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## **A Value-driven Method for the Design of Performance-based Services for Manufacturing Equipment**

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**ABSTRACT:** Industrial services are increasingly becoming more relational and customer-oriented, due to manufacturers' adoption of servitisation approaches and product service system offerings. Challenges remain regarding the effective design and delivery of these new offerings, and the understanding of their actual value for both providers and customers. This work focuses on one specific type of product service systems in the context of manufacturing equipment: result-oriented or performance-based services, which aim at delivering an outcome rather than selling the equipment to the customer. A proposal of a value-driven method for their design that engages the customer in the process is presented. This new method has been applied to a real industrial life setting through an application case, involving the service provider and its customer, and targeting manufacturing equipment within customers' plant. Results indicate the effectiveness of this prescriptive approach. Reported benefits from participants refer to its flexibility, adaptability and applicability for different types of equipment, as well as its potential to help providing a modular service portfolio adequate to equipment specific context and requirements.

**KEYWORDS:** Advanced service, performance-based service, product-service systems, FMEA, rating AHP

## **1. Introduction**

Creating value by adding services to products is at the core of the servitisation strategy (Vandermerwe and Rada 1988). Servitisation moves manufacturing organisations towards more relational and customer-oriented attitudes and value propositions. Benefits of engaging in this strategic approach as well as its subsequent challenges have been studied extensively in literature (e.g. Bigdeli et al. 2021; Moro et al. 2020; Kamal et al. 2020; Raja et al. 2017; Alghisi and Sacconi 2015; Löfberg et al. 2015; Martinez et al. 2010). However, studies are still mainly conceptual and qualitative, with limited practicality, or involve descriptive cases and post-event data collection (Kamal et al. 2020; Li et al. 2020; Rabetino et al. 2018; Nudurupati et al. 2016). Current gaps should be addressed by conducting more collaborative research, e.g., action research and application cases, jointly with industry practitioners which could provide data throughout the whole research process. Moreover, Baines et al. (2017) encourage further research attention on manufacturers as customers of advanced services, not only as service providers which is the usual approach; thus, calling for more servitisation studies in business-to-business (B2B) settings in the manufacturing industry. This is the context of our research work.

Through implementing a servitisation strategy, manufacturers expand their product offerings towards Product–Service Systems (PSSs). The term PSS refers to an integrated offering of product and services that delivers value-in-use, i.e., customer’s perceived benefits of the service (Vargo and Lusch 2008) and creates this value for and with the customer (Barile and Polese 2010). To achieve this, in a B2B manufacturing context, good understanding of customer needs and requirements regarding the equipment and its performance is needed. On some occasions, delivering a high value PSS implies the manufacturer taking over process responsibility and ensuring a certain result or level of performance to the customer (Matthyssens and Vandenbempt 2010). This change of focus

from the sale of equipment to the outcome of equipment use is a commonly acknowledged feature of a particular type of contracts or services named under several terms, e.g., functional products, integrated solutions, performance-based contracts, result-oriented PSS and advanced services (Grubic and Jennions 2018). This type of PSS offering is often associated to higher economic and environmental value. It is argued that, by delivering an optimised functional result, result-oriented PSS can potentially help to reduce resource consumption through a dematerialised offering (Kjaer et al. 2019) and through enabling circular business models (Yang et al., 2018).

For equipment manufacturers, designing PSS offerings that are efficiently offered and delivered can be a challenging process. Most research works focus on the early stage or conceptual design of the PSS, in both product-oriented and result-oriented PSSs, rather than on the detailed design of the service (Li et al. 2020; Xin et al. 2017). Further support from academia is needed to propose prescriptive approaches for PSS design, implementation and use in industry (Matschewsky et al. 2018).

