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REVIEW ARTICLE

Operative service delivery planning and scheduling in Product-Service Systems

A systematic literature review

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Abstract
To navigate competition and create higher value for customers, manufacturing companies are more and more adopting the strategy of Servitization by enriching their product offering with services in solutions known as Product-Service Systems (PSS). While the provision of PSS presents numerous advantages for customers and providers, they also pose significant challenges, particularly in the operative service delivery planning and scheduling. This study aims to identify decision-support within this context by conducting a systematic literature review. The analysis uncovers limitations in existing approaches and underscores unaddressed research gaps emphasizing the need for further development of decision-support systems for PSS operation.

Keywords Product-Service Systems · Operative service delivery planning · Scheduling

1 Introduction

Over the past few decades, manufacturing companies have faced significant market volatility (Pombo and Franco 2023). In response, and to differentiate themselves from competitors, companies have increasingly adopted the strategy of

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Servitization (Le-Dain et al. 2023). Servitization refers to the trend of companies extending their value propositions by offering services associated with their products (Khanra et al. 2021), marketed as *Product-Service Systems* (PSS). PSS are designed to continuously meet customer needs while reducing environmental impact, making them highly dynamic and complex systems (Gaiardelli et al. 2021). Usually, PSS are provided within innovative business models that differ from traditional ones, solely focused on high sales volumes, as the PSS ones emphasize the use, availability, or benefits of the product (Moro et al. 2022).

While PSS offer benefits such as risk avoidance for customers and continuous revenues for providers (Reim et al. 2015), their widespread adoption has not been as rapid as initially anticipated (Brissaud et al. 2022). In fact, there have been instances of deservitization, where companies have scaled back or discontinued their PSS offerings. This is due to numerous challenges associated with providing PSS, requiring companies to undergo a paradigm shift in their thinking to achieve success. Service activities should no longer be treated as reactive additional tasks but rather as key activities for value creation (Kowalkowski et al. 2017). For many manufacturing companies, creating value through services represents a risk, as ineffective or inefficient service delivery can result in high penalties or erode trust between the customer and provider (Reim et al. 2016). Thus, achieving effective, and efficient service delivery is crucial in PSS business models.

The effectiveness and efficiency of service delivery are mainly determined in the operative service delivery planning. However, this task is highly complex and requires suitable decision-support systems to make optimal decisions that enhance customer satisfaction and minimize costs (Sala et al. 2019). Accordingly, several approaches have been proposed in the literature to support operative service delivery planning and scheduling. This study aims to explore the state of the art in these approaches developed specifically for the operative service delivery planning and scheduling in the context of PSS. The research questions (RQ) of this study were formulated as follows:

RQ1: What is the current state of the art for operative service delivery planning and scheduling approaches in the context of PSS?
RQ2: What are the limitations of existing approaches, and what are the requirements for new approaches?
RQ3: What is the suitable research agenda to further advance the field?

To answer these research questions, a systematic literature review following the methodology outline by vom Brocke et al. (2009) was conducted. The review's scope is defined using the taxonomy of Cooper (1988). Hence, our literature review focuses on *methods* and *applications* with the goal of *identifying the central issues* related to operative service delivery planning and scheduling approaches in the context of PSS. While we aim to achieve *exhaustive coverage*, this article is directed to *general scholars,* thereby adopting a comprehensive approach.

The remainder of the article is organized according to the framework of vom Brocke et al. (2009) Sect. 2 serves as the *conceptualization of the topic* and

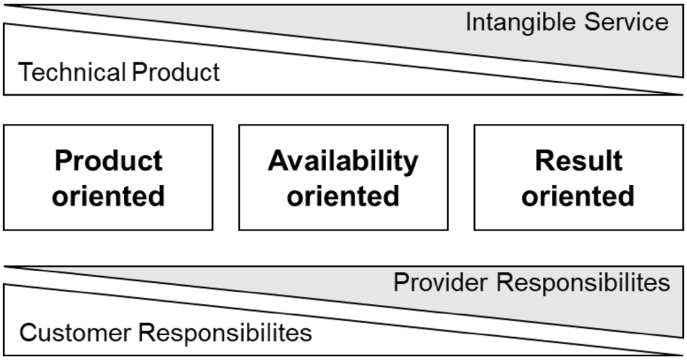

Fig. 1 PSS Business Models (Meier et al. 2011b; Tukker 2004)

includes the theoretical background to PSS business models, operative service delivery planning and scheduling, and the related challenges. Section 3 describes the *literature search* process in detail. Section 4 presents the key findings derived from the *literature analysis and synthesis* phase. After discussing the results in the research context, a future research agenda is given in Sect. 6.

2 Theoretical background

2.1 Product-Service Systems

Product-Service Systems (PSS) can be defined as "*a marketable set of products and services capable of jointly fulfilling a user's need*" (Goedkopp et al. 1999). Manufacturing companies adopt PSS as a strategic approach to achieve various objectives, including revenue growth, customer relationship development, and environmental sustainability improvement (Li et al. 2020). PSS business models are geared toward the long term and can be categorized based on the balance between tangible products and intangible services in the value proposition (Mont 2002). Tukker (2004) outlines three distinct business models, as depicted in Fig. 1. *Product-oriented* business models involve selling the technical product while offering related services like maintenance or end-of-life services. *Availability-oriented* business models focus on selling the availability of the product, with the provider assuming responsibility for ensuring guaranteed availability and facing penalties if the product is not available. *Result-oriented* business models shift the focus from the product itself to the desired output such as the pay-per-print concept used by copier manufacturers (Tukker 2004). Customers who engage with PSS can benefit by transferring activities to the provider, allowing them to focus on core competencies, minimizing high-risk investments, avoiding capital lock-up, and gaining access to new technologies (Meier et al. 2011b).

The adoption of service-intensive PSS business models, which involve the transfer of activities and responsibilities from customers to providers, introduces

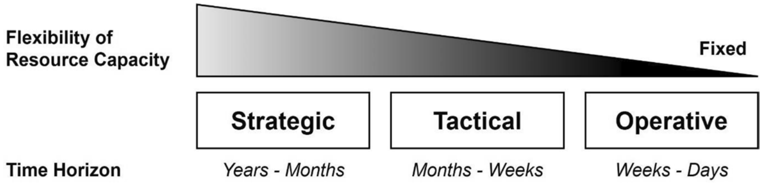

Fig. 2 Service Planning in PSS (Meier et al. 2012)

increased risks – encompassing *technical*, *behavioral*, and *delivery competence* aspects – for PSS providers (Herzog et al. 2014). Technical risks arise from unexpected breakdowns of the technical product, while behavioral risks relate to the possibility of customers treating the product less carefully since they do not own it. Delivery competence risks reflect the provider's ability and capacity to fulfill the value proposition effectively. Inadequate service delivery not only incurs high penalty costs for the provider but also endangers customer trust and satisfaction (Reim et al. 2016). Service delivery processes encompass all necessary activities to realize the value proposition such as "*maintenance procedures, technological upgrades, spare part deliveries*" or similar (Meier et al. 2013a). As a consequence of these innovative business models, effective and efficient service delivery across all customers assumes paramount importance for PSS providers.

2.2 Service planning in Product-Service Systems

Service planning in PSS can be categorized into *strategic*, *tactical*, and *operative planning* (see Fig. 2). Strategic planning involves long-term decisions made during the design and development phase of a PSS. Tactical planning focuses on mid-term decisions whereas operative planning deals with short-term decisions made in the operations or use phase and additionally, includes the task of scheduling (Dorka et al. 2014). In this context, the term planning pertains to determining "*what and how*" while scheduling pertains to "*who and when*" (Baldwin and Bordoli 2014). The following subsections explain the different planning dimensions in detail.

2.2.1 Strategic service planning

The main task of strategic planning is to determine and build up all necessary resources for service delivery in the right quantity and quality. These resources encompass technicians, spare parts, or tools, with technicians being the most critical resources. By employing or training technicians, PSS providers have to ensure the availability of qualified technicians in the long term to achieve effective and efficient service delivery (Meier et al. 2012). In cases where internal resources are insufficient, PSS providers may opt to establish *delivery networks* (Lagemann et al. 2015), which involve collaboration among different companies to deliver the PSS value proposition or the respective services. To ensure the availability of the required resource capacities, the PSS provider can enter partnerships with e.g., component or service suppliers (Meier et al. 2010).

Forecasting the required resources presents a significant challenge in strategic planning (Meier et al. 2012). To address this, Lagemann and Meier (2014) introduce a simulation-based capacity planning approach as a decision-support system for strategic planning. This approach enables to determine capacity requirements under the effects of different scenarios. Similarly, Zheng et al. (2017) present an approach based on fuzzy multiple linear regression for an efficient build-up of capacities despite the volatility of service requests.

