service innovations in inter-organizational settings. Journal of Business Research 69 (7), 2424-2431.

Paschou, T., Rapaccini, M., Adrodegari, F., Saccani, N., 2020. Digital servitization in manufacturing: A systematic literature review and research agenda. Industrial Marketing Management 89, 278-292.

Porter, M.E., Heppelmann, J. E., 2014. How smart, connected products are transforming competition. Harvard Business Review 92 (11), 64-88.

Rajala, R., Brax, S.A., Virtanen, A., Salonen, A., 2019. The next phase in servitization: transforming integrated solutions into modular solutions. International Journal of Operations & Production Management 39 (5), 630-657.

Raza-Ullah, T., Bengtsson, M., Kock, S., 2014. The coopetition paradox and tension in coopetition at multiple levels. Industrial Marketing Management 43 (2), 189-198.

Sandvik, H.O., Sjödin, D., Brekke, T., Parida, V., 2022. Inherent paradoxes in the shift to autonomous solutions provision: a multilevel investigation of the shipping industry. Service Business: An International Journal 16 (2), 227-255.

Sayar, D., Er, Ö., 2018. The antecedents of successful IoT service and system design: Cases from the manufacturing industry. International Journal of Design 12 (1), 67-78.

Sienkiewicz-Małyjurek, K., 2022. Interpretive structural modelling of inter-agency collaboration risk in public safety networks. Quality & Quantity 56 (3), 1193-1221.

Sjödin, D., Kamalaldin, A., Parida, V., Islam, N., 2021. Procurement 4.0: How Industrial Customers Transform Procurement Processes to Capitalize on Digital Servitization. IEEE Transactions on Engineering Management, 1-16.

Sjödin, D., Parida, V., Kohtamäki, M., 2019. Relational governance strategies for advanced service provision: Multiple paths to superior financial performance in servitization. Journal of Business Research 101, 906-915.

Sjödin, D., Parida, V., Kohtamäki, M., Wincent, J., 2020. An agile co-creation process for digital servitization: A micro-service innovation approach. Journal of Business Research 112, 478-491.

Sjödin, D., Parida, V., Visnjic, I., 2022. How can large manufacturers digitalize their business models? A framework for orchestrating industrial ecosystems. California Management Review 64 (3), 49-77.

Sklyar, A., Kowalkowski, C., Tronvoll, B., Sörhammar, D., 2019. Organizing for digital servitization: A service ecosystem perspective. Journal of Business Research 104, 450-460.

Smania, G.S., Mendes, G.H.S., Godinho Filho, M., Osiro, L., Cauchick-Miguel, P.A., Coreynen, W., 2022. The relationships between digitalization and ecosystem-related capabilities for service innovation in agricultural machinery manufacturers. Journal of Cleaner Production 343, 130982.

Smith, W.K., Lewis, M.W., 2011. Toward a theory of paradox: A dynamic equilibrium model of organizing. Academy of Management Review 36 (2), 381-403.

Spigel, B., 2017. The relational organization of entrepreneurial ecosystems. Entrepreneurship theory and practice 41 (1), 49-72.

Stegehuis, X., von Raesfeld, A., Nieuwenhuis, L., 2023. Inter-organizational tensions in servitization: A dialectic process model. Industrial Marketing Management 109, 204-220.

Struyf, B., Galvani, S., Matthyssens, P., Bocconcelli, R., 2021. Toward a multilevel perspective on digital servitization. International Journal of Operations & Production Management 41 (5), 668-693.

Svahn, F., Mathiassen, L., Lindgren, R., 2017. Embracing digital innovation in incumbent firms: How Volvo cars managed competing concerns. MIS Quarterly 41 (1), 239-253.

Thomas, L. D., Tee, R., 2022. Generativity: A systematic review and conceptual framework.

International Journal of Management Reviews 24 (2), 255-278.

Tóth, Z., Sklyar, A., Kowalkowski, C., Sörhammar, D., Tronvoll, B., Wirths, O., 2022. Tensions in digital servitization through a paradox lens. Industrial Marketing Management 102, 438-450.

Tranfield, D., Denyer, D., Smart, P., 2003. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British Journal of Management 14 (3), 207-222.

Tronvoll, B., Sklyar, A., Sörhammar, D., Kowalkowski, C., 2020. Transformational shifts through digital servitization. Industrial Marketing Management 89, 293-305.

Vargo, S.L., Akaka, M.A., 2012. Value cocreation and service systems (re) formation: A service ecosystems view. Service Science 4 (3), 207-217.