PSS is a recurrent topic in literature; however, contributions focusing solely on PSS design are very limited (Annarelli et al. 2016) and methods are either too broad or too focused (Matschewsky, 2019), whereas the co-creation process with the customers has not been adequately addressed (Khanra et al. 2021; Vasantha et al. 2012) and represents a research gap in industrial contexts (Bonamigo et al. 2020). In addition to this, the design of result-oriented PSS or performance-based services requires a high level of flexibility due to their high degree of customisation to adapt to varying customer needs (Reim et al., 2015; Batista et al., 2016). This flexibility is seldom exploited in engineering design approaches for PSS (Brambila-Macias et al, 2018) while a recent review study by Cong et al. (2020) highlights the remaining challenge on adaptability to different contexts. Thus, support for the

design of performance-based services is needed in the form of flexible and adaptable approaches to be used in industrial contexts.

This work aims at supporting the design of performance-based services through a value-centred method that revolves around the needs and requirements of the customer and engages the customer itself in the PSS offering development. Following an intervention-based research approach (Hatchuel and David, 2008), the method has been tested in a real industrial setting that proved its applicability and provided operational and managerial benefits for both the service provider and its customer, according to the feedback received from the industry participants. The article is structured as follows. Section 2 introduces the research background setting the basis for the development of the value-driven method, whereas Section 3 presents in detail the proposed method for performance-based services design. Section 4 describes stepwise the application case, and it is followed by a discussion of findings in section 5. Section 6 finally presents the conclusions, limitations and future research directions derived from this work.

## **2. Background**

This section presents the research background to this research work, including previous works and reviews that have highlighted key elements, challenges and needs in terms of PSS design with a focus on result-oriented PSS. As the background does not aim at providing a comprehensive review of servitisation or of available PSS design methods and tools, various references can be suggested to the reader for more insights (see for example Khanra et al. 2021, Moro et al. 2020, Bake et al. 2020, Li et al. 2020, Kohtamäki et al. 2019, Rabetino et al. 2018, Baines et al. 2017 for recent revisions of literature). Specifically, our background revolve around the following key elements for advanced services: i) technical and customer knowledge; ii) value co-creation and value-driven approaches; iii) PSS design methods and

tools.

### ***2.1. Technical and customer knowledge***

Servitisation transformations require changes in strategic thinking and operational practice, and the delivery of more highly valued services (Clegg et al. 2017). Alghisi and Saccani (2017) argue that successful transformations require internal alignment between the company strategy and its service portfolio as well as external alignment with the customer. Moreover, both technical and customer knowledge are highlighted as fundamental elements in the development of high value servitised offerings (Thenent et al. 2012; Hakanen et al. 2017) such as performance-based services.

Technical knowledge and capabilities can give the manufacturer a great competitive advantage for service design and provision, and can reinforce the integration of products and services in the definition of PSS processes and their interdependencies (Thenent et al. 2012). Equipment-related expertise is indeed a necessary element to develop relevant PSS offerings (Peillon et al. 2015). Customer knowledge, particularly the understanding of market and business customer-specific characteristics, is also essential to design competitive services and to adjust adequately the service processes (Hakanen et al. 2017) and can be achieved even involving customers actively in the process of value creation (Vargo and Lusch 2008). In the context of outcome-based services, servitised offerings bring opportunities to learn from the interaction with the customer about their specific needs and operation context, which could be used as feedback to improve the advanced service offering (Grubic 2018). Outcome-based value propositions for equipment are in-fact primarily customer-processing operations which revolve around the customers' operational requirements (Smith et al. 2012).

### ***2.2. Value co-creation and value-driven approaches***

Within servitisation, value co-creation with customers is positive both for building service capability and for better understanding and customisation of offerings to individual

customers' needs (Zhang and Chen 2008). Sjödin et al. (2020) refer to the latter as 'customizing the value architecture' which they consider one of the core activities in outcome-based services.