2.2.2 Tactical service planning

The goal of tactical service planning is to ensure the availability of the resources needed in the operation phase. Mid-term decisions within this realm include the management of vacations as well as the organization of training for the technicians. Additionally, appropriate stocks of spare parts need to be planned for each maintenance center (Lagemann 2015).

An exemplary approach to tactical service planning was published by Agnihothri and Mishra (2004). The authors focused on the mismatch between the existing skills of the technicians and the required skills of each order. Using a simulation model, the authors analyzed the questions about how many technicians should be trained and when training amortized (Agnihothri and Mishra 2004). A similar approach was introduced by Gutsche (2015). She concentrated on the human factor when mismatches between required and existing competencies occur and analyzed the impact on employee satisfaction (Gutsche 2015).

2.2.3 Operative service delivery planning and scheduling

The objective of the operative service delivery planning and scheduling in the context of PSS is to "*provide the resources which are needed for the delivery of services during the operation* [phase] *in the right quality and quantity at the correct time and place*" (Meier et al. 2012). For this, a dispatcher matches and assigns appropriate resources to the present delivery processes whether they arise from planned tasks or unexpected machine breakdowns (see Fig. 3). He or she can either choose from the internal resources or the resources of the network or subcontract the delivery process to other partners (Meier et al. 2011b). As a result, the dispatcher generates plans that are going to be executed in the short term.

For the assessment of plans, Meier et al. (2013c) introduce a list of key performance indicators (KPIs). According to the authors, the most important KPIs for the assessment of the delivery planning and scheduling performance are *Mean time to problem solution*, *costs*, *revenue*, *travel time proportion*, *resource utilization*, and *rescheduling quota* followed by the rates for *First time fix* and *On time delivery* (Meier et al. 2013c).

There are huge similarities and intersections between Field Service Management (FSM) and especially the field service planning and the operative service delivery planning and scheduling in the context of PSS. Vössing (2017) describes the field

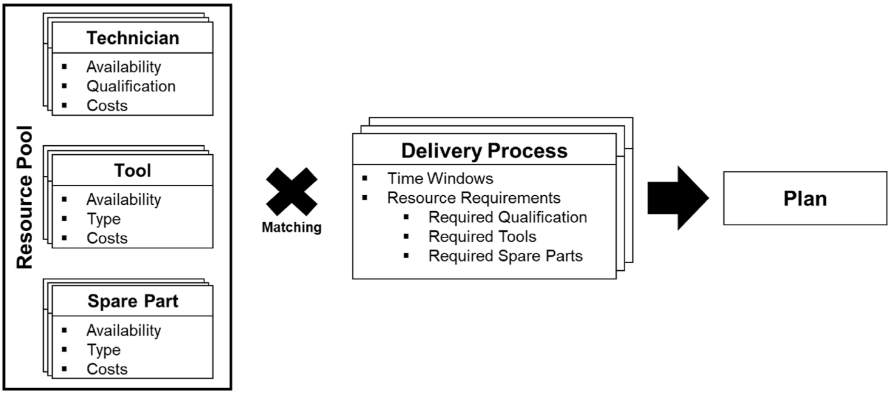

Fig. 3 Operative Service Delivery Planning and Scheduling (Dorka et al. 2014)

service planning problem as "*Spatially distributed customer requests need to be allocated to spatially distributed technicians,*" whereby requests can be urgent or less critical tasks. The author classifies the problem as a "*unique variant of the vehicle routing problem*" (Vössing 2017), which is a problem presented in the late 1950s characterized by finding the optimal routes for a number of vehicles that have to serve customers that are geographically scattered (Dantzig and Ramser 1959).

Despite the similarities in the basic structure of problem understanding, there are also some differences and peculiarities in the operative service delivery planning and scheduling in the context of PSS due to the innovative business model logic. In the area of field service planning, it is not clear, whether the company under consideration is an original equipment manufacturer (OEM) providing additional services or a pure service provider that independently from any asset development and ownership offers services. Besides, information on business models and remuneration of services (e.g., remuneration of individual service according to time spent or lump-sum remuneration according to maintenance contracts) as well as potential penalties for tardy service delivery is mostly not specified (Vössing et al. 2018). In contrast, PSS are characterized by the mutual and integral design and development of a value proposition with the consideration of the use phase. Hence, already in the early stages of PSS development, strategic decisions about service delivery are made (Hazée et al. 2020). The technical knowledge about own products in PSS, resulting from the development phases as well as the high customer interaction in the use phase, has a high impact on the effectiveness and efficiency of service delivery. In general, the goal behind providing PSS is to establish a relationship based on a partnership between the provider and the customer (Meier et al. 2011b). There are also approaches to integrate the customers already in the design and engineering processes of PSS (Pezzotta et al. 2017). Since the provision of PSS is motivated by differentiating from the competitors and extending the relationship to the customer over years or decades (Li et al. 2020), the non-fulfillment of the value proposition has a completely different significance. While for companies providing solely services, field service serves as a revenue source, PSS providers, especially

Table 1 Variance options in delivery planning and scheduling

Variance Option	Explanation
Variance in Time	Ability to vary the execution date of delivery processes (e.g., postponing or bringing forward)
Variance of Resources	Ability to vary the assigned technician for a delivery process (e.g., sending a novice technician instead of an expert)
Variance of Processes	Ability to vary the delivery process itself (e.g., replacement instead of repair or remote assistance instead of traveling to the customer)
Variance of Allocation Speed	Ability to vary the mode of transportation to conduct service delivery (e.g., train instead of car or planes)
Partial Substitution of Product and Service Shares	Flexibility to vary the proportion of products and services in the delivery process (e.g., sending a new machine instead of dismantling a used machine, transporting it to the customer and, performing installation)
Service Distribution	Option to seek resources from external service partners or subcontract the delivery process to a partner for execution
Integration of Customers' Resources	Ability to utilize customer resources in the delivery process (e.g., involving customer technicians to perform services with a remote assistance)

in availability-oriented business models, conduct service deliveries to realize the promised value proposition and do not get paid for the individual service processes. Whereas tardy service delivery can cause additional costs due to penalties, losing the trust of the customers is a higher risk that can disturb the long-term relationship (Reim et al. 2016).

Besides the increased number and criticality of constraints, there are also peculiarities of PSS business models that can have a positive effect on the operative service delivery planning and scheduling. Due to the high customer proximity and knowledge about their own products, uncertainties regarding the amount and time of requests can be reduced (Wan et al. 2014). With appropriate knowledge management systems and training, the efficiency in fault diagnosis and troubleshooting can be increased, thus resulting in higher predictable service delivery durations. Another characteristic of PSS business models is that not only customers can request delivery processes but the PSS provider is also able to initiate delivery processes, enabling to flexibly conduct preventive measures (Meier et al. 2011b). Since the value proposition in PSS is not specified on certain services or products but focuses on fulfilling customer needs through a variable combination of products and services, the provider gets a higher flexibility in decision-making while planning the service delivery. To leverage this flexibility and optimize service delivery plans, Meier et al. (2011a) introduced a set of variance options, which are summarized in Table 1. These variance options enlarge the solution space for plans and provide opportunities for generating optimized plans.

In summary, despite there are great similarities and intersections between field service planning and operative service delivery planning and scheduling in the context of PSS, the business model logic in PSS gives additional constraints and flexibilities when making decisions. Operative service delivery in the context of PSS can be understood as a specialized form of field service planning where not only economic logic influences the decisions but also social values regarding the relationship with customers and partners.

Thus, matching the appropriate resources with the right delivery processes to generate an operative plan is a complex process. The variance option inherent in PSS makes this task a large-scale optimization problem (Meier et al. 2011b). To structure the decision-making process, Sala et al. (2021a) introduced the D3M framework to improve the decision-making based on real-time and historical data. According to the D3M framework data that arises from the services, resources, customers, and products can be as a basis to make delivery decisions. Additionally, data that emerge from delivering the process itself can help to improve decision-making (Sala et al. 2021a). Because of the large solution space as well as the huge data basis that could be considered, generating optimal plans remains a huge challenge. With the aim of minimizing costs and maximizing profits as well as customer satisfaction, PSS providers are in need of suitable decision-support systems for operative service delivery (Sala et al. 2019).

2.3 Solving operative planning and scheduling problems

The huge solution space makes the operative planning and scheduling an NP-hard problem. This means that using exact methods to solve the problem is only possible for small problem sizes. Therefore, *heuristic* methods are typically used to solve such problems (Vössing 2017). Heuristics resemble "*rules of thumb*" for a particular domain application and can find good (near-optimal) solutions within a short computational time. While heuristics do not guarantee optimality and may converge to local optima (Burke and Kendall 2014), they align with the fact that "*Real-world scheduling often does not require optimal solutions, but reasonable good solutions in reasonable time*" (Vössing 2017). A further development of heuristics is *metaheuristics* which operate on a higher level and can find optimal solutions even for large problem sets (Dokeroglu et al. 2019), by employing search strategies based on phenomena in the nature, physical laws, or human behavior (Abualigah et al. 2022). Typical metaheuristics are the *Genetic Algorithm* (García-Martínez et al. 2018), *Simulated Annealing* (Aarts et al. 2014), or *Tabu Search* (Laguna 2018). Recent advancements in the field of heuristics led to the development of *hyperheuristics*. Hyperheuristics offer a higher-level search methodology that does not operate on the problem domain itself but on heuristics that solve the problem which increases the generality of the algorithms (Drake et al. 2020).

