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RESEARCH PAPER

Understanding service complexity in manufacturing companies: Insights and implications from a mixed methods study on drivers and levers of complexity

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Abstract
Expanding industrial service offerings is an essential growth and diversification strategy for manufacturing companies. However, the unstructured development of service portfolios introduces complexity drivers into organizations and presents new challenges in providing services efficiently and flexibly. This paper explores service complexity in manufacturing companies and evaluates levers for complexity management approaches. Applying an exploratory sequential mixed methods design, complexity drivers are qualitatively identified and clustered into complexity categories. The effect of these complexity categories on the efficiency and flexibility of the service provision is then quantitatively explored via an online survey. Correlation analysis reveals substantial interrelations among task complexity (0.61), service program complexity (0.49), and the complexity of service, support, and customer processes (0.48), highlighting these as most critical to efficiency in successful service provision. This study enables companies to assess and mitigate service complexity by identifying the key pain points for implementing complexity management measures.

Keywords Service complexity · Complexity drivers · Complexity management · Mixed methods study

JEL Classification L70 · L80 · M10 · O14 · O32 · O33

Introduction

Satisfying customer needs is considered the most crucial driver of variant generation in a company's offering (Wildemann, 2018). This growing emphasis on customer-centricity leads to a steady service portfolio expansion (Böhmann & Krcmar, 2006; Lang & Lichtblau, 2021; Schuh et al., 2019; Zou et al., 2018). In addition to individualization, the possibilities of digitalization also strongly impact the range of services offered by manufacturing companies. Emerging technologies like machine learning pose extensive possibilities for companies from various industries (Jin & Xu, 2024a, b). A well-thought-out digital servitization strategy can positively impact industrial companies' performance (Kohtamäki et al., 2020; Sklyar et al., 2019). In the wake of this trend of digital servitization (Paschou et al., 2020), manufacturing companies equip products and machines with sensors and actuators to offer data-based services for individual product variants (Jäger et al., 2016; Meiren & Neuhüttler, 2019). These developments lead to a steadily growing variety of offerings consisting of different products and variants as well as growing service portfolios consisting of industrial and data-based services that often cannot be transparently structured and communicated either internally or externally (Elmaraghy et al., 2013; Krause & Gebhardt, 2018; Masior et al., 2020).

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The resulting complexity in industrial service portfolios presents companies with the challenge of flexibly providing this variety of offerings without sacrificing efficiency and effectiveness (Arpe, 2012; Buchmüller, 2019; Schuh & Riesener, 2017; Schuh et al., 2019). Wildemann (2018) puts a doubling of the number of variants at a cost increase of up to 30%. However, industrial practice often does not consider the complexity of industrial service systems, so enormous potential remains untapped (Braun, 2015; Bruhn & Hadwich, 2017; Zou et al., 2018). Service research, therefore, recognizes complexity as an essential field to study (Polese et al., 2014). Gummesson et al. (2019) argue for closing the research gap on complexity in service systems.

In the case of manufacturing companies, there is generally an explicit lack of servitization research (Kohtamäki et al., 2019). Still, companies must deal with the complexity of industrial service systems to successfully provide classic and data-based services and exploit their potential. This poses a challenge, since, e.g., for digital service offerings, manufacturing companies need to adapt their organizational structures and processes to exploit the corresponding potential (Ciasullo et al., 2021; Schild et al., 2024). To ensure competitiveness in providing industrial services, complexity management approaches are applied to achieve an optimal balance between efficiency and flexibility, also considering costs (Binckebanck & Lange, 2020; Link, 2014). However, the understanding of complexity and complexity management activities for industrial services provided by manufacturing companies is still in a nascent state. Also, current concepts and standards for service design are mainly focused on large enterprises and are not suitable for application in SMEs (Feversani et al., 2023). Kapoor et al. (2022) highlight this by examining service portfolios. They conclude that manufacturing companies suffer from broad service portfolios, customer structures, and complicated products.

Understanding service complexity in manufacturing companies requires transparency about the roots of complexity in service operations. A model that identifies granular complexity drivers and organizes them according to their origins within service operations can facilitate this understanding. The existing literature provides several contributions to the complexity drivers of service operations. Benedettini and Neely (2012) derived 75 service complexity factors from a systematic literature review. Galvani and Bocconcelli (2022) tracked an Italian manufacturer of woodworking machines on its transition to offering a digital service platform. The single case study identified intra- and inter-organizational factors that influenced the complexity of offering these industrial services. Husmann (2020) provides insights into complexity drivers during the market introduction of data-based services by manufacturing companies. Bruhn and Blockus (2011) conceptualize a framework that distinguishes service complexity along the phases of service provision. The framework differentiates complexity in service operations along three dimensions with underlying complexity categories. It provides examples of complexity drivers within each complexity category. The existing literature provides various contributions to complexity drivers for service operations but misses a consolidated and empirically tested contribution for manufacturing companies. Building on the conceptualization of service complexity by Bruhn and Blockus (2011), we ask the question:

> RQ1: What are the complexity drivers of industrial service offerings in organizations, and how can these drivers be categorized?

The goal for companies should be effectively managing the complexity of their service operations (Riesener et al., 2019). For instance, Kwan and Spohrer (2021) suggest applying standardization measures to reduce service complexity, especially for digital services such as AI in enterprises. The service complexity framework by Bruhn and Blockus (2011) offers a structured way to conceptualize complexity in service operations. While the proposed complexity categories could serve as action fields for complexity management, their relevance and suitability for this application have not been thoroughly investigated by the authors. Riesener et al. (2019) propose efficiency and flexibility as measures of successful service operations in complexity management. This view is shared by Husmann (2020) and Grefrath (2015), who also highlight efficiency and flexibility as predominant success factors for service complexity management. Building on these two success factors and the service complexity framework by Bruhn and Blockus (2011), we ask the question:

> RQ2: Which complexity categories are particularly relevant and most suitable for complexity management in manufacturing companies?

Methodologically, we follow an exploratory sequential mixed methods design comprising a qualitative and a subsequent quantitative phase (Given, 2008). We apply the service complexity framework by Bruhn and Blockus (2011) to conceptualize complexity in service operations. The framework differentiates complexity in service operations along three dimensions with underlying complexity categories and provides examples of complexity drivers within each complexity category. Building on this framework, we extend each complexity category by supplementing it with a list of granular complexity drivers, thereby enhancing the framework's detail and linking specific complexity drivers to overarching categories and dimensions. Complexity drivers are identified from existing literature and further enriched through case studies and expert interviews.

Additionally, we contribute to understanding the relevance of complexity categories for service operations. We examine the interrelationships of service complexity categories with the efficiency and flexibility of service operations. Our results show positive correlations between complexity categories, especially with challenges to deal with the efficiency of service operations. We discover that complexity in service, support, and customer processes, task complexity, and service program complexity strongly correlate with the challenges in the efficiency of the service offering. These correlations indicate that out of all ten complexity categories of the framework by Bruhn and Blockus (2011), these three categories might play a prominent role.

The paper is structured as follows: The next section explores the literature and terminologies of industrial services, complexity measures and categories, and complexity drivers, and lastly, introduces efficiency and flexibility as success factors for managing complexity. Then, the paper's mixed methods research methodology and analysis methods are introduced. This is followed by two sections on the data collection, analysis, and findings for the research approach's qualitative and quantitative phases. Then, the implications of the qualitative and quantitative findings are discussed. Finally, the conclusion and section on further research derive theoretical and managerial implications, and formulate limitations of the study and avenues for further research.

Literature and terminology

Industrial services

Services are classified into business-to-customer (B2C) and business-to-business (B2B) offerings. Within B2B services, a further division exists between manufacturing services and other industry-specific services (Dreyer et al., 2019). Manufacturing companies exclusively provide the former type of service. This paper examines the specific domain of these manufacturing services, also termed industrial services (Dreyer et al., 2019; Herterich et al., 2015; Lightfoot et al., 2013; Poeppelbuss et al., 2022).