Tacit knowledge of customer's processes needs to be developed to clarify expected performance and define performance indicators for the service (Sjödin et al. 2020), and it is a necessity to extract the value inherent in the equipment in equipment-based services (Smith et al. 2012). These are key elements for the operationalisation of the concept of value-in-use for customers in manufacturing industry settings. In this context, well-established engineering disciplines such as systems engineering are considered fundamental for the development of PSS and service engineering (Cavalieri and Pezzota, 2012). Indeed value-driven design (Isaksson et al. 2013), value-driven maintenance (Rosqvist et al. 2009) and value-driven engineering (Macchi et al. 2014) methods could support a deeper understanding of value for PSS offerings in industrial settings. Bertoni et al. (2016) conducted a review of value-driven approaches for PSS development and their findings highlight the need to convert into practical and actionable terms the context-dependent and multi-faceted notion of value in PSS, and that most value-driven works address the 'hardware' part of a PSS offering, thus, focusing on product-oriented PSS and on some elements of result-oriented PSS offerings.

Finally, in performance-based services relational capabilities of the service provider are fundamental, and more important than contractual capabilities as legal contracts do not guarantee service success (Bigdeli et al. 2018; Kreye et al. 2015; Guo and Ng 2011). Both customer relationship and trust are crucial for moving towards the service agreement and implementation (Visnjic et al. 2017). Customers may require support to help them determine the potential value and risks of the proposed solutions and may become reluctant to share information (Brax and Johnson 2009). This calls for co-creation approaches in this type of PSS offerings and building trust-based relations among the companies involved in service

development and delivery in order to achieve successful implementations. Brax and Johnson (2009) suggest that improving credibility could be done through pilot cases and well-defined, guaranteed, and measurable performance targets for the result-oriented PSS.

### **2.3. PSS development and requirements**

Despite being being a relevant share of scientific production on PSS topics, the design of PSS has not achieved maturity and lacks reference standards and well-established models (Barravecchia et al. 2021).

Different PSS methods and tools have been proposed (e.g., see reviews by Richter et al. 2019; Qu et al. 2016; Bertoni et al. 2016; Vasantha et al. 2012; Clayton et al. 2012) for specific contexts of application. Qu et al. (2016) suggest further research to adapt methods from engineering, environmental and business management for PSS design, and to extend works on PSS alternatives evaluation towards sustainability aspects based on quantitative studies. For example, environmental or sustainability aspects could be integrated through requirements in the PSS development process (Kjaer et al. 2019). Ability to adapt methods and techniques to different application contexts, e.g., different industries, and to apply them to detailed PSS design could be key to achieve a wider implementation of PSS in practice (Tukker, 2015). According to Kohtamäki et al. (2019), contextual domains and business ecosystems should be taken into consideration when developing PSS solutions. Richter et al. (2019) conclude that adaptation of PSS development to current and evolving customer requirements can be achieved by leveraging on digital technologies. In this line, PSS configuration works have underlying basis on information systems, e.g., ontologies, context-awareness and automation (Zambetti et al. 2021; Cong et al. 2020; Shen et al. 2017).

The design of result-based PSS offerings could bring additional challenges to PSS developers, as they are highly customer specific, thus, providers cannot present a complete offering before interacting with the customer (Visnjic et al. 2017). The involvement of the



customer in the definition of requirements often happens at the early stages of service development rather than through the whole PSS development process (Cavalieri and Pezzotta, 2012). The value-in-use derived by the equipment performance needs to be considered within the PSS offering. This brings challenges to product manufacturers, as they are used to consider value in the tangible offering (i.e., the equipment) rather than as endogenous of its offering and service delivery system (Smith et al. 2012). Indeed, setting requirements for PSS offerings, including requirement elicitation, (i.e., how and where to find relevant information to use when developing requirements), and requirement prioritisation (including also traceability to the origin of the requirement and the potential trade-offs and relations between different requirements) is a source of challenges for servitised manufacturers (Nilsson et al. 2018). Different techniques and tools have been presented in PSS engineering research works for requirements generation and analysis (Cavalieri and Pezzotta, 2012); however, there is still research needed to enhance customer involvement (Cavalieri and Pezzotta, 2012) and advance understanding on the PSS requirement management process, methods and tools, including potential opportunities emerging from big data (Song 2017) and from artificial intelligence (Wang et al. 2021).