Vendrell-Herrero, F., Bustinza, O.F., Parry, G., Georgantzis, N., 2017. Servitization, digitization and supply chain interdependency. Industrial Marketing Management 60, 69-81.

Vidickiene, D., Gedminaite-Raudone, Z., 2018. Challenges for agricultural policy in the service-driven economic system. Ekonomika Poljoprivrede (Economics of Agriculture) 65, 1545–1555.

Visnjic, I., Jovanovic, M., Raisch, S., 2022. Managing the transition to a dual business model: tradeoff, paradox, and routinized practices. Organization Science 33 (5), 1964-1989.

Wagstaff, S., Burton, J., Zolkiewski, J., 2021a. Should we cooperate? Game theory insights for servitization. Journal of Service Management 32 (5), 835-859.

Wagstaff, S., Burton, J., Zolkiewski, J., 2021b. Tensions and territoriality: the dark side of servitization. Journal of Business & Industrial Marketing 36 (10), 1755-1766.

Warfield, J.N., 1974. Developing interconnection matrices in structural modeling. IEEE Transactions on Systems, Man, and Cybernetics 4 (1), 81-87.

Wei, R., Geiger, S., Vize, R., 2019. A platform approach in solution business: how platform openness can be used to control solution networks. Industrial Marketing Management 83, 251-265.

Wei, R., Geiger, S., Vize, R., 2022. Managing paradoxical tensions in platform-based modular solution networks. Industrial Marketing Management 100, 96-111.

Wohlin, C., 2014. Guidelines for snowballing in systematic literature studies and a replication in software engineering. In Proceedings of the 18th international conference on evaluation and assessment in software engineering (pp. 1-10).

Zimmermann, H.J., 2011. Fuzzy set theory—and its applications. Springer Science & Business Media.

## Appendix A

**Table A.1 – Unified Structural Self-Interaction Matrix**

| *i/j* | T16 | T15 | T14 | T13 | T12 | T11 | T10 | T9 | T8 | T7 | T6 | T5 | T4 | T3 | T2 | T1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T1** | V | V | V | O | V | X | V | V | O | V | X | V | V | V | A | X |
| **T2** | V | V | V | V | V | V | V | V | V | V | V | V | V | V | X | |
| **T3** | V | V | V | V | V | A | A | O | X | A | A | A | V | X | | |
| **T4** | V | V | V | V | V | X | X | X | V | X | V | X | X | | | |
| **T5** | V | V | V | V | A | X | X | X | X | X | V | X | | | | |
| **T6** | V | V | V | O | O | O | A | O | X | V | X | | | | | |
| **T7** | V | V | V | V | V | O | V | O | V | X | | | | | | |
| **T8** | O | V | V | V | V | O | A | O | X | | | | | | | |
| **T9** | O | A | V | V | V | A | X | X | | | | | | | | |
| **T10** | V | O | V | V | V | A | X | | | | | | | | | |
| **T11** | O | V | V | X | V | X | | | | | | | | | | |
| **T12** | O | V | X | X | X | | | | | | | | | | | |
| **T13** | O | O | V | X | | | | | | | | | | | | |
| **T14** | A | X | X | | | | | | | | | | | | | |
| **T15** | O | X | | | | | | | | | | | | | | |
| **T16** | X | | | | | | | | | | | | | | | |

**Table A.2 – Initial Reachability Matrix**

| *i/j* | T16 | T15 | T14 | T13 | T12 | T11 | T10 | T9 | T8 | T7 | T6 | T5 | T4 | T3 | T2 | T1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T1** | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 |
| **T2** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **T3** | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| **T4** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| **T5** | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 |
| **T6** | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 |
| **T7** | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 |
| **T8** | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| **T9** | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| **T10** | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| **T11** | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 |
| **T12** | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| **T13** | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T14** | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T15** | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T16** | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table A.3 – Final Reachability Matrix**