The characteristics of industrial services are effectively described through three service dimensions. These potential, process, and result dimensions correspond to a distinct phase in the service delivery process (Hilke, 1984; Meffert et al., 2018). The potential dimension refers to the initial phase of service delivery prior to actual execution. Here, the service is defined by the service provider's capabilities, which include various production factors, such as employees, machinery, and organizational knowledge. Services are non-transportable, necessitating the service being delivered at the customer's location or the customer visiting the service site. The challenge in this dimension lies in aligning these resources to meet customer requirements (Bruhn & Blockus, 2011; Bruhn & Meffert, 2012; Neuhüttler et al., 2017). For instance, this stage may include deploying rapidly evolving technologies, ensuring service delivery across multiple locations, and managing labor-intensive processes (Benedettini & Neely, 2012).

The process dimension emphasizes the actual process of service delivery. In this phase, an external factor from the customer is integrated into service production, representing material or intangible assets provided by the customer. The production phase combines internal and external production factors, resulting in an achievement contribution or utility from this achievement. Service delivery inherently requires collaboration with the customer, leading to the expiration of service capacity if unused at the production time (Bruhn & Meffert, 2012; Neuhüttler et al., 2017). For example, meeting customer requirements in this phase involves extensive interaction between the service provider and the customer during the delivery process or entails multiple procedural steps necessary for service completion. The process dimension may also encounter challenges like information asymmetry between the client and provider (Benedettini & Neely, 2012).

The result dimension focuses on the outcome as a defining characteristic of industrial services. This outcome is perceived as a change in the customer's external factors as a direct result of the service provision (Bruhn & Meffert, 2012; Neuhüttler et al., 2017). In this dimension, meeting customer requirements involves tasks such as delivering services to a diverse range of customer groups or introducing a new service offering. Challenges in this phase may include difficulty in predicting the exact outcome of the service (Benedettini & Neely, 2012).

Complexity and complexity measures

As a concept of relevance for many disciplines, diverse approaches exist to define complexity within the literature. Recently, the topic gained further interest in service research (Alt, 2021; Gummesson et al., 2019; Sachse, 2018). Many authors in the broader field of management research and complexity theory view complexity as a characteristic of systems (Barile & Polese, 2010; Kirchhof, 2003; Luhmann, 1975; Ulrich & Probst, 1991). Systems are defined as a whole consisting of several distinguishable elements that are interconnected through relations (Ehrlenspiel & Meerkamm, 2017; Göpfert & Steinbrecher, 2000; Luhmann, 1975; Ulrich & Probst, 1991). These systems include cities, companies, markets, and service systems through which services are provided, so complexity theory is an appropriate concept within this paper (Holland, 2006; Sachse, 2018).

For the application field of internal industrial services, Braun and Hadwich (2016) derive the four complexity

measures of multiplicity, diversity, mutual interdependence, and dynamics as the manifestations of complexity from 27 in-depth interviews regarding internal services across different industries. They define multiplicity as the number of involved elements, i.e., system components, stakeholders, and interaction within the service context. The authors further define diversity as the heterogeneity of elements as the degree of difference between stakeholders, interactions, and service components. Thirdly, the authors view mutual interdependence as interrelationships of system elements occurring between components and stakeholders of industrial services. Lastly, dynamics constitute the changes in the states of a system. In industrial services, this variability or changeability describes the changes in service components, stakeholders, and their interrelationships over time (Braun & Hadwich, 2016). These four measures of complexity are at least partially in line with the contributions of various authors in management research (Malik, 2015; Patzak, 1982; Reiß, 1993; Ulrich & Probst, 1991). This view of complexity measures is adapted in the context of product-service systems by Zou et al. (2018), who conducted a substantial literature review of complexity definitions in the field. Even though the internal industrial services addressed by Braun and Hadwich (2016) are not entirely congruent with the external industrial services addressed in this paper, a comparison with other authors of the broader management research field implies their applicability to this paper. Since the four measures align with these other contributions, they will be applied in this paper to assess the complexity of industrial services.

Complexity categories in service offerings

The complexity of industrial service offerings can be structured along their potential, process, and result dimensions with complexity categories for each dimension (Bruhn & Blockus, 2011). Complexity is thereby mapped on the phases of service provision as described above. Each dimension is assigned specific complexity categories, as shown in Table 1. The four complexity measures, as stated above, can be utilized to assess each complexity category of service offerings.

The *potential dimension* addresses the necessary resources for service delivery, i.e., the employees, technological know-how, and tangible requirements like machines and materials. Following these input factors of service offerings, employee complexity, technological complexity, site complexity, and material complexity are clustered within the potential dimension. Employee complexity comprises factors regarding the structure and dynamics of the workforce. Technological complexity addresses factors regarding the utilized technologies during service provision, i.e., communication systems or customer databases. Site complexity includes factors stemming from the company's existing locations and branches. Material complexity describes the factors of coordinating and planning the necessary materials for the service provision (Bruhn & Blockus, 2011).

The complexity of the service delivery is structured within the *process dimension* of the service. The process dimension first includes the complexity that is induced through all types of processes in a company. Namely, this entails the complexity in service, support, and customer processes. Service processes characterize processes that are directly linked to the service and may partly take place with the customer's participation in the liking of value co-creation. Support processes define the service-providing company's indirect processes, like providing a workforce at the customer's site. Lastly, customer processes are the necessary processes carried out by the customer to enable service delivery. The process dimension further entails task complexity, which stems from the tasks within a process, e.g., the knowledge or other requirements necessary to carry out a task. Lastly, the process dimension comprises the complexity of the external factor, which characterizes the customers and the modalities of their participation in performing a specific service offering (Bruhn & Blockus, 2011).

The complexity of the intended outcome of service provision is assigned to the *result dimension* of service offerings. The complexity of the service program addresses the characteristics of the categories and variants of services a company offers. Next, the service complexity describes the sub-services bundled into a service offering. For example, a milling machine manufacturer might provide the customer with a predictive maintenance package that consists of the data analytics part to predict failures in the bearings and the

Table 1 Service dimensions and their complexity categories following Bruhn and Blockus (2011)

Service dimension	Service categories			
Potential dimension	Employee complexity	Technological complexity	Site complexity	Material complexity
Process dimension	Complexity in service, support, and customer processes	Task complexity	Complexity of the external factor	-
Result dimension	Service program complexity	Service complexity	Customer structure complexity	-

subsequent maintenance service to change the bearings. The package, therefore, bundles different sub-services, i.e., prediction and maintenance, into one service package. Lastly, the customer structure complexity assesses the complexity of the various customer segments to which a company offers its service (Bruhn & Blockus, 2011).

Complexity drivers and the effects on complexity

Each of the introduced complexity categories comprises various complexity drivers. Existing literature introduces these complexity drivers as the cause of complexity in companies (Bruhn & Blockus, 2011; Gießmann, 2010; Kirchhof, 2003; Sachse, 2018; Schoeneberg, 2014). Complexity drivers describe the causal factors influencing complexity in companies. Complexity drivers are the reason for an increasing complexity level in a company and help to characterize the complexity of a system such as a company. While complexity drivers may influence each other, two cannot be wholly reduced into one. A distinction between external and internal complexity drivers is made by their exogeneity or endogeneity (Bliss, 2000; Picot & Freudenberg, 1998; Vogel & Lasch, 2016; Wildemann & Voigt, 2011). External complexity drivers stem from beyond the company's borders, prohibiting any direct influence on them. Internal complexity drivers are located within the company's borders and can, therefore, be at least partially influenced by it. The degree of realizable influence on an internal complexity driver depends on its correlation with external factors. Complexity stemming from offerings in a portfolio, e.g., is created by the company itself but is subject to external factors like customer requirements or changing market needs. Other complexity drivers, like a company's organizational and operational structure, are entirely in its control and can be influenced completely (Bliss, 2000; Gießmann, 2010; Kirchhof, 2003; Picot & Freudenberg, 1998; Schoeneberg, 2014).

The success of service offerings relies on a company's ability to manage the complexity drivers within its control (Riesener et al., 2019). As this effort solely addresses complexity drivers, which have the potential to be influenced, a company's focus might only be on internal complexity drivers. Nonetheless, a service offering's success is influenced by all complexity drivers regardless of a company's ability to influence them. The case could also be made that many external complexity drivers can be, at least in the long term, influenced to some degree by a company via strategic decisions. For example, the complexity of the customer structure may be changed via strategic decisions to include or exclude certain customers for a service offering. Furthermore, the competition in a market may be influenced by inorganic growth strategies. This paper will, therefore, view both internal and external complexity drivers in the following sections.