When solving operative planning and scheduling problems, two categories (*online* or *offline*) of problem settings can be distinguished. In offline problems, all the relevant information regarding requests, requirements, process times, etc. is given before the planning and scheduling. Thus, the entire plan can be generated at time zero. In contrast, in an online setting, not all information is known in the beginning but becomes available during the execution. The decision-maker does not know how many delivery processes will be requested and what their attributes will be (Pinedo 2022).

In the past, research has focused on solving operative planning and scheduling problems in general. This study aims to conduct a systematic literature review to identify and analyze the existing approaches for generating optimized operative service delivery plans in the context of PSS. The objective is to gain insights into the methodologies, main characteristics, and limitations of these approaches.

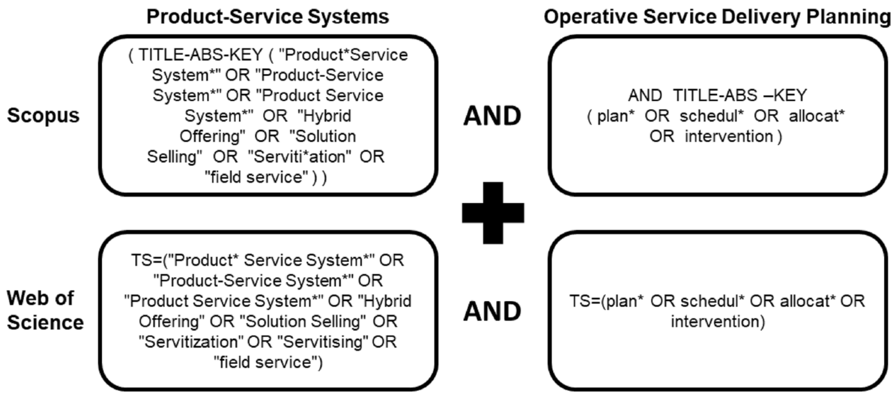

Fig. 4 Search terms and keywords

3 Methodology

This section describes the literature search phase for the systematic literature review. The primary objective was to identify the relevant studies and publications that address operative service delivery planning and scheduling approaches within the context of PSS. The notion of relevance in this context encompasses all publications presenting or proposing an approach or methodology that can be used or followed to generate operative service delivery plans.

For the literature search, *Scopus* and *Web of Science* were used as the main databases due to the extensive presence of peer-reviewed literature across various disciplines. The search was carried out in August 2022 utilizing the search terms and keywords in Fig. 4. With the aim of generating a substantial number of search results, several synonyms for PSS were combined with general terms for the operative service delivery planning and scheduling. The search string incorporated specific filters to exclude irrelevant documents and leave only publications in *English*, *German*, and *Italian* languages, as well as in the subject areas of *Engineering*, *Computer Science*, *Business, Management and Accounting*, *Energy*, *Decision Sciences*, *Environmental Science*, *Mathematics* and *Economics, Econometrics and Finance*.

The search results are presented in Fig. 5, showcasing the outcomes of each filtering phase. After applying various filters, the initial number of 1356 documents in total was decreased to a final pool of 17 documents. For the filtering process, *rayyan*[1] – a collaborative tool for systematic reviews – was used. After cleaning the initial sample from duplicates, the researchers read the titles and abstracts of the whole sample independently and decided blindly (the researchers did not see the decisions of the others until the decisions on all documents were made) whether to include or exclude the document for the next phase. This helped avoiding any bias during the decision process. For the title, the main driver for the exclusion resided in

[1] https://www.rayyan.ai/

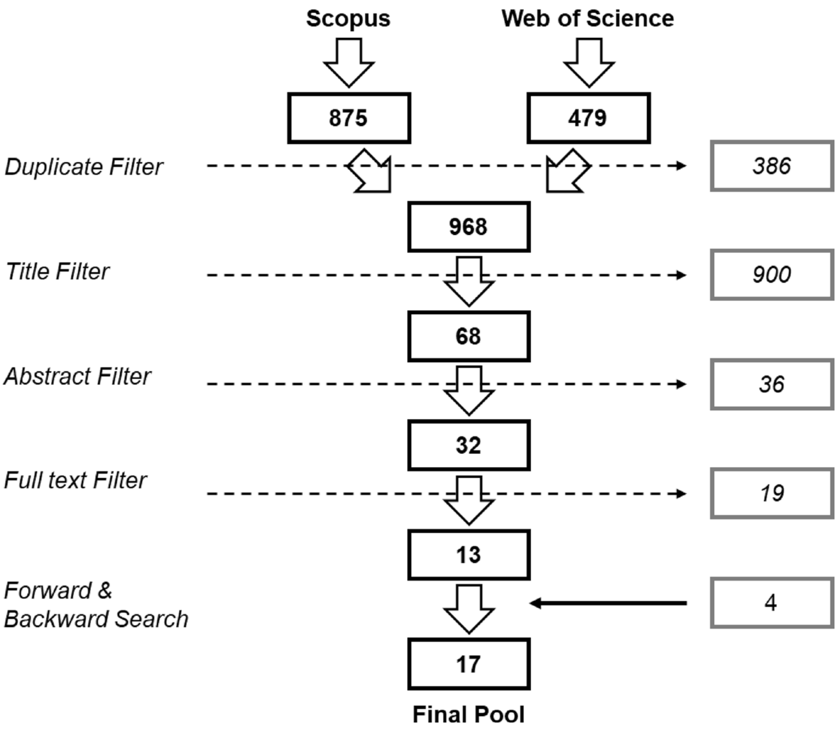

Fig. 5 Protocol of the filtering process

the misuse of the term PSS and/or the topic out of scope. Similarly, for the abstract, considerable attention was devoted to understanding the perspective adopted by the paper and its relationship with the scope of the research. Full-text reading allowed framing the full content of the paper and, thus, ensuring the usefulness of the publication. After all decisions were made, the researchers engaged in discussions to resolve any discrepancies or conflicting decisions regarding the exclusion or inclusion of the documents. Most of the documents were excluded due to their lack of focus on PSS. Additionally, many documents were filtered out because they primarily addressed service planning at a strategic or tactical level, rather than operative service delivery planning and scheduling. Furthermore, a considerable number of documents did discuss operative service delivery planning and scheduling but did not present a comprehensive approach for generating operative service delivery plans.

While analyzing the documents, it was noticed that several publications did not use the term PSS explicitly, but the approach presented in them was developed for a circumstance that can also be classified as PSS by definition. These documents originated from the research area of Field Service Management (FSM) and mainly described product-oriented business models (see Sect. 2.1). By including these documents additionally, our review encompassed a wider range of approaches and methodologies, enabling us to derive further insights, also from outside the core

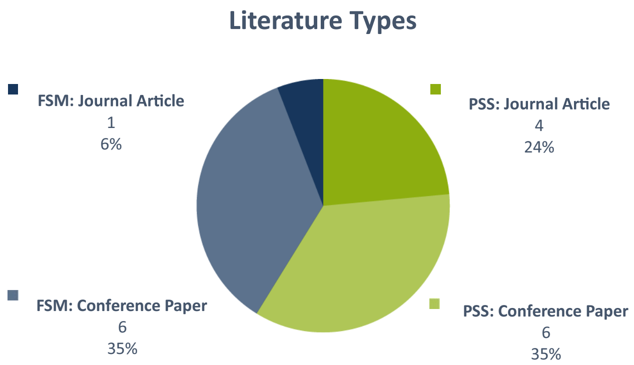

Fig. 6 Literature types of the documents

PSS community. Thereby, a high value was placed on ensuring that approaches developed for pure service providers were not included in the final pool. The list of all documents in the final pool can be found in the Appendix (Table 9).

4 Results

This section presents the findings of our analysis conducted on the documents in the final pool. To begin, the document characteristics are analyzed descriptively to gain insights into the scholarly landscape and the sources contributing to the knowledge base of operative service delivery planning and scheduling in the context of PSS. Subsequently, the contents of the documents are analyzed systematically to gain a comprehensive understanding of the current state of the art and to identify important trends and areas of further exploration.

4.1 Descriptive analysis

In this subsection, we provide a descriptive analysis of the literature within the final pool of 17 documents. Figure 6 illustrates the distribution of literature types across these documents. Ten of the documents originate from the research field of PSS, and the remaining seven can be assigned to the area of FSM. It is noteworthy that the content of all documents, regardless of their categorization, pertains to PSS, as explained in the previous section. The distribution between conference proceedings and journal publications leans toward conferences, with over two-thirds of the documents originating from conference proceedings and nearly one-third being journal articles.