| *i/j* | T16 | T15 | T14 | T13 | T12 | T11 | T10 | T9 | T8 | T7 | T6 | T5 | T4 | T3 | T2 | T1 | Driving power |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T1** | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 15 |
| **T2** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 16 |
| **T3** | 1 | 1 | 1 | 1 | 1 | 1* | 1* | 1* | 1 | 1* | 1* | 1* | 1 | 1 | 0 | 0 | 14 |
| **T4** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 0 | 1* | 15 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T5** | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1* | 15 |
| **T6** | 1 | 1 | 1 | 1* | 1* | 0 | 1* | 1* | 1 | 1 | 1 | 1* | 1* | 1 | 0 | 0 | 13 |
| **T7** | 1 | 1 | 1 | 1 | 1 | 1* | 1 | 1* | 1 | 1 | 1* | 1 | 1 | 1 | 0 | 0 | 14 |
| **T8** | 1* | 1 | 1 | 1 | 1 | 1* | 1* | 1* | 1 | 1* | 1 | 1 | 1* | 1 | 0 | 0 | 14 |
| **T9** | 1* | 1* | 1 | 1 | 1 | 1* | 1 | 1 | 1* | 1* | 1* | 1 | 1 | 1* | 0 | 0 | 14 |
| **T10** | 1 | 1* | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 0 | 0 | 14 |
| **T11** | 1* | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 1* | 1* | 1 | 1 | 1 | 0 | 1 | 15 |
| **T12** | 1* | 1 | 1 | 1 | 1 | 1* | 1* | 1* | 1* | 1* | 1* | 1 | 1* | 1* | 0 | 0 | 14 |
| **T13** | 0 | 1* | 1 | 1 | 1 | 1 | 1* | 1* | 0 | 0 | 0 | 1* | 1* | 1* | 0 | 1* | 11 |
| **T14** | 0 | 1 | 1 | 1* | 1 | 0 | 0 | 1* | 0 | 0 | 0 | 1* | 0 | 0 | 0 | 0 | 6 |
| **T15** | 0 | 1 | 1 | 1* | 1* | 0 | 1* | 1 | 0 | 0 | 0 | 1* | 1* | 0 | 0 | 0 | 8 |
| **T16** | 1 | 1* | 1 | 0 | 1* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| **Dep. power** | 13 | 16 | 16 | 15 | 16 | 12 | 14 | 15 | 12 | 12 | 12 | 15 | 14 | 13 | 1 | 6 | |

**Note: the symbol 1* represents the entries obtained by the transitivity condition**

**Table A.4 – Level partitions**

| # | Reachability set | Antecedent set | Intersection set | Level |
|---|---|---|---|---|
| **T1** | T1, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16. | T1, T2, T4, T5, T11, T13. | T1, T4, T5, T11, T13. | IV |
| **T2** | T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16. | T2. | T2. | V |
| **T3** | T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16. | T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13. | T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13. | III |
| **T4** | T1, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16. | T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T15. | T1, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T15. | III |
| **T5** | T1, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16. | T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15. | T1, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15. | III |
| **T6** | T3, T4, T5, T6, T7, T8, T9, T10, T12, T13, T14, T15, T16. | T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12. | T3, T4, T5, T6, T7, T8, T9, T10, T12. | III |
| **T7** | T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16. | T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12. | T3, T4, T5, T6, T7, T8, T9, T10, T11, T12. | III |
| **T8** | T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16. | T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12. | T3, T4, T5, T6, T7, T8, T9, T10, T11, T12. | III |
| **T9** | T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16. | T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15. | T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15. | III |
| **T10** | T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16. | T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T15. | T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T15. | III |
| **T11** | T1, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16. | T1, T2, T3, T4, T5, T7, T8, T9, T10, T11, T12, T13. | T1, T3, T4, T5, T7, T8, T9, T10, T11, T12, T13. | IV |
| **T12** | T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16. | T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16. | T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16. | I |
| **T13** | T1, T3, T4, T5, T9, T10, T11, T12, T13, T14, T15. | T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15. | T1, T3, T4, T5, T9, T10, T11, T12, T13, T14, T15. | I |
| **T14** | T5, T9, T12, T13, T14, T15. | T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16. | T5, T9, T12, T13, T14, T15. | I |
| **T15** | T4, T5, T9, T10, T12, T13, T14, T15. | T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16. | T4, T5, T9, T10, T12, T13, T14, T15. | I |
| **T16** | T12, T14, T15, T16. | T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T16. | T12, T16. | II |