A company's influence on complexity drivers is directed toward reducing inefficiencies in providing service offerings to avoid unnecessary costs. Efficiency marks the ratio of an actual and necessary value. In terms of offered service variants, portfolio efficiency describes to what degree these variants are requested from the market and are, therefore, necessary (Schuh et al., 2019). The second target of managing complexity is providing an optimal level of flexibility during the provision of service offerings. This is especially important for the successful carry-out of services, as the customer simultaneously performs and consumes services. A company, therefore, needs to provide a certain level of flexibility regarding its potential to perform a service, as it must adhere to the customer's demand during its performance, which is hard to predict (Bruhn & Schmidt, 2009; Corsten & Gössinger, 2003; Grefrath, 2015; Husmann, 2020). Flexibility is, therefore, defined as a company's ability to deal with uncertainties and dynamic surroundings in a defined corridor (Zanker & Reisen, 2015).

Research methodology

To answer the research questions posed in the previous section, this paper applies an exploratory sequential mixed methods design comprising a qualitative and a subsequent quantitative phase (see Fig. 1). Mixed methods approaches, in general, combine qualitative and quantitative empirical methods to collect and analyze data, which is then integrated to investigate a research topic. As a subcategory of mixed methods approaches, the exploratory sequential mixed methods design is applied to collect and investigate data in an exploratory qualitative phase. Results are then applied to construct a questionnaire to test explorations in the subsequent quantitative phase (Given, 2008). This paper investigates and categorizes complexity drivers of the provision of service offerings and explores success factors for efficiency and flexibility in the initial qualitative phase. The relationships between complexity categories, flexibility, and efficiency are later tested in the quantitative phase.

The first phase aims to derive complexity drivers of the provision of industrial services and their impact on the organization. Literature research, case studies, and expert interviews were used to identify and consolidate specific complexity drivers in relation to industrial services. As roots of complexity, these should serve as concrete starting points for complexity management and facilitate operationalization in companies. A list of complexity drivers from existing approaches was extended and validated for the application field of service offerings via semi-structured interviews and workshops. The complexity drivers were comprehensively recorded and subsequently divided into internal and external drivers, depending on whether the company can directly

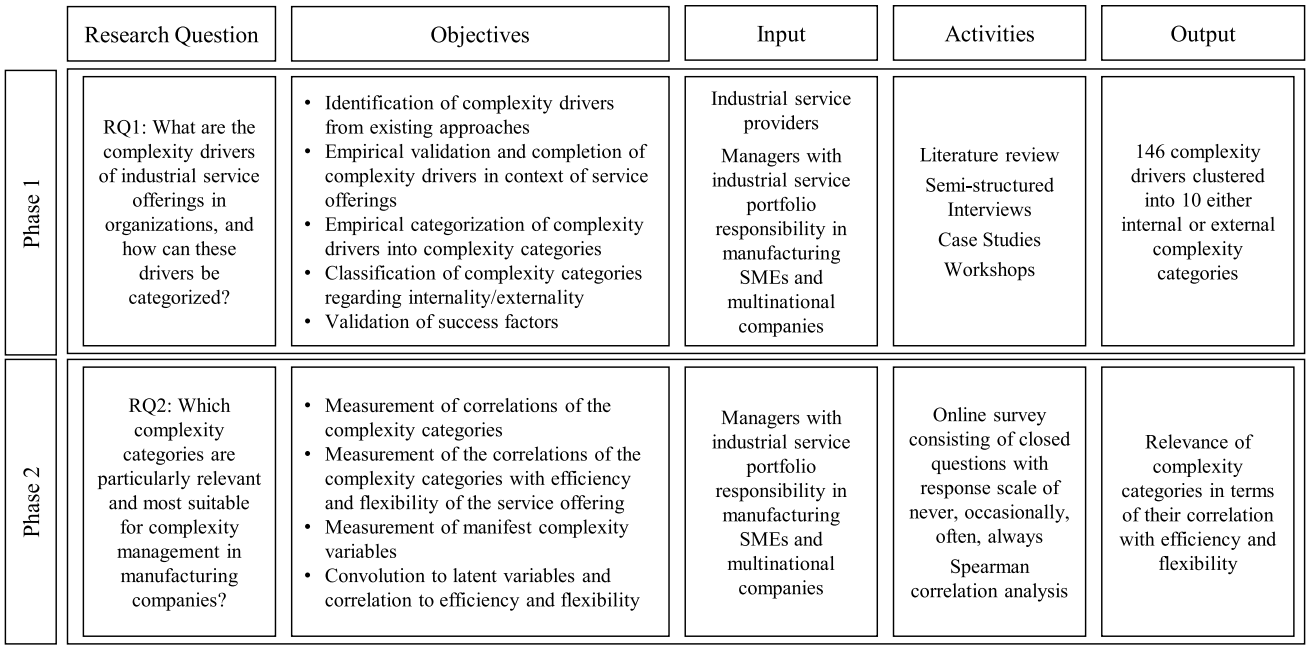


Fig. 1 Mixed methods approach comprising qualitative phase 1 and quantitative phase 2

influence them or not. Applying the style of Benedettini and Neely (2012), the complexity drivers were reformulated into concrete statements to render each complexity driver clearly distinguishable from the other drivers and make them actionable. Equivalent drivers from different sources were aggregated, and their applicability to manufacturing companies was assessed using a focus group of manufacturing companies who provide industrial services. The complexity framework of Bruhn and Blockus (2011) was used to aggregate complexity drivers into the aforementioned complexity categories. As stated above, each complexity category is assigned to either the potential, process, or result complexity dimension and is either internal or external. Due to the characteristic of complexity drivers stating that they may influence each other, their allocation into external and internal complexity categories may come with certain overlap. In our study, the complexity categories should be viewed as primarily internal or external instead of purely internal or external.

Phase 2 of the methodology aims to determine which complexity categories are particularly influential regarding service provision. Applying a quantitative research approach, we conducted an online survey to explore the interrelations between complexity categories, flexibility, and efficiency. The questionnaire was designed to explore the actual situation in the respondents' companies. The questionnaire opened with questions regarding the respondent's role and the company she is affiliated with. It included questions to evaluate the complexity levels of the complexity categories through the complexity measures multiplicity, diversity, mutual interdependence, and dynamics as manifest complexity variables. The mean of the four measures was applied in the following analyses as composed measure for complexity. The questions in the survey applied a Likert scale measuring, e.g., the degree of frequency of specific actions: "How often do you adjust your portfolio?" As answers, the participants could choose from "never," "occasionally," "often," and "always." Success factors were measured and grouped by efficiency and flexibility to measure a company's success in service operations. These factors were then evaluated by a correlation analysis from which implications for the service portfolio can be derived. As ordinal data is measured, Spearman's correlation analysis was applied to evaluate the influence of ordinal factors in the study. Spearman's correlation, when used with a Likert scale, is usually referred to as Spearman's rho. A perfect positive correlation has a value of 1. This means that "always" occurs every time together. A perfect negative correlation is represented by a value of − 1, indicating that an "always" as an answer for one question results in a "never" for another. A coefficient of 0 indicates no correlation (Kotz et al., 2006). This paper identifies a strong correlation beginning from the coefficient of 0.5 or higher. A moderate correlation begins at 0.30. Lower coefficients with a minimum value of 0.10 indicate a weak correlation (Cohen, 1988). One Likert item does not predict the other Likert item's value. The answers based on the Likert scale were attributed a number from 0 to 3, whereas 0 is attributed to "never" and 3 is attributed to "always."

Qualitative data analysis and findings

Data collection

The long list of complexity drivers from existing approaches in literature was extended and validated for the application field of service offerings via semi-structured interviews and case studies. The interviews were conducted with companies from various sectors, including security solutions, IT services, industrial robots, electronic payment systems, medical imaging systems, automation solutions, engineering services, hydraulic and pneumatic systems, and industrial cleaning technology. The respondents' profiles included job descriptions such as team lead customer care, team lead sales and project management service, chief technology officer (CTO) enterprise business unit industrial, and product owner digital service. In addition, case studies were conducted with companies in computer hardware, IT services, online food delivery services, software solutions, facility management, automotive engineering, electronics and electrical engineering, and automotive services. While manufacturing companies made up the predominant part of our selected cases, we expanded the case studies to service-oriented fields beyond the manufacturing industry to integrate the experience from companies whose operations are based heavily around services. The analyzed company landscape is heterogeneous and includes large and multinational corporations as well as medium-sized companies. We conducted our studies until saturation, where additional investigations did not add any more insights regarding complexity drivers.