The respective journals and conferences are listed in Fig. 7 while also showing the research area of the documents. Except for the *CIRP Industrial Product-Service Conference*, where two documents have been presented, all list entries were used only once for publication.

Conference	Area of Documents
Applied Mechanics and Materials	FSM
CIRP Industrial Product-Service Systems Conference	PSS
CIRP Lifecycle Engineering Conference	PSS
Conference on Industrial Electronics and Applications	FSM
IEEE International Conference on Systems, Man and Cybernetics	FSM
IFIP Advances in Information and Communication Technology	PSS
International Conference on Advances in Production Management Systems	PSS
International Conference on Intelligent Systems and Knowledge Engineering	FSM
International Conference on Tools with Artificial Intelligence	FSM
Summer School Francesco Turco	PSS
Winter Simulation Conference	FSM

Journal	Area of Documents
Computers and Industrial Engineering	PSS
Decision Support Systems	FSM
Journal of Industrial and Management Optimization	PSS
Journal of Intelligent Manufacturing	PSS
Zeitschrift für Wirtschaftlichen Fabrikbetrieb	PSS

Fig. 7 Journals and conferences

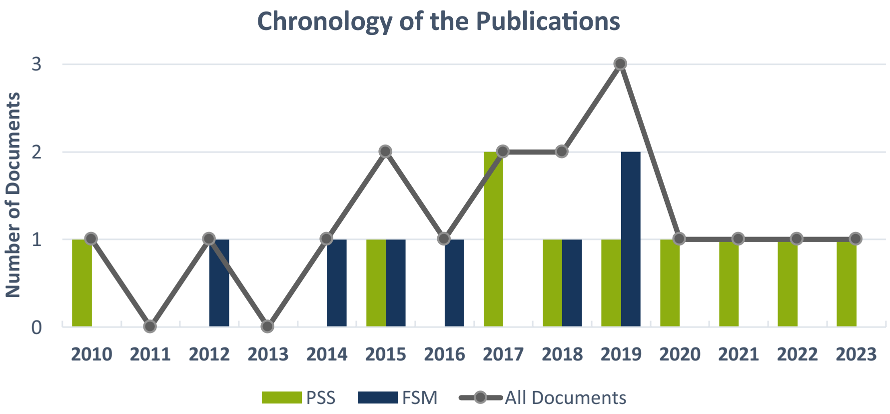

Fig. 8 Chronology of the publications

Figure 8 shows the chronological development of the publications. Although the importance and criticality of suitable operative service delivery planning and scheduling approaches are evident, the PSS community published sparsely new approaches over the last decade. Higher interest has been gained since 2017, leading to a frequency of one document per year. The documents from the field of FSM mainly appeared in the years between 2014 and 2019.

Analyzing the 61 authors who contributed to the documents, 32 were identified from the field of PSS as well as 29 from the field of FSM. Similar numbers of authors despite different numbers of documents are due to the fact that a document

Author	Documents	Area
Hu, Y.	3	FSM
Wen, J.	3	FSM
Antunes, M.	2	FSM
Brown, K.N.	2	FSM
Dan, B.	2	PSS
Gao, H.	2	PSS
Lin, Y.	2	FSM
Meier, H.	2	PSS
Ozturk, C.	2	FSM
Pezzotta, G.	2	PSS
Pirola, F.	2	PSS
Sala, R.	2	PSS
Simonis, H.	2	FSM
Zhang, Y.	2	PSS
Zhou, R.	2	FSM

Affiliation	Country	Documents
Beijing Institute of Technology	*China*	3
Chair of Production Systems, Ruhr-Universität Bochum	*Germany*	3
Business School, Southwest University of Political Science & Law	*China*	2
Chongqing University	*China*	2
Insight Centre for Data Analytics, University College Cork	*Ireland*	2
United Technologies Corporation	*Canada*	2
United Technologies Research Centre	*Ireland*	2
Università degli Studi di Bergamo	*Italy*	2
University College Cork	*Ireland*	2

Fig. 9 Authors and affiliations with more than one publication

from the FSM area has 15 authors. This is also reflected in the affiliations. Ten affiliations for the PSS publications could be identified, whereas there are twelve for the FSM. Overall, scientists from the following eight countries have contributed to the documents: China (6 documents), Germany (5), Canada (2), Ireland (2), Ireland (2), Italy (2), United States (2), Greece (1), and Japan (1). The tables in Fig. 9 show the authors and affiliations with more than one publication. In comparison with the values from the chronological course of the publications (Fig. 8), it can already be assumed that, in terms of content, not 17 different operative service delivery planning and scheduling approaches will be presented, but that the respective authors will present further developments or modified approaches in each case.

In Table 2, a list of documents that have been cited over five times is presented. Out of the seven highly cited documents, five of them originate from the research area of PSS. The presence of a highly cited document focusing on environmental issues is not unexpected. Environmental sustainability concerns have been drivers for PSS research and development.

4.2 Content analysis

As anticipated in the descriptive analysis above, the content analysis revealed that the 17 documents under review do not present entirely distinct approaches. Instead, several publications are authored primarily by the same group of researchers and demonstrate evaluations, adaptions, or further developments of the respective approaches. This is due to the complexity of the underlying problem of operative service delivery planning and scheduling in the context of PSS. For a comprehensive understanding, a detailed overview of the historical development of these approaches is provided in Fig. 11. Further insights into the documents are presented in the subsequent subsections.

4.2.1 Main characteristics

Table 3 presents the main characteristics of each document, arranged to highlight the interrelated documents within the analysis. This organizational structure

Table 2 Most cited documents

Authors	Title	Year	Cited by
Ding K., Jiang P., Zheng M	*Environmental and economic sustainability-aware resource service scheduling for industrial product service systems*	2017	40
Petrakis I., Hass C., Bichler M	*On the impact of real-time information on field service scheduling*	2012	25
Alexopoulos K., Koukas S., Boli N., Mourtzis, D	*Resource planning for the installation of industrial product service systems*	2017	17
Meier H., Funke B	*Resource Planning of Industrial Product-Service Systems (IPS^2) by a Heuristic Resource Planning Approach*	2010	13
Zhang Y., Dan Y., Dan B., Gao H	*The order scheduling problem of product-service system with time windows*	2019	10
Li X., Wen J., Zhou R., Hu Y	*Study on resource scheduling method of predictive maintenance for equipment based on knowledge*	2015	8
Dan B., Gao H., Zhang Y., Liu R., Ma S	*Integrated order acceptance and scheduling decision making in product service supply chain with hard time windows constraints*	2018	6

Table 3 Main characteristics of the approaches

PSS Literature

FSM Literature

	PSS-Type	Problem Classification	Online vs. Offline	Objectives	Maturity Stage
Meier et Funke (2010)	-	Multidimensional and multiobjective optimization problem	Offline	MAX (Punctuality), MIN (Costs), Even (Workload)	2
Dorka et al. (2015)	-	Traveling Salesman Problem with Time Windows (TSPTW) as basis	Offline	MAX (Punctuality), MIN (Costs), Even (Workload)	5
Petrakis et al. (2012)	Availability-based	Field Service Scheduling with Priorities (FSSP)	Online & Offline	MIN (Transportation Costs, Deadline Penalties, Overtime Costs)	4
Zhao et al. (2014)	Product-oriented	Multiple Traveling Salesman Problem	Offline	MIN (Mileage Costs, Deploy Costs, Invalid time Costs, Satisfaction loss Costs)	3
Li et al. (2015)	Product-oriented	Technician Scheduling Problem	Offline	MIN (Total Cost of Service --> Mileage Costs, Time Charge, Downtime Loss, Waiting Costs)	3
Zhou et al. (2016)	Product-oriented	Maintenance field service delivery problem	Offline	MIN (Total Cost of Maintenance Service Delivery)	4
Alexopoulos et al. (2017)	Product-oriented	Production and Installation Planning	Offline	MIN (Time, Costs)	4
Ding et al. (2017)	Result-oriented	Environmental and Economic sustainability-aware resource service scheduling problem (RSSP)	Offline	MAX (Customer Satisfaction Degree, Resource Utility Efficiency), MIN (Product-Service Costs)	4
Dan et al. (2018)	Product-oriented	Integrated Order Acceptance and Scheduling (OAS)	Offline	MAX (Revenue)	3
Zhang et al. (2019)	Product-oriented	PSS order scheduling Problem with Time Windows (PSS-OSPTW)	Offline	MIN (Storage Cost, Tardiness Costs)	3
Antunes et al. (2018)	Availability-based	Mobile Workforce Scheduling Problem	Offline	MIN (Earliness, Lateness, Penalty Costs)	4
Castane et al. (2019)	Product-oriented	Field Service Problem	Online	MIN (Travel time, Idle Time Costs), MAX (Percentage of on-time Task Completion by Task Priority)	4
Yumbe et al. (2019)	Availability-based	Field Service Technicians Scheduling Problem	Online	MIN(Total Labor Costs) by equalizing the work amount for each date and worker	5
Sala et al. (2020)	-	Parallel Machine Scheduling Problem	Offline	MIN (Total Tardiness)	3
Sala et al. (2021)	Availability-based	-	Offline	MIN (Number of Tardy Interventions)	4
Alp et al. (2022)	-	Vehicle Routing Problem with Time Windows (VRPTW)	Offline	MAX (Punctuality), MIN (Costs), Even (Workload)	1
Yi et al. (2023)	Availability-based	Modified Travel Salesperson Problem	Offline	MIN (Costs, Energy, Risk Level, or Time)	3

is consistent throughout the subsequent sections. Notably, the literature exhibits considerable heterogeneity in terms of terminology and information availability. The authors do not clarify all aspects of their approach, leaving room for assumptions.