## Appendix B

**Table B.1 – Binary Direct Reachability Matrix**

| *i/j* | T16 | T15 | T14 | T13 | T12 | T11 | T10 | T9 | T8 | T7 | T6 | T5 | T4 | T3 | T2 | T1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T1** | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 |
| **T2** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 |
| **T3** | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **T4** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| **T5** | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 |
| **T6** | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| **T7** | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| **T8** | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| **T9** | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| **T10** | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| **T11** | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 |
| **T12** | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| **T13** | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T14** | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T15** | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **T16** | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table B.2 – Frequency Direct Relationship Matrix**

| *i/j* | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 | T11 | T12 | T13 | T14 | T15 | T16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T1** | 0 | 0 | 15 | 14 | 12 | 15 | 13 | 0 | 12 | 12 | 13 | 12 | 0 | 16 | 13 | 14 |
| **T2** | 14 | 0 | 18 | 15 | 14 | 15 | 18 | 17 | 13 | 15 | 13 | 13 | 13 | 15 | 12 | 15 |
| **T3** | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 14 | 17 | 14 | 13 | 15 |
| **T4** | 0 | 0 | 0 | 0 | 12 | 14 | 13 | 11 | 14 | 11 | 13 | 10 | 13 | 16 | 10 | 9 |
| **T5** | 0 | 0 | 15 | 13 | 0 | 14 | 10 | 14 | 11 | 11 | 13 | 0 | 12 | 14 | 13 | 14 |
| **T6** | 0 | 0 | 16 | 0 | 0 | 0 | 10 | 13 | 0 | 0 | 0 | 0 | 0 | 11 | 8 | 14 |
| **T7** | 0 | 0 | 13 | 9 | 11 | 0 | 0 | 15 | 0 | 12 | 0 | 11 | 13 | 11 | 11 | 13 |
| **T8** | 0 | 0 | 8 | 0 | 10 | 12 | 0 | 0 | 0 | 0 | 0 | 11 | 12 | 17 | 10 | 0 |
| **T9** | 0 | 0 | 0 | 14 | 11 | 0 | 0 | 0 | 0 | 12 | 0 | 15 | 11 | 13 | 0 | 0 |
| **T10** | 0 | 0 | 14 | 14 | 11 | 11 | 0 | 14 | 12 | 0 | 0 | 12 | 14 | 11 | 0 | 10 |
| **T11** | 11 | 0 | 13 | 15 | 16 | 0 | 0 | 0 | 16 | 13 | 0 | 17 | 14 | 17 | 14 | 0 |
| **T12** | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 14 | 13 | 0 |
| **T13** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 9 | 0 | 13 | 0 | 0 |
| **T14** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 0 | 12 | 0 |
| **T15** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 14 | 0 | 0 |
| **T16** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 0 |

**Table B.3 – Fuzzy Direct Reachability Matrix**

| *i/j* | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 | T11 | T12 | T13 | T14 | T15 | T16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T1** | 0 | 0 | 0,75 | 0,75 | 0,5 | 0,75 | 0,5 | 0 | 0,5 | 0,5 | 0,5 | 0,5 | 0 | 0,75 | 0,5 | 0,75 |
| **T2** | 0,75 | 0 | 1,00 | 0,75 | 0,75 | 0,75 | 1,00 | 1,00 | 0,5 | 0,75 | 0,5 | 0,5 | 0,5 | 0,75 | 0,5 | 0,75 |
| **T3** | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0,75 | 1,00 | 0,75 | 0,5 | 0,75 |
| **T4** | 0 | 0 | 0 | 0 | 0,5 | 0,75 | 0,5 | 0,5 | 0,75 | 0,5 | 0,5 | 0,25 | 0,5 | 0,75 | 0,25 | 0,25 |
| **T5** | 0 | 0 | 0,75 | 0,5 | 0 | 0,75 | 0,25 | 0,75 | 0,5 | 0,5 | 0,5 | 0 | 0,5 | 0,75 | 0,5 | 0,75 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T6** | 0 | 0 | 0,75 | 0 | 0 | 0 | 0,25 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0,25 | 0,75 |
| **T7** | 0 | 0 | 0,5 | 0,25 | 0,5 | 0 | 0 | 0,75 | 0 | 0,5 | 0 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 |
| **T8** | 0 | 0 | 0,25 | 0 | 0,25 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0,5 | 1,00 | 0,25 | 0 |
| **T9** | 0 | 0 | 0 | 0,75 | 0,5 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0,75 | 0,5 | 0,5 | 0 | 0 |
| **T10** | 0 | 0 | 0,75 | 0,75 | 0,5 | 0,5 | 0 | 0,75 | 0,5 | 0 | 0 | 0,5 | 0,75 | 0,5 | 0 | 0,25 |
| **T11** | 0,5 | 0 | 0,5 | 0,75 | 0,75 | 0 | 0 | 0 | 0,75 | 0,5 | 0 | 1,00 | 0,75 | 1,00 | 0,75 | 0 |
| **T12** | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0,75 | 0,5 | 0 |
| **T13** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,25 | 0,25 | 0 | 0,5 | 0 | 0 |
| **T14** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0,5 | 0 |
| **T15** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0,75 | 0 | 0 |
| **T16** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 |