A subsequent focus group with experts from the field of manufacturing was then conducted to additionally validate the occurrence of complexity drivers in the specialized field of industrial services. In addition, the focus group discussed and approved the success factors of efficiency and flexibility and the chosen operationalization of these. The interviewees were managing directors of small and medium-sized German companies in the mechanical engineering, metal processing, pharmaceutical, and plant engineering sectors. The interviewees' titles ranged from service program manager to managing director.

Qualitative analysis of drivers of complexity

A total of 146 complexity drivers in the provision of industrial service offerings were identified (Table 2). Of these, 24 were new drivers uncovered as part of the research project. Benedettini and Neely's (2012) research has already created a comprehensive basis for identifying complexity drivers for general services, which served as a foundation for the following concretization for industrial services. The results of the focus group did not indicate a rejection of the existing literature on drivers in general service research. This suggests that the applicability of this research in the specific area of manufacturing companies providing industrial services remains valid.

Notably, the categories task complexity, complexity of the external factor, and customer structure comprise the greatest number of complexity drivers. This indicates a significant interest in these dimensions in academic literature and practice. However, it is not possible to determine whether these categories also have the greatest influence on the complexity of the service offering. All complexity categories will be analyzed in more detail as part of the quantitative study in this paper.

It is important to note that there are still specific drivers in the application field of industrial services that were identified by the expert interviews and have not yet been mapped in the existing literature. A significant proportion of the newly identified drivers relate to international and project-based working issues, which may be highly relevant to the provision of industrial services. The driver "Project-specific specialists must be set up to provide the service." within the category employee complexity illustrates that specific competencies are required for certain projects. This occurs, for example, when one of the customers operates in a specialized sector such as the pharmaceutical industry, and project execution must be adapted accordingly. The drivers "The international rules and regulations for the provision of the service differ from the national rules and regulations.", "The labor law regulations for employees abroad differ internationally from national law (e.g., when posting employees abroad).", "Time shifts occur in the provision of (international) services.", "An (international) service partner network exists for the provision of the service," and "Service personnel must be coordinated in international projects." refer to potential complexity that may arise when performing services in international projects outside the home market.

The complexity in industrial services is significantly influenced by the product-induced complexity inherent in these services. "The products and services are strongly interconnected." in the category service complexity describes that the complexity increases when the service is closely linked to a specific product and cannot be prepared or performed without it. "The products to which the industrial service refers are complex" refers to the fact that the greater the complexity of the product, the greater the complexity of the corresponding industrial services. The material complexity category also includes the driver "The service relates to third-party products of the OEM business." This describes the additional complexity that arises when the service relates to a product not produced by the company but by a third party. It should, therefore, be noted that such drivers are

Table 2 Systematic overview of complexity drivers from literature and qualitative phase

Dimension	Complexity category	Internal/external	Complexity drivers	Literature
Potential	Employee complexity	Internal	• The company has a high number of hierarchies in relation to service provision. • The degree of division of labor/degree of centralization influences the provision of services. • Power struggles play a role in the employee base. • Employees are lacking in social and professional skills. • Employees are lacking in motivation and identification with company goals. • Negative emotions exist in the employee base. • The capacity of employees must be planned to provide the service. • The service process requires intensive input of human labor. • The input of human labor in the service process is predominantly intellectual. • The employees need a certain level of qualifications to provide the service. • *Project-specific specialists must be set up to provide the service.** • *Service personnel must be coordinated in international projects.**	• Piller (2006) • Bruhn and Blockus (2011) • Benedettini and Neely (2012)
	Site complexity	Internal	• The service locations are geographically distributed for the provision of the service. • The division of tasks and competencies of the service locations needs to be coordinated. • The service is delivered at many different locations (geographical dispersion of the firm's domain). • *An (international) service partner network exists for the provision of the service**	• Bruhn and Blockus (2011) • Benedettini and Neely (2012)
	Material complexity	Internal	• The service relates to third-party products of the OEM business. • The company has a variety of suppliers in terms of service. • The service has low commodity content. • The service requires a variety of inputs. • The provision of the service involves the use of shared resources. • The service requires intensive investments. • The service material is changing. • The service material is heterogeneous. • There is a variety of service material. • The service material is diverse. • *Physical components must be maintained for the provision of the service.** • *Parts must be kept in stock to provide the service.**	• Piller (2006) • Bruhn and Blockus (2011) • Benedettini and Neely (2012) • Grefrath (2015)
	Technological complexity	Internal	• The service requires a large number of information and technology interfaces. • The service uses new and sophisticated technologies. • The service uses rapidly developing technologies. • The service delivery involves several different technologies. • *The information systems lack transparency about processes.** • *Non-standardized data formats are used in the provision of the service.**	• Piller (2006) • Benedettini and Neely (2012) • Husmann (2020)

Table 2 (continued)

Dimension	Complexity category	Internal/external	Complexity drivers	Literature
Process	Complexity in service, support, and customer processes	External	• Information technology used by customers consists of many different resources. • The information technology is implemented chaotically on the customer side. • Innovative service features are developed in collaboration with customers. • The service involves an ongoing interaction between the customer and the service so that the customer can make decisions. • The service requires a high number of interactions between the service provider and the customer during the service delivery process. • The service involves a high interrelation of activities taking place between the service provider and the customer during the service delivery process. • The service requires the customers to be in the system for a high percentage of the time it takes to serve them, i.e., high customer contact. • The service needs to be carried out cooperatively with the customers, i.e., high customer involvement. • The service is delivered in a process that is to be tightly integrated into the business processes of customers (industrial services only). • The pricing structure for the service changes frequently • Customers have a wide range of requirements. • The customer requirements for the service are difficult to interpret. • The customer requirements for the service are subject to change.	• Neu and Brown (2005) • Piller (2006) • Bruhn and Blockus (2011) • Benedettini and Neely (2012) • Galvani and Bocconcelli (2022)

Table 2 (continued)

Dimension	Complexity category	Internal/external	Complexity drivers	Literature
	Task complexity	Internal	• The decision-making processes for the provision of services are long. • Information asymmetries regarding the service (e.g., about responsibilities or changed service procedures) exist in the company due to constant service development. • Media discontinuities occur at the interfaces during the provision of the service. • The service provision processes are characterized by a strong system of form-based processes. • The type of task coordination influences the provision of the service. • Divisional egoisms occur in the provision of services. • Responsibilities are being shifted during service provision. • There are many interfaces between the various service processes (coordination between people and technologies) • Unforeseen process deviations/uncertainties can occur during service provision. • The service is delivered across multiple channels. • The service incorporates a variety of distinct knowledge bases, skills, and competencies. • Operations relative to the service involve a high number of people. • The production and delivery system for the service involves a high number of feedback loops. • The service involves complicated commercial arrangements, such as stage payments, penalty clauses, and performance bonds. • Management takes responsibility for the entire task of providing the service through a performance-based contract. • The contractual relationship between the service provider and the customer is highly individual. • A variety of pricing structures are available for the service, or different pricing structures exist for different customer groups. • The service delivers many different functions / addresses a wide range of customer requirements. • The service delivers sophisticated functions/ addresses sophisticated customer needs. • A high number of steps are required to produce the service. • The service is produced through a high number of steps. • Highly interrelated steps are required to produce the service. • The service is produced through highly interrelated steps. • The process of service production may need to adapt non-routine procedures and methods. • The service does not rely on established bodies of knowledge, yet it requires new solutions. • The provision of the service is based on judgment as the service involves tacit, as opposed to codifiable, information. • The service can be produced according to a number of alternative paths. • The service involves a great deal of specialized knowledge to undertake the service tasks. • *The steps involved in providing the service are very diverse.** • *The service process is prone to human error.** • *Service processes are highly optimized to save costs.** • *The products to which the industrial service refers are complex.**	• Piller (2006) • Bruhn and Blockus (2011) • Benedettini and Neely (2012) • Grefrath (2015) • Galvani and Bocconcelli (2022)