The majority of publications describe product-oriented PSS business models, wherein the PSS provider is responsible for scheduling after-sales services such as maintenance or repairs. In (Petrakis et al. 2012), (Antunes et al. 2018), (Yumbe et al. 2019), and (Sala et al. 2021b), the provider is obligated to deliver services within a specific point in time or face penalties, indicating an availability-based business model. Only in the work by Ding et al. (2017), a result-oriented business model is discussed. For the remaining publications, the available information is insufficient to definitively assign a specific business model type.

Regarding the classification of the operative service delivery planning and scheduling problem, significant variations can be observed across publications. Each author tends to present their own classification scheme for the underlying problem, resulting in a lack of consensus or standardized categorization.

The majority of the approaches in the analyzed literature can be categorized as offline planning approaches, where schedules are generated in advance based on available information. Only Petrakis et al. (2012), Castane et al. (2019), and Yumbe et al. (2019) address the aspect of online planning, where plans are generated in real-time when a new service request is added.

The objectives pursued by the various approaches are largely aligned and revolve around common themes. The primary objectives commonly observed in the analyzed publications are minimizing costs and maximizing the number of in-time service deliveries in order to achieve high customer satisfaction and avoid penalties. Additionally, some publications consider worker utilization as an additional objective to be balanced.

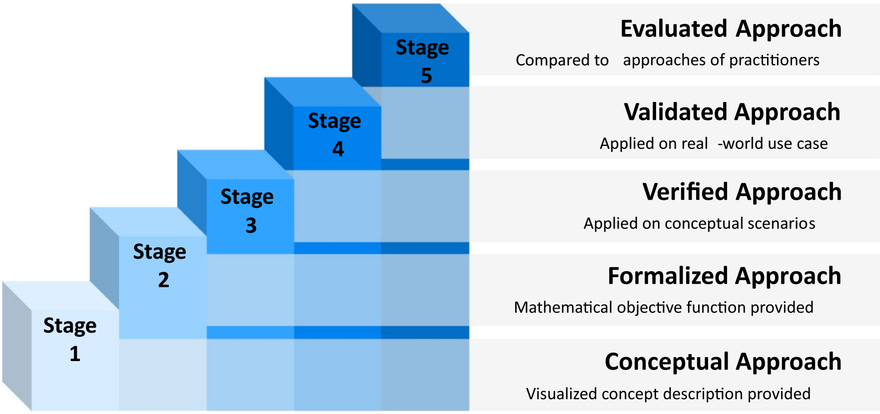

Fig. 10 Maturity model of operative planning and scheduling approaches

To assess the level of comprehensiveness of the approaches presented in each publication, a 5-stage maturity model was developed following Poeppelbuss and Roeglinger (2011). The model, visualized in Fig. 10, categorizes the approaches based on their level of development.

Stage 1 represents approaches that introduce descriptive and/or visual concepts of an operative planning and scheduling approach. In Stage 2, the mathematical formulations of objective functions and further formalized constraints regarding the problem are provided. Stage 3 encompasses approaches that were tested and verified using synthetic data in conceptual scenarios. Typically, publications in this stage focus on showing the general applicability of their developed algorithms and methodologies in the context of PSS operative planning and scheduling. Stage 4 presents approaches that underwent validation in real-world use cases using company data and thus prove their suitability for reality. Stage 5 describes approaches that are applied in real-world use cases and whose performances are compared to the existing methods and approaches in the respective use cases, e.g., manual planners. The analysis reveals that the majority of the publications present at least a verification of their approaches within conceptual scenarios. Furthermore, nine of the 17 publications evaluated their approaches using real-world data within specific use cases. In two of these publications, Dorka et al. (2015) and Yumbe et al. (2019) compared the performance of their approaches to existing methods used in the respective companies. In both cases, the proposed approaches outperformed the existing methods, highlighting their effectiveness in practical settings.

4.2.2 Considered data

As discussed in Sect. 2.2.3, operative service delivery planning and scheduling can draw upon data from four sources (Sala et al. 2021a). Table 4 provides an overview of the publications and their consideration of data during the planning process. All publications consider data and information about the delivery processes

Table 4 Considered data

	Data from or about			
	Delivery Process	Resource	Machine/ Equipment	Customer
Meier et Funke (2010)	●	●	○	○
Dorka et al. (2015)	●	●	○	○
Petrakis et al. (2012)	●	●	○	○
Zhao et al. (2014)	●	●	○	○
Li et al. (2015)	●	●	●	○
Zhou et al. (2016)	●	●	○	○
Alexopoulos et al. (2017)	●	●	○	○
Ding et al. (2017)	●	●	○	○
Dan et al. (2018)	●	●	○	○
Zhang et al. (2019)	●	●	○	○
Antunes et al. (2018)	●	●	○	○
Castane et al. (2019)	●	●	○	○
Yumbe et al. (2019)	●	●	○	○
Sala et al. (2020)	●	●	○	○
Sala et al. (2021)	●	●	●	○
Alp et al. (2022)	●	●	○	○
Yi et al. (2023)	●	●	○	○

PSS Literature (green rows); FSM Literature (blue rows)

● = incorporated

○ = not incorporated

and resources. A detailed analysis of the considered attributes of delivery processes and resources can be found in the subsequent section. Only two out of the 17 publications consider data from the installed machines. Li et al. (2015) and Sala et al. (2021b) utilize machine condition data to determine the remaining lifespan before potential breakdowns, which supports scheduling the processes timely. It is noteworthy that none of the approaches incorporate additional information about the customer, such as their history or their significance to the PSS provider. Similarly, data that could be collected from the service execution processes, such as feedback or performance metrics, are not utilized in any of the analyzed approaches.

4.2.3 Delivery process and resource attributes

As mentioned earlier in the foundational section, the main logic behind the approaches for operative service delivery planning and scheduling is to match delivery processes with appropriate resources. In the analyzed publications, the term "delivery process" is referred to as e.g., *Customers' requirement* in (Ding et al. 2017), *orders* in (Dan et al. 2018), and *tasks* in (Yumbe et al. 2019). While the majority of publications primarily focus on planning maintenance-related delivery

Table 5 Considered attributes of delivery processes and resources

	Delivery Processes							Resources						
								Employees						
	Location	Time Windows	Penalties	Skill Requirements	Stochastic Duration	Priorities	Team Requirement	Working Times	Overtime	Skills	Familiarity	Spare Parts	Tools & Equipment	Additional Supplier
Meier et Funke (2010)	●	●	○	●	○	○	●	●	●	●	●	●	●	●
Dorka et al. (2015)	●	●	○	●	○	○	●	●	●	●	○	○	○	○
Petrakis et al. (2012)	●	●	●	●	●	●	○	●	●	●	○	○	○	○
Zhao et al. (2014)	●	●	○	○	○	○	○	○	○	○	○	○	○	○
Li et al. (2015)	●	◑	○	●	○	○	○	○	○	●	○	○	○	○
Zhou et al. (2016)	●	●	○	●	○	●	○	○	○	●	○	○	○	○
Alexopoulos et al. (2017)	●	○	○	○	○	○	○	○	○	○	○	○	○	●
Ding et al. (2017)	○	●	●	○	○	○	●	○	○	○	○	●	●	○
Dan et al. (2018)	○	●	●	○	○	○	○	○	○	○	○	○	○	○
Zhang et al. (2019)	○	●	●	○	○	○	○	○	○	○	○	○	○	○
Antunes et al. (2018)	●	●	●	●	○	○	○	●	○	●	●	○	○	○
Castane et al. (2019)	●	○	●	●	●	●	○	●	●	●	○	○	○	○
Yumbe et al. (2019)	●	◑	●	○	○	○	○	●	●	○	○	○	○	○
Sala et al. (2020)	●	◑	○	●	○	○	○	○	○	●	○	●	○	○
Sala et al. (2021)	●	●	●	●	○	○	○	○	○	●	○	●	○	○
Alp et al. (2022)	●	●	○	●	○	○	○	●	●	●	○	○	○	○
Yi et al. (2023)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

PSS Literature (green): Meier et Funke (2010), Dorka et al. (2015), Alexopoulos et al. (2017), Ding et al. (2017), Dan et al. (2018), Zhang et al. (2019), Sala et al. (2020), Sala et al. (2021), Alp et al. (2022), Yi et al. (2023)

FSM Literature (blue): Petrakis et al. (2012), Zhao et al. (2014), Li et al. (2015), Zhou et al. (2016), Antunes et al. (2018), Castane et al. (2019), Yumbe et al. (2019)

● = incorporated

◑ = partly incorporated

○ = not incorporated

processes, there are a few exceptions. For instance, Alexopoulos et al. (2017), Dan et al. (2018), and Zhang et al. (2019) specifically address the scheduling of installation services for technical products within a PSS, including the coordination of their preceding production. Throughout these diverse approaches, the key resource consistently considered is the human element responsible for executing the delivery processes, referred to as e.g., *technicians* in Meier and Funke (2010), *engineers* (Petrakis et al. 2012), or *operators* in Sala et al. (2020).