**Table B.4 – Fuzzy MICMAC Stabilized Matrix**

| ***i/j*** | **T1** | **T2** | **T3** | **T4** | **T5** | **T6** | **T7** | **T8** | **T9** | **T10** | **T11** | **T12** | **T13** | **T14** | **T15** | **T16** | **Driving power** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T1** | 0,5 | 0 | 0,75 | 0,75 | 0,75 | 0,75 | 0,5 | 0,75 | 0,75 | 0,5 | 0,5 | 1 | 1 | 1 | 0,75 | 0,75 | 11 |
| **T2** | 0,5 | 0 | 0,75 | 0,75 | 0,75 | 0,75 | 0,5 | 0,75 | 0,75 | 0,5 | 0,5 | 1 | 1 | 1 | 0,75 | 0,75 | 11 |
| **T3** | 0 | 0 | 0,25 | 0 | 0,5 | 0,75 | 0,5 | 0,5 | 0,75 | 0,5 | 0,5 | 0,5 | 0,5 | 1 | 0,5 | 0,25 | 7 |
| **T4** | 0,5 | 0 | 0,75 | 0,75 | 0,75 | 0,75 | 0,25 | 0,75 | 0,75 | 0,5 | 0,5 | 1 | 0,75 | 1 | 0,75 | 0,75 | 10,5 |
| **T5** | 0,5 | 0 | 0,75 | 0,75 | 0,75 | 0,75 | 0,5 | 0,75 | 0,75 | 0,5 | 0,5 | 1 | 1 | 1 | 0,75 | 0,75 | 11 |
| **T6** | 0 | 0 | 0,5 | 0,5 | 0,5 | 0,5 | 0 | 0,75 | 0,5 | 0,5 | 0 | 0,75 | 1 | 1 | 0,5 | 0,75 | 7,75 |
| **T7** | 0 | 0 | 0,75 | 0,75 | 0,5 | 0,75 | 0,5 | 0,75 | 0,75 | 0,5 | 0,5 | 0,75 | 1 | 1 | 0,5 | 0,75 | 9,75 |
| **T8** | 0 | 0 | 0,75 | 0,5 | 0,5 | 0,75 | 0,25 | 0,75 | 0,5 | 0,5 | 0,5 | 0,75 | 1 | 0,75 | 0,5 | 0,75 | 8,75 |
| **T9** | 0 | 0 | 0,75 | 0,75 | 0,5 | 0,75 | 0,5 | 0,75 | 0,75 | 0,5 | 0,5 | 0,5 | 0,75 | 0,75 | 0,5 | 0,75 | 9 |
| **T10** | 0 | 0 | 0,75 | 0,75 | 0,5 | 0,75 | 0,5 | 0,75 | 0,75 | 0,5 | 0,5 | 0,75 | 1 | 1 | 0,5 | 0,75 | 9,75 |
| **T11** | 0 | 0 | 0,75 | 0,75 | 0,5 | 0,75 | 0,5 | 0,75 | 0,75 | 0,5 | 0,5 | 0,75 | 1 | 0,75 | 0,5 | 0,75 | 9,5 |
| **T12** | 0 | 0 | 0,75 | 0,5 | 0 | 0,75 | 0,25 | 0,75 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,75 | 0,5 | 0,75 | 7,5 |
| **T13** | 0,5 | 0 | 0,5 | 0,75 | 0,75 | 0 | 0 | 0 | 0,75 | 0,5 | 0 | 1 | 0,75 | 1 | 0,75 | 0 | 7,25 |
| **T14** | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0 | 0,5 | 0,75 | 0,5 | 0 | 2,75 |
| **T15** | 0 | 0 | 0 | 0,75 | 0,5 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0,75 | 0,5 | 0,5 | 0,5 | 0 | 4 |
| **T16** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0 | 0,5 | 0 | 1 |
| **Dep. power** | 2,5 | 0 | 8,75 | 9 | 8,25 | 8,75 | 4,75 | 8,75 | 9,5 | 7 | 5,5 | 11,5 | 12,25 | 13,25 | 9,25 | 8,5 | |