Table 2 (continued)

Dimension	Complexity category	Internal/external	Complexity drivers	Literature
Result	Complexity of the external factor	External	• Material and data flows exchanged between partners in the service delivery network are affected by uncertainty. • Due to a lack of expertise, cooperation with an external partner is required for service provision (especially for new technologies) • The service requires a high degree of customer knowledge. • The service is affected by information asymmetry between the client and the service provider. • The process of service innovation involves suppliers and customers. • The service is delivered through a network consisting of a complex web of direct and indirect ties between various actors, all delivering value either to their immediate customer or to the end customer. • The delivery network for the service comprises actors, each of whom might be involved with multiple other delivery networks, each with their own demands. • The delivery network for the service involves different parties that depend on each other to accomplish their tasks. • The cost and quality of the service, i.e., the relationship between input and service output, are affected by changes in the environment. • Tolerance for the time it takes to produce the service is low. • The value network of the service comprises a high number of actors with which the service provider has to manage a relationship. • The service involves conflicts between multiple stakeholders. • The service is subject to a pressing regulatory environment. • There are a large number of interfaces within the service value chain. • *The industry is characterized by a high level of technical progress, and the technologies that are used quickly become obsolete.** • *When providing the service, it is mandatory to work together with various institutions (e.g., BaFin).** • *The international rules and regulations for the provision of the service differ from the national rules and regulations.** • *The labor law regulations for employees abroad differ internationally from national law (e.g. when posting employees abroad).** • *Time shifts occur in the provision of (international) services.**	• Schuh (2005) • Piller (2006) • Benedettini and Neely (2012) • Galvani and Bocconcelli (2022)
	Service program complexity	Internal	• The service portfolio is offered internationally. • Technically appealing products/services are created without any prior consideration. • The company uses services to differentiate itself from competitors. • The company individualizes services to satisfy customer feedback. • The service is new. • The service is offered according to many differentiated options. • The service has a short life cycle. • The service has a high risk of obsolescence. • The service organization offers many different services. • *The service is regularly adapted to fulfill the customer's demand for the latest technologies.** • *The company wants to gain further market share as a full-service provider.** • *The range of services is highly diversified.**	• Schuh (2005) • Neu and Brown (2005) • Böhmann and Krcmar (2006) • Piller (2006) • Bruhn and Blockus (2011) • Benedettini and Neely (2012) • Wildemann (2017) • Husmann (2020)

Table 2 (continued)

Dimension	Complexity category	Internal/external	Complexity drivers	Literature
	Service complexity	Internal	• The services are individualized to the customer. • Services are expanded non-transparently and at will. • Several individually customized service elements in the customer offering are bundled. • The service is highly individual. • The outcome of the service is difficult to predict. • The outcome of the service is difficult to monitor. • The service entails some innovation that is perceived as being difficult to understand and use. • The service is offered according to sophisticated options, e.g., with the purchase of new technology and more advanced infrastructure. • The service is difficult to provide in a cost-effective and efficient manner. • The service has a high cost. • The service contains a high number of sub-services. • The service contains very heterogeneous sub-services. • The service contains highly interrelated sub-services. • The service is delivered through assembling sub-services offered by a pool of seller candidates, which provide complementary as well as substitutive services. • *The products and services are strongly interconnected.**	• Schuh (2005) • Neu and Brown (2005) • Böhmann and Krcmar (2006) • Bruhn and Blockus (2011) • Benedettini and Neely (2012) • Grefrath (2015) • Galvani and Bocconcelli (2022)
	Customer structure complexity	External	• The company is experiencing strong international competitive pressure regarding services. • The service is infrequently purchased. • The market for the service is highly competitive. • The company's customers are international. • Customers demand individualization of the service. • The market for the service is very dynamic. • The company has a high number of customers. • The customers' international markets have diverse specific characteristics. • Individual, cross-industry, and cross-border business models of business customers are changing rapidly • The service is offered to many different groups of customers (heterogeneity of the firm's domain). • The needs and wants for the service are very heterogeneous among the firm's customers. • The timing and level of customer demand for the service are uncertain. • The customers tend to look for new offerings for the service all the time. • The customer will purchase the service based on credence qualities, i.e., supplier reputation and relationship with the supplier. • The service is difficult to understand for the customers. • A large amount of information is needed to specify the attributes of the service in enough detail to allow potential buyers to make a selection. • The customers lack the technical knowledge to evaluate the service. • *The service is used to outsource individual corporate strategies to the service provider (e.g., emission or cost savings)** • *Services are provided to fulfill the requirements of the market.** • *Services are needed to remain competitive in the market.** • *The products relating to the industrial service are very diverse among customers.**	• Neu and Brown (2005) • Schuh (2005) • Piller (2006) • Bruhn and Blockus (2011) • Benedettini and Neely (2012) • Grefrath (2015) • Wildemann (2017)

*Newly identified in expert interviews

specific to industrial services and have not yet been sufficiently represented in the literature.

Other drivers worth mentioning include, e.g., "The service is regularly adapted to fulfill the customer's demand for the latest technologies." or "The international rules and regulations for the provision of the service differ from the national rules and regulations." However, regarding the regulation aspect, it was noted that this can also be a complexity-reducing factor as it might help standardize interfaces.

A comprehensive catalog of complexity drivers has now been created to support companies in defining measures for complexity management. However, this step has not yet defined the extent to which these complexity dimensions and categories have the greatest empirical influence on companies and which of the derived measures have the greatest impact.

Operationalization of success factors

Eight questions were developed to operationalize the success factors of flexibility and efficiency for the subsequent survey. These were validated in conjunction with the focus group. The efficiency factor was represented by questions around statements such as "The effort required to prepare a service is high for a new customer." This statement is designed to measure the amount of effort required to onboard a new customer. A high level of effort may indicate inefficiencies in the initial preparation process of complex services, suggesting potential areas for improvement in customer onboarding procedures. "There are often quality deficiencies due to deviations in the provision process": This measures the frequency and impact of deviations from standard procedures that result in quality issues. Due to complex processes, frequent deficiencies may suggest inefficiencies in maintaining consistent service quality. The question around the statement "The documentation after the service has been provided takes a long time" refers to the time required to complete the necessary follow-up and documentation after a service has been provided. Long documentation times may indicate inefficient processes caused by complexity in the service. "The customer's case is recorded in detail in advance" examines the thoroughness and detail of the information gathered in advance about the client's case. A detailed collection may allow for efficient delivery of the services to the client's specific needs, whereas complex services can hinder this process.

The flexibility factor was represented by questions around statements such as "We have a large pool of staff available to handle inquiries on call." This question aims to capture the availability and flexibility of personnel to respond to short-notice requests. A large and flexible workforce may indicate high flexibility, whereas complexity can be a hindrance in this context. Similarly, "We cannot serve customers due to staff shortages or similar" indicates the impact of staff shortages on the ability to serve customers. Frequent bottlenecks due to staff shortages may suggest low flexibility due to complexity. The question around the statement "We find it difficult to bill our services" captures difficulties in the service billing process. Issues in billing may indicate a lack of flexibility caused by complex processes. Finally, "We cannot serve customers as we do not specialize in their sector or similar" examines the ability to serve clients from various industries. Issues in this area may suggest a lack of flexibility in processes, which may be complex due to a high degree of specialization.

Quantitative data analysis and findings

Survey demographics

The survey was conducted with 59 respondents. The respondents' roles within their companies are predominantly in senior management positions, with 21 participants from the management/board of directors, 19 from division or department management, and 14 from team or project management. This ensures that the survey results are influenced by those with significant managerial and strategic responsibilities. The industrial and mechanical engineering sector is most strongly represented, with 28 participants. This is followed by the automotive industry with 12 participants and the pharmaceuticals and medical technology sector with 8 participants.