An overview of the considered attributes of delivery processes and resources across the investigated publications is found in Table 5. Analyzing the attributes of the delivery processes, it becomes evident that in nearly every approach, the location of a delivery process is used to calculate traveling time and costs. A special case is presented in the approach of Li et al. (2015), where it is mentioned that locations are changing dynamically. Notably, Ding et al. (2017), Dan et al. (2018), Zhang et al. (2019), and Yi et al. (2023) do not incorporate location-based information in their respective approaches. Time windows, specifying allowable delivery times, are included in the majority of publications, whereby three publications solely focus on deadlines, e.g., resulting from the remaining lifetime of the equipment like in (Li et al. 2015), (Yumbe et al. 2019), or (Sala et al. 2020). In most cases, penalties are associated with delayed delivery of the processes. Skill requirements for effective process delivery are taken into account in ten out of the 17 publications and process duration is typically represented as a fixed value or calculated deterministically. Only Petrakis et al. (2012) and Castane et al. (2019) incorporate stochastic times, considering the inherent uncertainties in service delivery durations. Additionally, Petrakis et al. (2012), Zhou et al. (2016), and Castane et al. (2019) introduce priorities for delivery processes. In general, in the investigated approaches, only one technician is required to deliver the processes. However, Meier and Funke (2010), Dorka et al. (2015), and Ding et al. (2017) introduce the possibility of having the requirement of multiple technicians operating as a team to deliver certain service processes.

In terms of the attributes related to resources, there are bigger differences between the approaches. The working times of technicians are taken into account in seven out of the 17 approaches, restricting their availability for allocation. Six approaches consider the option of technicians working overtime to meet increased service demands. Skills and qualifications of technicians are considered in ten approaches, while two of them introduce the aspect of familiarity. Here, familiarity refers to the experiences and nearness of technicians to individual customers and sites. Meier and Funke (2010) mention the familiarity of the technicians with the requested process as a duration-effecting factor, while Antunes et al. (2018) assume that familiarity enhances delivery quality. The authors use the aspect of familiarity as a decision criterion for technician allocation and aim to always send the same technician to the customers. The technical, allocable resources receive less consideration. Spare parts are taken into account in four approaches, tools are incorporated or mentioned in two. In cases where internal resources are insufficient, Meier and Funke (2010) and Alexopoulos et al. (2017) address the option of contracting additional service or resource suppliers in order to meet service demands effectively.

It is noteworthy that throughout the analyzed publications, the problem descriptions often include detailed discussions of multiple attributes related to delivery processes and resources. However, when it comes to presenting the actual approach, authors tend to make simplifications and do not incorporate all of the mentioned attributes. To give an example, Dorka et al. (2015) explain the relevance of technician preferences regarding travel times and durations. A technician could prefer to come home daily or to stay near the customer over the weekend. The incorporation of this attribute, however, is neither shown nor mentioned in the approach description. This could be due to the inherent challenges associated with developing comprehensive solutions that encompass all important aspects. As with all models, the challenge lies in striking the balance between the complexity and feasibility of implementing practical solutions. These simplifications, while necessary, also open up opportunities for further research and the development of more sophisticated approaches that can effectively address the complexities and nuances of operative service delivery planning and scheduling. In Sect. 4.2.7, the limitations and further research opportunities stated by the authors are explained.

Table 6 Solving methods

	Objective Function	Formalized Constraints	Solving Method	Software Tools
Meier et Funke (2010)	●	○	Evolutionary Algorithms, Simulated Annealing, Brute Force Search	-
Dorka et al. (2015)	○	○	Genetic Algorithm	-
Petrakis et al. (2012)	●	●	Online, Offline, Hybrid Heuristics	-
Zhao et al. (2014)	●	●	Genetic Algorithm	-
Li et al. (2015)	●	●	Genetic Simulated Annealing Algorithm	-
Zhou et al. (2016)	●	●	Genetic Simulated Annealing Algorithm	-
Alexopoulos et al. (2017)	○	○	Intelligent Search Algorithm	-
Ding et al. (2017)	●	●	Non-dominated Sorting Genetic Algorithm II	-
Dan et al. (2018)	●	●	MILP, Servable Orders First – Simulated Annealing (SOF-SA), Dynamic Acceptance and Scheduling Heuristic (DASH)	lingo + Matlab
Zhang et al. (2019)	●	●	Iterated Local Search, Simulated Annealing, Tabu Search	Matlab
Antunes et al. (2018)	●	●	Dynamic Programming	Cplex
Castane et al. (2019)	○	○	-	AnyLogic
Yumbe et al. (2019)	●	●	Heuristic	-
Sala et al. (2020)	●	●	Mathematical Programming	Cplex
Sala et al. (2021)	●	●	Mathematical Programming	Cplex
Alp et al. (2022)	○	○	Hyperheuristic	-
Yi et al. (2023)	●	●	Quantum Annealing, Tabu Search + Simulated Annealing	-

PSS Literature (Meier et Funke, Dorka, Alexopoulos, Ding, Dan, Zhang, Sala 2020, Sala 2021, Alp, Yi); FSM Literature (Petrakis, Zhao, Li, Zhou, Antunes, Castane, Yumbe)

● = incorporated
○ = not incorporated

4.2.4 Solving methodologies

To solve the optimization problem of matching delivery processes with appropriate resources, various methods are employed across the analyzed approaches. Table 6 provides an overview of the mathematical formulations, solving methods, and software utilized in each approach. The majority of publications include a mathematical objective function to evaluate plans, with the exception of Dorka et al. (2015) and Alexopoulos et al. (2017) who mention its use without explicitly providing a function. Besides, Castane et al. (2019) utilize a simulation model for plan evaluation. Alp et al. (2022) do not introduce an objective function in their approach, as they are in the early stages of development. Furthermore, most approaches with an objective function also include mathematically formalized constraints that ensure the feasibility of the generated plans.

The solving method in each approach resembles the cores for operative service delivery planning and scheduling. Analyzing the 17 publications, it becomes evident that the majority of the approaches employ (meta-) heuristic optimization methods to generate and optimize plans. Modified versions of the Genetic Algorithm and

Table 7 Functionalities

	Initial Plans	Rescheduling	Skill as Prerequisite	Skill-based Duration	Alternative Processes	Alternative Vehicles	Distance Calculation	Speed
Meier et Funke (2010)	○	○	○	●	●	●	-	-
Dorka et al. (2015)	○	○	●	○	○	○	Route Planning Services	-
Petrakis et al. (2012)	◑	●	●	○	○	○	Euclidean Distance	50 km/h
Zhao et al. (2014)	○	○	○	○	○	○	-	-
Li et al. (2015)	○	○	○	●	○	○	-	40 km/h
Zhou et al. (2016)	○	○	○	●	○	○	Geographic Information System	-
Alexopoulos et al. (2017)	●	○	○	○	○	○	-	-
Ding et al. (2017)	◑	●	○	○	○	○	-	-
Dan et al. (2018)	○	○	○	○	○	○	-	-
Zhang et al. (2019)	○	○	○	○	○	○	-	-
Antunes et al. (2018)	●	●	○	○	○	○	Open Street Map Data	-
Castane et al. (2019)	◑	●	○	●	○	○	-	-
Yumbe et al. (2019)	◑	●	○	○	○	○	-	40 km/h
Sala et al. (2020)	○	○	○	●	○	○	-	-
Sala et al. (2021)	●	○	●	●	●	○	-	-
Alp et al. (2022)	○	○	○	○	○	○	-	-
Yi et al. (2023)	○	○	○	○	●	○	-	-

PSS Literature
FSM Literature
● = incorporated
◑ = partly incorporated
○ = not incorporated

Simulated Annealing are particularly common. Meier and Funke (2010), for example, use a sequential combination of Evolutionary Algorithms, Simulated Annealing, and Brute Force Search methods to generate optimized schedules by leveraging the variance options (see Sect. 2.2.3) in service delivery. Petrakis et al. (2012) and Zhang et al. (2019) compare the results and performance of different (meta-)heuristics. Some authors introduce their own heuristics specific to their approach, such as Dan et al. (2018) or Yumbe et al. (2019). Besides the heuristic approaches, mathematical programming (Sala et al. 2021b) and quantum annealing (Yi et al. 2023) are also used. Although few authors indicate the software used in their approach, there is evidence of increased use of the Cplex software in the analyzed literature.