Last but not least, understanding performance requirements in result-oriented PSS brings an additional level of complexity due to their higher degree of customisation and customer specificity. Surprisingly, Glas et al. (2018) found limited instances of use of performance measurement and management literature in servitisation works on result-oriented PSS development. This indicates that, even if closely tied to equipment performance, there is a lack of focus on performance outcomes and of clear performance measures in these types of PSS.

#### ***2.4 Concluding remarks***

This background section presents the underpinning elements that inspired the development of the proposed value-driven method for performance-based services.

Particularly, we take as starting point the technical knowledge and expertise of the equipment, having a particular emphasis on a maintenance engineering viewpoint to establish technically sound service offerings. Besides, the business and operational requirements of the customer for the manufacturing equipment are essential to achieve external alignment and to produce a tangible effect in the performance-based service agreement. Then, the method is informed by value co-creation and value-driven approaches, as it focuses strongly on involving the customer staff in the definition and prioritisation of value-in-use elements for the equipment that will guide the analysis of activities to be included in the PSS offering. The details of the proposed method are described in next section.

### **3. Value-driven method for performance-based services**

This section describes the proposed method, which consists of three steps divided into sub-steps. Figure 1 presents a stepwise overview of the value-driven method, starting with a preliminary step in which the unit of analysis is defined, and finalising with a defined PSS proposal to be taken forward for a service agreement between the companies (note that contractual aspects are out of the scope of this work). The unit of analysis has been defined as ‘target equipment’ in the remainder. The description herein refers to a single machine, although the method can be also applied at a more aggregated level, i.e., a set of machinery with similar characteristics.