The companies participating in the survey represent various sizes, locations, and revenues. Regarding employee numbers, 20 companies have more than 5,000 employees, while 17 have only up to 10 employees. This provides a diverse representation of both large and small companies. Furthermore, 23 companies operate in more than 11 locations, while 21 are based in one location. This further highlights the diversity of respondents. Regarding international presence, 28 companies operate in more than 20 countries, indicating a significant global footprint among the respondents. Conversely, 17 companies are focused on operations within a single country.

Most companies have been in business for more than 20 years, demonstrating a strong presence of established companies in the survey. However, there is also representation from newer companies, some of which have been in business for less than a year. This suggests a mix of experienced companies and emerging players in the market. The annual revenue figures also reflect this diversity, with 25 companies reporting revenues of more than €500 million and eight companies reporting revenues of less than €0.5 million. This spread across revenue levels underscores the varying economic size of the participating companies.

The comprehensive survey demographics can be found in Appendix.

Correlation between internal and external complexity and success factors

The influencing factors are presented at different levels of granularity to guide the assessment. The complexity factors can be divided into internal and external factors according to the extent to which the company can influence them. Therefore, the correlation between these and the success factors of efficiency and flexibility is analyzed below. The results of the correlation analysis are shown in Table 3.

The correlation analysis shows that internal and external complexity factors have noteworthy correlations with the success factors. Internal complexity correlates more strongly with efficiency (0.45) than flexibility (0.09). Similarly, external complexity shows a moderate correlation with efficiency (0.45) and a weak correlation with flexibility (0.16). It can be seen that both complexity factors show similar correlations with the success factors, and neither one dominates.

A moderate correlation (0.32) can be seen when analyzing the correlations between internal and external complexity. This indicates that companies confronted with internal complexity factors also tend to experience external complexity factors. This correlation may suggest that complex internal structures and processes can make a company more susceptible to external challenges or that companies operating in complex external environments have more complex internal structures.

Correlation analysis of the complexity dimensions and success factors

The complexity dimensions of Bruhn and Blockus (2011) are analyzed with regard to their influence on the success factors of flexibility and efficiency. This serves as an initial overview on a higher abstraction level before the individual complexity categories are analyzed in more detail. The corresponding correlation analysis is shown in Table 4.

The correlation analysis shows relevant correlations between the overarching complexity dimensions and the success factors of flexibility and efficiency. The potential dimension correlates strongly with efficiency (0.52), while the correlation with flexibility is weak (0.16). The process dimension shows a stronger correlation with both success factors. The correlation with flexibility is 0.33, and with efficiency, 0.65. The result dimension shows a weak correlation with flexibility (0.01) and a moderately weak correlation with efficiency (0.28).

Analyzing the correlations between the complexity dimensions themselves shows several relevant correlations. The correlation between the potential and process dimensions is 0.52, which indicates a strong correlation between the two dimensions. A strong correlation can also be observed between potential and result (0.54). The process and result dimensions correlate moderately (0.38). Overall, the dimensions show moderate to strong correlations with each other, indicating that an improvement in one dimension could also positively impact the other dimensions. In addition, similar to the classification of complexity drivers, it could be shown that the dimensions by Bruhn and Blockus (2011) are not clearly separated from each other and show overlaps.

Table 3 Correlation between internal and external complexity and success factors

	Internal complexity	External complexity	Flexibility	Efficiency
Internal complexity	1.00			
External complexity	0.32	1.00		
Flexibility	0.09	0.16	1.00	
Efficiency	0.45	0.45	0.28	1.00

Table 4 Correlation of the complexity dimensions and success factors of industrial service offerings

	Potential	Process	Outcome	Flexibility	Efficiency
Potential	1.00				
Process	0.52	1.00			
Result	0.54	0.38	1.00		
Flexibility	0.16	0.33	0.01	1.00	
Efficiency	0.52	0.65	0.28	0.28	1.00

Correlation analysis between complexity categories and success factors

At the highest level of granularity, the subordinate complexity categories are correlated with the success factors of efficiency and flexibility. The results of the correlation analysis are shown in Table 5.

Within the potential dimension, there is a relevant correlation between technological complexity (0.34) and, to a lesser extent, material complexity (0.29) and efficiency. In contrast, the correlation with employee complexity (0.21) or site complexity (−0.01) is only weakly pronounced or even negative. Meanwhile, all complexity categories within the process dimension are strongly correlated with efficiency. The strongest correlation is between efficiency and task complexity (0.61). In addition, complexity in service, support, and customer processes shows a moderate correlation with efficiency, with a coefficient of 0.48. Finally, the complexity of the external factor also shows a moderate correlation with

Table 5 Correlation between complexity categories and success factors

		Employee complexity	Site complexity	Material complexity	Technological complexity	Complexity in service, support, and customer processes	Task complexity	Complexity of the external factor	Service program complexity	Service complexity	Customer structure complexity	Flexibility	Efficiency
Potential dimension	Employee complexity	1.00											
	Site complexity	0.41	1.00										
	Material complexity	0.00	0.12	1.00									
	Technological complexity	0.19	0.23	0.50	1.00								
Process dimension	Complexity in service, support, and customer processes	0.25	0.01	0.23	0.28	1.00							
	Task complexity	0.30	0.17	0.34	0.40	0.51	1.00						
	Complexity of the external factor	0.10	0.10	0.07	−0.05	0.17	0.19	1.00					
Result dimension	Service program complexity	0.28	0.25	0.43	0.44	0.30	0.59	0.14	1.00				
	Service complexity	0.25	0.04	0.17	0.22	0.05	0.45	0.10	0.63	1.00			
	Customer structure complexity	0.18	0.14	0.20	0.44	0.17	0.11	0.05	0.07	−0.27	1.00		
Success factors	Flexibility	−0.06	−0.10	0.04	0.00	0.23	0.38	0.04	0.14	0.08	0.08	1.00	
	Efficiency	0.21	−0,01	0.29	0.34	0.48	0.61	0.33	0.49	0.35	0.11	0.28	1.00

efficiency (0.33). In the results dimension, a moderate correlation can be found between service program complexity (0.49) and service complexity (0.35). Customer structure complexity only shows a weak correlation with 0.11.

The correlations between complexity categories and success factor flexibility show a different picture. Notably, most complexity categories show only very low or even negative correlations with flexibility. Only task complexity from the process dimension indicates a moderate correlation with flexibility (0.38). In the results dimension, service program complexity (0.14), service complexity (0.08), and customer structure complexity (0.08) only show weak correlations with flexibility. Within the complexity categories analyzed, several factors show no or a negative correlation with flexibility. These include the employee complexity (−0.06), site complexity (−0.10), and technological complexity (0.00) from the potential dimension.

The correlations between the complexity categories show various relationships. The strong correlation between service program complexity and service complexity (0.63) is particularly striking. There is also a strong correlation between service program complexity and task complexity (0.59). Furthermore, task complexity and complexity in service, support, and customer processes also strongly correlate (0.51). Further relevant positive correlations can be found between material complexity and technological complexity (0.50) and task complexity and service complexity (0.45). This leads to the conclusion that the aforementioned complexity categories generally occur together or that the complexity categories cannot be clearly distinguished from one another.

Correlations between the measures of complexity and success factors

This study utilizes the mean of multiplicity, diversity, dynamics, and mutual interdependence as complexity measures (Braun & Hadwich, 2016) as composed complexity value. We now analyzed the correlations of these four measures with flexibility and efficiency on a granular level. The correlation analysis in Table 6 presents a correlation matrix of these complexity measures, flexibility, and efficiency.

The correlation analysis indicates that various complexity measures positively correlate with flexibility and efficiency. For efficiency, strong correlations appear with multiplicity (0.56) and dynamics (0.50), while diversity shows a moderately strong correlation (0.49). Mutual interdependence only demonstrates a weak correlation (0.24). In contrast, correlations between flexibility and complexity measures are generally weaker. Specifically, flexibility has a weak correlation with only multiplicity (0.28) and minimal correlations with diversity (0.16), dynamics (0.09), and mutual interdependence (0.02). This analysis highlights that multiplicity, followed by diversity and dynamics, holds the greatest relevance for both success factors, while mutual interdependence demonstrates low relevance.