4.2.5 Functionalities

Subsequent to the analysis of solution methods, the individual mechanisms incorporated in each approach are examined in this subsection, as summarized in Table 7. While most approaches assume that technicians do not have preassigned tasks or appointments, Alexopoulos et al. (2017), Antunes et al. (2018), and Sala et al. (2021b) deviate from this by planning with technicians who already have a partly

Table 8 Application scenarios

	Application	Conceptual Use-Case	Real Use-Case	Industry	Planning Horizon	Number of Jobs	Number of Resources	Depot
Meier et Funke (2010)	○	○	○	-	-	-	-	-
Dorka et al. (2015)	●	●	●	Machine Tools	Weeks	118	30	-
Petrakis et al. (2012)	●	●	●	Telecommunication	14-30 Days + Daily	708-1416	177	Multi
Zhao et al. (2014)	●	●	○	Agricultural Machinery	Hours	21	6	Single
Li et al. (2015)	●	●	○	Agricultural Machinery	One Week	20	5	Single
Zhou et al. (2016)	●	●	○	Agricultural Machinery	Days	15	5	Single
Alexopoulos et al. (2017)	●	○	●	Laser Cutting Industry	Week	10	13	Multi
Ding et al. (2017)	●	●	●	Compression Industry	Weeks	4	10	Single
Dan et al. (2018)	●	●	○	Elevators	-	10-100	1	Single
Zhang et al. (2019)	●	●	○	Equipment Manufacturing	-	20-50	1	Single
Antunes et al. (2018)	●	○	●	Machinery	Monthly + Daily	-	-	5
Castane et al. (2019)	●	○	●	-	Monthly + Daily	-	-	-
Yumbe et al. (2019)	●	○	●	IT-Equipment	10 Days	51 + 209	31	Single
Sala et al. (2020)	●	●	○	-	Week	50-300	10-100	Single
Sala et al. (2021)	●	○	●	Machinery	-	7, 10, 12	5	Single
Alp et al. (2022)	○	○	○	-	-	-	-	Single
Yi et al. (2023)	●	●	○	Commercial Vehicles	-	12-1281	4-50	Single

PSS Literature (green); FSM Literature (blue); ● = incorporated; ○ = not incorporated

filled schedule with appointments, such as delivery processes, training, or holidays. In four other approaches, preassigned delivery processes are partly considered, as these approaches conduct rescheduling when unexpected tasks occur or assigned tasks cannot be executed as planned. Some approaches make skill requirement matching a prerequisite for allocation. In (Petrakis et al. 2012; Dorka et al. 2015; Sala et al. 2021b), technicians must have the necessary skills in order to be assigned to the respective delivery process. In other approaches, such as in (Castane et al. 2019; Li et al. 2015; Sala et al. 2020), all technicians have the skills to deliver all tasks; however, the duration of the delivery process is adjusted based on their skills, and qualifications.

Regarding delivery process durations, Dorka et al. (2015) stand out since their approach incorporates longer-duration delivery processes, e.g., 16 h, by distributing the process across consecutive days. In terms of decision-making flexibility, three approaches stand out. Meier and Funke (2010), Sala et al. (2021b), and Yi et al. (2023) provide the PSS provider with the ability to choose alternative delivery processes. For instance, Meier and Funke (2010) explore the effects of replacements instead of repairs on the overall plan, while Sala et al. (2021b) consider options such as remote support or sending spare parts instead of deploying a technician. Another particularity of the approach presented by Meier and Funke (2010) is the inclusion of planning with different vehicles, such as cars or trains, which allows for potential cost reduction or time-saving measures in service delivery.

4.2.6 Application scenarios

This subsection focuses on the verifications, validations, and evaluations conducted in the analyzed publications, as summarized in Table 8. The table gives an overview of the main characteristics related to the application scenarios. Among the 17 approaches, 15 present their application scenarios, with ten utilizing conceptual use cases and eight employing real-world use cases for validation. Notably, Dorka et al. (2015) and Yumbe et al. (2019) conducted comparisons with existing methods in their respective companies. With their approach, Dorka et al. (2015) generated a plan, that demonstrated approximately 35% less technician utilization and 30% less travel times compared to the plan generated by the operative planner of the company. However, it is worth noting that these results were obtained after nearly two days of computing time. Similarly, Yumbe et al. (2019) compared their approach to conventional planning methods used in a Japanese IT company. They were able to reduce the number of required technicians by 25% and travel distance by approximately 22% when generating an initial plan. Furthermore, with dynamic rescheduling, their approach achieved a reduction of approximately 13% in required technicians and approximately 21% in travel distance, while also significantly reducing the number of tardy tasks. Notably, their approach delivered the best results in less than 10 s.

The analyzed approaches were primarily applied in the field of the mechanical engineering industry. The use cases varied significantly in scale and complexity. For example, Sala et al. (2021b) considered scenarios with a range of seven, ten, or twelve delivery processes to be scheduled with five technicians in a single depot setting. On the other hand, Petrakis et al. (2012) employed a larger use case involving 177 technicians, with each technician having four to five delivery processes assigned to them. This use case was designed based on real-world data and implemented in a multi-depo scenario. Yi et al. (2023) test their approach on large-scale problems with 1281 alternative service processes. It is worth noting that the majority of the approaches utilized single depot setting as the standard scenario, while only a few explored multi-depot scenarios.

5 Discussion

The literature search conducted in this study yielded a total of 17 publications relevant to the topic of operative service delivery planning and scheduling in the context of PSS. Through analysis of these publications, several key findings emerged. Firstly, a limited correlation was observed across different author groups. Several author groups published their approaches in several stages and presented adjustments, modifications, or evaluations of the contents in the previous publication. Thus, eleven distinguishable clusters across the 17 publications could be identified. Most of the approaches were still in the early stages of development, lacking real-world testing and comparison with existing methods employed by companies. Furthermore, the majority of the approaches were offline in nature, working with static data despite the dynamic nature of service delivery. There is a lack of a decentralized view of the problem as proposed by Avraham et al. (2017). Data utilization in the approaches also showed room for improvement. Machine data, despite its potential in prognostics and condition monitoring (Teixeira et al. 2013), was rarely considered but could help schedule necessary services more efficiently. Customer or process execution data, which could provide valuable insights for decision-making, were not incorporated into any of the approaches. None of the approaches encompassed all analyzed attributes, leading to an overly simplified consideration of the problem. Additionally, most approaches assumed deterministic travel and service durations, which may not reflect the uncertainties present in practices. In general, service delivery is seen as a centralized problem, in which the OEM oversees the execution of all service processes. Regarding solving methodologies, heuristic and metaheuristic algorithms were commonly employed. However, the lack of benchmark instances prevented meaningful performance comparisons among these algorithms. Although some approaches were applied to different use cases and demonstrated superior performance compared to existing methods, none of the authors conducted comparisons between the generated plans and their actual execution, or calculated costs and actual expenses. This highlights a need for further evaluation and validation of the approaches in real-world settings.

6 Conclusion and research agenda

Operative service delivery planning and scheduling in the context of PSS is not merely an academic problem. It holds practical significance for business, as effective service delivery is essential for customer satisfaction and operational success. To address the challenges and complexities inherent in service delivery, it is imperative to develop suitable approaches. Thus, a comprehensive research agenda has been synthesized to guide future endeavors. Research in the following seven areas could lead to the development of improved decision-support systems within the context of PSS, thereby facilitating optimized service delivery planning and scheduling and ultimately enhancing the overall performance and success of PSS business models.

6.1 Realistic attributes and constraints

To gain a more comprehensive and realistic understanding of the factors influencing decision-making in operative serviced planning and scheduling, further research could involve conducting field studies and engaging with industry practitioners. Case studies and close collaboration with companies can provide valuable insights into the attributes that are considered in real-world scenarios. Additionally, taking a human-centric approach, it would be beneficial to interview besides the dispatcher also technicians to gather their perspectives and input, which can contribute to the development of more effective and practical approaches. By incorporating these realistic attributes and constraints, future research can enhance the application and accuracy of operative service delivery planning and scheduling methods.