An analysis of the measures among themselves reveals that multiplicity and diversity exhibit a strong correlation (0.68). Multiplicity also shows a strong correlation with dynamics (0.55) and a weak correlation with mutual interdependence (0.24). Similarly, diversity correlates strongly with dynamics (0.64) but has a weak correlation with mutual interdependence (0.27). Finally, dynamics displays a moderate correlation with mutual interdependence (0.32). These correlations among the measures suggest that various facets of complexity in industrial service offerings are interconnected and should not be regarded as entirely independent. This interconnectedness may indicate that these measures represent different manifestations of complexity occurring simultaneously.

Implications of the findings

Correlations of complexity categories with flexibility and efficiency

When manufacturing companies follow the path of servitization by introducing and expanding their service portfolio, they encounter various types of complexity. The correlation analysis shows correlations of complexity categories, for the most part, with efficiency. There exists only one noteworthy correlation between complexity categories and flexibility, which is task complexity (0.38). This result does

Table 6 Correlation between the complexity measures and success factors

	Multiplicity	Diversity	Dynamics	Mutual interdependence	Flexibility	Efficiency
Multiplicity	1.00					
Diversity	0.68	1.00				
Dynamics	0.55	0.64	1.00			
Mutual interdependence	0.24	0.27	0.32	1.00		
Flexibility	0.28	0.16	0.09	0.02	1.00	
Efficiency	0.56	0.49	0.50	0.24	0.28	1.00

not directly align with the existing literature or our results from the qualitative part of this study. Especially the characteristic of services to be simultaneously performed and consumed indicates that there may be a relation between flexibility and complexity categories of the process dimension of service provision. This leads to the conclusion that there might be other factors of flexibility that have not been within the scope of the questionnaire. Since the success factors have been empirically validated in phase 1 of the study, we conclude that our sample of the qualitative part of the study might benefit from further investigations into measures of flexibility for the application field of service offerings.

The correlation analysis shows several moderate or moderately strong relations between complexity categories. The most prominent levers to interact with complexity seem to be in the service delivery process and its intended results. This might reflect the relative novelty of providing services for manufacturing companies, which may lead to companies not having the most advanced processes established in their organization and may require process streamlining and standardization. This becomes most prevalent in the categories task complexity (0.61), complexity of the external factor (0.33), and complexity in service, support, and customer processes (0.48), which are all part of the process dimension (see Table 3). For task complexity, the qualitative part of the study yielded the internal complexity driver "The steps involved in providing the service are very diverse," which underlines the challenge of process inefficiencies affecting service delivery. Task complexity of the service delivery may also stem from a product on which the service is performed, as shown in the complexity driver "The products to which the industrial services refer are complex." The complexity category complexity of the external factor is moderately correlated with efficiency. This correlation aligns with the workshops and interviews conducted in phase 1. Experts pointed out that the national rules and regulations that must be abided by a company when it performs a service internationally introduced inefficiencies in the service provision. This point is reflected, for example, in the complexity driver "The labor law regulations for employees abroad differ internationally from national law (e.g., when posting employees abroad)." Lastly, complexity in service, customer, and support processes strongly correlates with efficiency. This may be due to a high level of customer involvement in the service delivery, which in turn causes alterations in the delivery process. The last two correlations show that companies in the short term may not be in control of all complexity drivers, which nonetheless influence the success of the service offering. Strategic decisions on which markets to serve may help alter the external factor's complexity levels. The conception of the value proposition may help reduce the level of needed customer involvement. These examples show how external complexity categories may differ from internal complexity categories in the conditions companies must adhere to when influencing them.

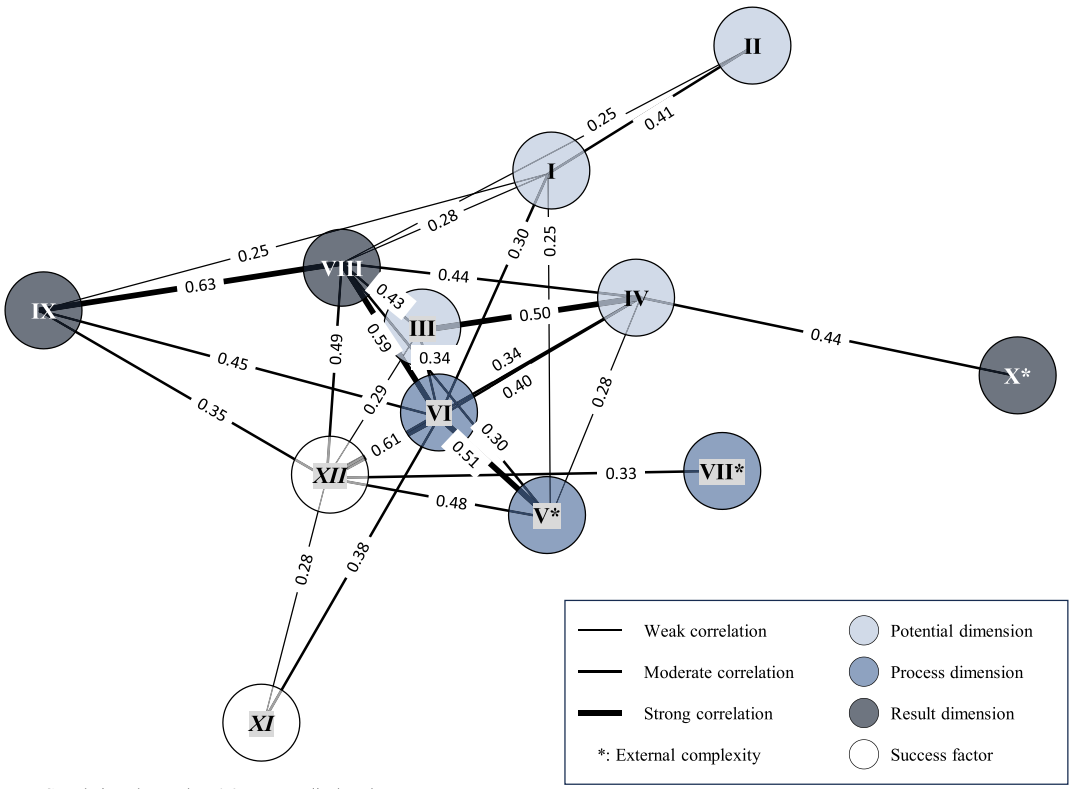
As shown in Table 5, the result dimension holds correlations of efficiency with both service program complexity (0.49) and service complexity (0.35). Service program complexity addresses the service portfolio of a company. The complexity level of a service portfolio is subject to complexity drivers like "Technically appealing products/services are created without any prior consideration.", and "The range of services is highly diversified." Both of these complexity drivers may be created by a company that opens a new business field, like service offerings without a clear portfolio strategy, or a company that tries to expand market share by adding service variants wherever possible. This increases the number and diversity of the services provided by the company and expands the service portfolio. This leads to less efficient service provision, i.e., increasing the time it takes to conduct the service and calculate the service fee. The second category, service complexity, is inter alia related to the integrating of several sub-services into one offering, as described in the complexity driver "Several, individually customized service elements in the customer offering are bundled." This bundling may again lead to inefficiencies by increasing the time-of-service delivery and calculation. Both complexity categories express internal complexity that a company may directly influence. Both instances may benefit from standardization and modularization approaches, as they allow the reduction of internal complexity needed to address a certain external complexity. Both complexity categories, therefore, may present useful levers to address complexity in service offerings.

Lastly, the potential dimension holds two complexity categories with a moderately weak to moderate correlation to efficiency (see Table 5). Material complexity (0.29) addresses the physical materials necessary for the service provision, as stated, e.g., in the complexity driver, "Parts must be kept in stock to provide the service." Keeping parts in stock for service provision plays a relevant role in efficiency, as warehousing and distribution of the right part to the place of service provision may increase costs, administration efforts, and documentation. Especially the subsequent introduction of services to products that are already in the market may affect the efforts to provide needed materials for the service since adaptations to optimize efficiency in material use may not have been thought of during the conception of the products. This may be exacerbated in the case of a non-standardized and non-modularized product portfolio. Again, this may lead to the conclusion that standardization and modularization efforts might be a valuable lever to increase service efficiency. The complexity category of

technological complexity also shows a relation to efficiency (0.34). Technological complexity comprises complexity drivers like "The information systems lack transparency about processes." The shortage of information regarding the service process itself and the missing information on the progress of the service provision may prolong the work on the customer's site and may hinder operations decisions. The delivery effort may be misjudged due to missing transparency about the necessary process steps, so timeliness and efficiency are at stake. Well-integrated technology may reduce documentation efforts, which in turn may increase efficiency. The complexity driver regarding missing standardization of data formats along the process of service provision may hinder data analytics and might, therefore, represent a relevant lever for companies.

The emergence of clusters of complexity categories and success factors

The results of the correlation analysis show that a significant number of the complexity categories exhibit a high degree of intercorrelation with each other and with the defined success factors. These relationships are illustrated in Fig. 2, which provides a further visual representation of the correlations between the various complexity categories and the success factors.



Correlations lower than 0.25 are not displayed

Number	Corresponding complexity category
I	Employee complexity
II	Site complexity
III	Material complexity
IV	Technological complexity
V*	Complexity in service, support, and customer processes (external)
VI	Task complexity

Number	Corresponding complexity category
VII*	Complexity of the external factor (external)
VIII	Service program complexity
IX	Service complexity
X*	Customer structure complexity (external)
XI	*Flexibility*
XII	*Efficiency*

Fig. 2 Network diagram of complexity categories and success factors organized by complexity dimensions and internality/externality

A central cluster emerges between the categories of service program complexity, material complexity, technological complexity, complexity in service, support and customer processes, and the success factor efficiency, which are closely linked. Service complexity and employee complexity also show a noteworthy degree of interconnectedness with the other categories, while flexibility, site complexity, and customer structure complexity show only a low degree of interconnectedness and appear isolated.

Given these findings, future complexity management measures should prioritize the identified central cluster to leverage the interactions between the different complexity categories. By focusing on these interrelated dimensions, companies can develop more targeted strategies to manage complexity and enhance efficiency in their service offerings. Furthermore, the high degree of intercorrelation between the complexity categories indicates potential overlap and a lack of discriminatory power within the framework proposed by Bruhn and Blockus (2011). While a certain level of intercorrelation between the different dimensions is to be expected, further refinement may be required to ensure clearer distinctions between the categories. This could involve redefining some dimensions or introducing new categories to better capture the complexity of industrial service offerings.

Comparison of internal and external complexity

The correlations of internal and external complexity with the success factors confirm the assumption based on the literature that both characteristics are relevant for companies. Companies can directly influence internal complexity through targeted complexity management and achieve positive effects in terms of efficiency and flexibility. However, external factors that lie outside the company's sphere of influence can also have an impact on the company's success. Therefore, it is also up to companies to influence these external factors through a long-term and strategic definition of their business areas (e.g., selection of customer segments).

The analysis of the complexity categories at the complexity category level shows that the central cluster of complexity categories consists mainly of internal complexity categories (Fig. 2). Only complexity in service, support, and customer processes is included here as an external factor. This indicates that the central cluster can be a promising starting point for complexity management, as the company itself can influence these complexity categories. Nevertheless, it is advisable not to neglect the external factors, which have relevant correlations with efficiency.

Conclusion and further research

Theoretical contributions

Managing and identifying complexity is vital to successful service operations. This paper investigates and categorizes complexity drivers and explores the relevance of the complexity categories through their interrelations to efficiency and flexibility. We provide an overview of complexity drivers from the literature, which is validated and extended to fit the field of service offerings by manufacturing companies. The categorization of complexity drivers into complexity categories helps to situate them along the three dimensions of service provision. A differentiation between internality and externality allows companies to evaluate the degree of influence they can exert on them. This study provides two theoretical contributions to extend the literature on service complexity by adding to the service complexity framework by Bruhn and Blockus (2011).

The service complexity framework by Bruhn and Blockus (2011) structures complexity in service offerings in three dimensions with a total of ten underlying complexity categories. Each complexity category is supplemented with complexity drivers, for which the authors provide examples. Our study combines existing literature and empirical evidence in order to add to the service complexity framework by investigating complexity drivers of service offerings and subordinating them to the complexity categories in the framework.

We further examine the interrelationships of service complexity categories from the service complexity framework by Bruhn and Blockus (2011) with the efficiency and flexibility of service operations. Our study shows that all moderate and strong correlations of complexity categories with efficiency or flexibility are positive. This finding suggests that for all complexity categories with moderate or high values, higher levels of complexity indicate higher values in our measures for corresponding efficiency and flexibility. Higher measures for efficiency or flexibility indicate that companies are increasingly challenged in offering their service in an efficient or flexible way. Our findings, therefore, support the relevance of the complexity categories from the service complexity framework by Bruhn and Blockus (2011). Strong correlations also indicate the complexity categories that have the highest interdependencies with flexibility and efficiency. Those complexity categories might, therefore, be the focus of complexity management activities. We further identify that "complexity in service, support, and customer processes," "task complexity," and "service program complexity" have strong correlations with the efficiency of the service offering. These correlations indicate that out of all ten complexity categories of the framework by Bruhn and Blockus (2011), these three complexity categories might play a prominent role.

Managerial contributions

Our study has two implications for managers in service-oriented B2B companies. The way a company deals with service complexity poses a relevant lever for service success. To that end, managers need to identify possible complexity drivers of their service operations and address them in their actions. Our first managerial contribution is to provide a list of complexity drivers that may be applied as a checklist to better identify complexity in service operations. This checklist consolidates the existing works by Benedettini and Neely (2012), Galvani and Bocconcelli (2022), and other authors, who provide complexity drivers in service operations. The arrangement of complexity drivers into complexity categories provides action fields from which managers can evaluate and address complexity in their service offerings.

As discussed in complexity literature, not all types of complexity can be influenced by a company. Our second managerial contribution is, therefore, the application of the internal/external complexity framework (Bliss, 2000; Picot & Freudenberg, 1998; Vogel & Lasch, 2016; Wildemann & Voigt, 2011) to the service complexity framework by Bruhn and Blockus (2011). While each complexity category in the framework constitutes a cause of complexity to a company, not all of these categories can be directly influenced by it. The differentiation of internal from external complexity categories yields action fields for managers to address complexity. We suggest that measures to counteract complexity in service operations should be focused on the internal complexity categories of task complexity and service program complexity. While external complexity categories also play a relevant role in the complexity of a service offering, we suggest that these categories should be addressed with a long-term perspective.

Limitations and further research

The results of our study reveal only one moderate to strong correlation between a complexity category and flexibility. Literature, as well as our empirical results from the first phase, suggest that flexibility plays a highly relevant role in service success and is interconnected with the complexity of service operations. Therefore, we initially expected that the results would show multiple moderate or strong correlations between flexibility and various complexity categories. This discrepancy may stem from limitations in how flexibility was measured in our study. We recommend further research to explore and refine the operationalization of flexibility in service offerings.

Further research may also carry out detailed investigations on the three complexity categories "complexity in service, support, and customer processes," "task complexity," and "service program complexity," which showed strong correlations with efficiency. These investigations might help quantify complexity in these categories or address the relevance of complexity drivers within each complexity category. It might be valuable to bring the results of this study together with quantitative approaches to complexity measurement, e.g., from Riesener et al. (2019) or Schuh et al. (2019). For example, the measure of homogeneity of an industrial service portfolio from Riesener et al. (2019) might be strongly related to the service program complexity. Thus, the possible influence of complexity could also be assessed by the quantitative properties of the service portfolio.

The results of our study provide a basis for the management of complexity. Efforts might be best focused on internal complexity categories with strong correlations to efficiency or flexibility. Further research should develop concrete mechanisms and best practices to deal with complexity and then validate them with respect to manufacturing companies. For example, Kapoor et al. (2022) state that manufacturing companies suffering from broad service portfolios, complex customer structures, and complicated products prefer modularization approaches in their service offerings. The issues addressed are directly related to task complexity, service complexity, and service program complexity, which have a mediocre or strong correlation with efficiency.

Furthermore, the design of the development processes for interconnected services and products presents a major lever for successful service offerings, as is shown by several complexity drivers in the list. A harmonized development process that improves the coordination between both development processes might reduce complexity as design decisions could be taken from a more holistic standpoint. This challenge is particularly pronounced for smart services, where strong interdependencies with physical products further intensify complexity.

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