6.2 Dynamics of service delivery and execution of plans

While the analyzed approaches focus on generating optimized plans, the execution of these plans and their corresponding costs remain a significant aspect to consider. It is essential to investigate whether the calculated costs in the optimization algorithms align with the actual expenses incurred during the execution of the plans. To address this gap, further field studies with companies and practitioners are needed to examine the dynamics of service delivery in real-world scenarios. By observing and analyzing the dynamics in service delivery processes, researchers can gain valuable insights into the dynamic nature of these operations. This understanding can shed light on the challenges and factors that impact the execution of plans, including unforeseen events, changing resource availability, or customer requirements. Future research can focus on developing approaches that bridge the gap between planning and execution. This could involve the integration of real-time data, adaptive algorithms like hyperheuristics, and further online decision-making approaches.

6.3 Use of simulations

Simulations can be a valuable tool in operative service delivery planning and scheduling. By developing realistic models, stochastic elements can be incorporated into the decision-making process. Understanding the dynamics of service delivery could enable the design of realistic scenarios of unexpected during plan execution. Through various experiments, alternative decisions and coping strategies to mitigate disruptions in plan execution can be explored. Hence, the use of simulations could bridge the gap between planned and actual costs.

6.4 Heuristics of planning

Heuristics play a crucial role in the decision-making process of operative service delivery planning and scheduling. However, the use of metaheuristic optimization algorithms in many approaches lacks transparency in terms of the logic behind resource-matching decisions. Furthermore, there is limited evidence available on the long-term effects of these decisions. For instance, matching technicians to delivery processes that require higher skills than their current qualifications could serve as training opportunities and facilitate skill development. Conversely, consistently assigning technicians to the same delivery processes may lead to reduced employee satisfaction. Exploring decision rules that consider the long-term effects on customer relationships is another potential avenue for future research in this area. By enhancing the transparency and long-term perspective of heuristics, the effectiveness and efficiency of operative service delivery planning and scheduling can be further improved.

6.5 Subcontracting

The concept of subcontracting or involving third-party companies in the provision of PSS has been discussed in Sect. 2.2. However, it is noteworthy that the majority of analyzed approaches in this study do not explicitly consider subcontracting as an option for resource allocation. To further expand the solution space of optimization algorithms, future research could explore the incorporation of subcontracting or the assignment of technicians from external service providers. At the same time, the approaches would have to consider the satisfaction of the subcontractors and find an optimum of outsourcing service tasks to escape bottlenecks and self-executing for cost savings like in (Avraham et al. 2017). This additional dimension would provide more flexibility in resource allocation and could lead to improved efficiency and effectiveness in service delivery planning and scheduling in the context of PSS.

6.6 Sustainable objectives

Presently, a predominant focus in current approaches revolves around the objective of cost minimization, achieved through strategies such as reducing travel distances and avoiding penalties. Given the foundational roots of the PSS research field in sustainability ideals (Goedkopp et al. 1999; Mont 2002), future approaches for operative service delivery planning and scheduling in the context of PSS should shift toward a more holistic integration of sustainability objectives. For addressing the environmental dimension, emphasis could be placed on promoting remote services as an alternative to physical interventions, thereby reducing carbon footprints. Regarding the social dimension, the utilization rate of technicians as well as their satisfaction could serve as further key performance indicators.

6.7 Benchmark instances

The lack of comparability among the analyzed approaches highlights the need for the development of realistic benchmark instances in the field of operative service delivery planning and scheduling for PSS. As already suggested by Dorka et al. (2015), future research could focus on creating benchmark instances that accurately reflect the complexities and challenges faced by PSS providers. Ideally, these benchmark instances should be derived from real-world PSS providers, ensuring a high degree of realism and relevance. Such benchmark instances would provide a standardized basis for evaluating and comparing different approaches, enabling researchers and practitioners to assess their performance and identify areas for improvement in operative service delivery planning and scheduling in the context of PSS.

Appendix

See Table 9 and Fig. 11.

Table 9 List of all documents in the final pool

Authors	Title	Year	Source title
Meier H., Funke B	Resource Planning of Industrial Product-Service Systems (IPS^2) by a Heuristic Resource Planning Approach	2010	Proceedings of the 2nd CIRP IPS2 Conference
Petrakis I., Hass C., Bichler M	On the impact of real-time information on field service scheduling	2012	Decision Support Systems
Zhao J., Hu Y.G., Wen J.Q	Study on scheduling algorithm of field maintenance service for agricultural machinery	2014	Applied Mechanics and Materials
Dorka T.M., Lagemann H., Meier H	Quantitative analysis of an IPS2 delivery planning approach	2015	Procedia CIRP
Li X., Wen J., Zhou R., Hu Y	Study on resource scheduling method of predictive maintenance for equipment based on knowledge	2015	Proceedings—The 2015 10th International Conference on Intelligent Systems and Knowledge Engineering, ISKE 2015
Zhou R., Hu Y., Xiao S., Wen J	A decision-making approach to field service delivery under mixed maintenance policy	2016	Proceedings of the 2016 IEEE 11th Conference on Industrial Electronics and Applications, ICIEA 2016
Alexopoulos K., Koukas S., Boli N., Mourtzis, D	Resource planning for the installation of industrial product service systems	2017	International Conference on Advances in Production Management Systems, APMS 2017
Ding K., Jiang P., Zheng M	Environmental and economic sustainability-aware resource service scheduling for industrial product service systems	2017	Journal of Intelligent Manufacturing
Antunes M., Vincent A., Brown K.N., Desmond D., Escamocher G., George A.-M., Grimes D., O'Keeffe M., Lin Y., O'Sullivan B., Ozturk C., Quesada L., Siala M., Simonis H., Wilson N	Assigning and scheduling service visits in a mixed urban/rural setting	2018	Proceedings—International Conference on Tools with Artificial Intelligence, ICTAI

Table 9 (continued)

Authors	Title	Year	Source title
Dan B., Gao H., Zhang Y., Liu R., Ma S	Integrated order acceptance and scheduling decision making in product service supply chain with hard time windows constraints	2018	Journal of Industrial and Management Optimization
Castane G.G., Simonis H., Brown K.N., Lin Y., Ozturk C., Garraffa M., Antunes M	Simulation-Based Optimization Tool for Field Service Planning	2019	Proceedings—Winter Simulation Conference
Yumbe Y., Komoda N., Fujiwara T	Workforce scheduling system to manage static optimization and dynamic re-optimization for field service	2019	Conference Proceedings—IEEE International Conference on Systems, Man and Cybernetics
Zhang Y., Dan Y., Dan B., Gao H	The order scheduling problem of product-service system with time windows	2019	Computers and Industrial Engineering
Sala R., Pinto R., Pirola F., Pezzotta G	Task allocation with tardiness minimization for maintenance delivery of smart Product-Service Systems	2020	Proceedings of the Summer School Francesco Turco
Sala R., Pirola F., Pezzotta G., Vernieri M	Improving Maintenance Service Delivery Through Data and Skill-Based Task Allocation	2021	IFIP Advances in Information and Communication Technology
Alp E., Herzog M., Kuhlenkötter B	A Hyperheuristic Approach for Operative Service Planning in Product-Service Systems	2022	Zeitschrift für Wirtschaftlichen Fabrikbetrieb
Yi L., Wu X., Werrel M., Schworm P., Wei W., Glatt M., Aurich J. C	Service provision process scheduling using quantum annealing for technical Product-Service Systems	2023	Procedia CIRP

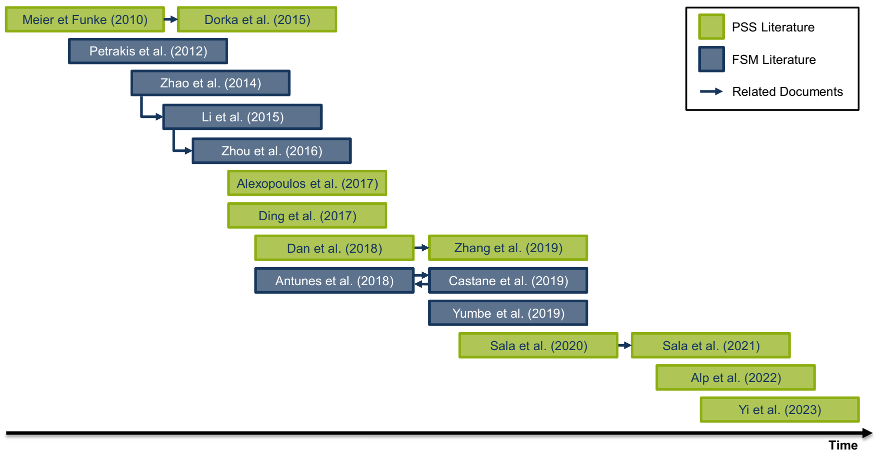

Fig. 11 Historical development of the approaches (see Section Error! Reference source not found.)

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