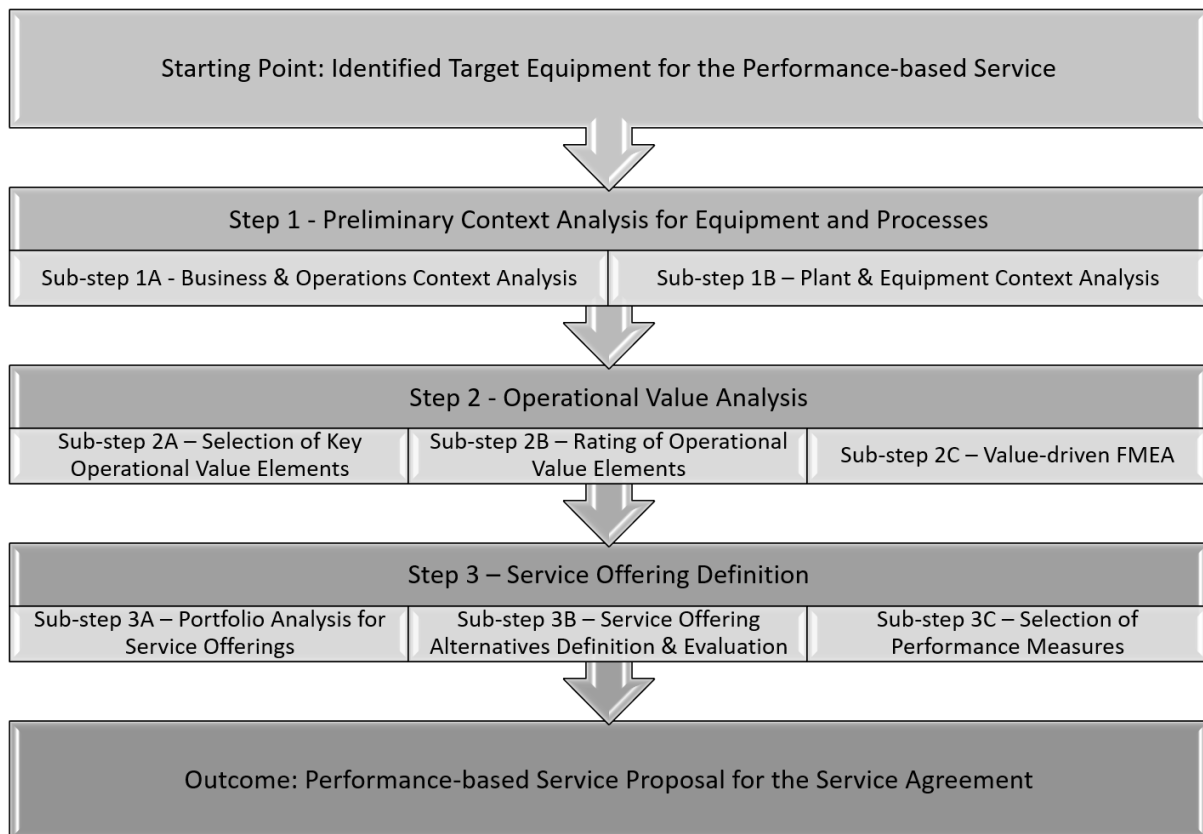


Figure 1. Overview of the value-driven method for performance-based services

### ***3.1. Step 1 –Preliminary Context Analysis for Equipment and Processes***

This step supports the gathering of information related to the target equipment context and to the customer strategy and processes relevant to this equipment. Through a set of pre-defined questions, it provides in-depth understanding and knowledge of customers’ context to inform subsequent steps and ensure that the final design outcome is adapted to the customer needs and its requirements at strategic and operational level, respectively.

This step is divided into two sub-steps: the first one (1A) concerns the context analysis of customer needs in business and operations strategy; the second one (1B) performs a more detailed context analysis for the manufacturing plant and the target equipment for the service offering, thus addressing operational and functional requirements. Each sub-step may require engagement with different customer stakeholders, according to knowledge needed for

each set of questions. Exemplary guiding questions has been defined to support each of these analyses (Table 1).

Table 1. Exemplary pre-defined questions for Step 1

Sub-step	Expected outcome	Guiding questions
1A - Business and operations context analysis	Description of business & operations strategy of customer	<p>What are the main strategic priorities and goals?            How does this plant contribute to them?            In what sector/s does the company operate?            Which is its main target market?            What are the main products connected to this manufacturing site? How is their demand (constant, variable, seasonal)?</p>
	High-level description of manufacturing operations and plant	<p>What is the functional chart of plant departments/functions?            What is the production process, and its main steps?            What is the plant layout? Where is the target equipment located?            What environmental and safety standards are implemented?</p>
1B – Plant and equipment context analysis	Detailed description of target equipment in its operational context	<p>How old is the target equipment?            When was installed? When was the last revamping activity?            What are its main functional requirements?            Which is its expected working time? Does it vary between days, weeks, or months?            Is the equipment in redundancy with others?</p>
	Detailed description of target equipment related processes and specific requirements in terms of environment and human safety	<p>In case of unavailability of the target equipment, is there a possibility for outsourcing its function? Would it imply an extra high cost or delay in the operation?            What other equipment or business functions are directly related or affected by the target equipment?            Is there any hazardous material related to the equipment? If yes, what safety measures are adopted?            Are working conditions of this equipment particularly critical?            Does it have potential risk of injuries and / or environmental damage? Are extra safety or preventive measures put in place?            Have energy consumption peaks or material consumption increases being observed in the target equipment? Is it part of an energy intensive production process?</p>

### *3.2. Step 2 – Operational value analysis*

This step first focuses on identifying the key operational value elements for the target equipment and takes a multi-stakeholder perspective. Then, it links these value elements with actions and impacts at the equipment level. The customer is closely involved in this step, which requires its participation and inputs as key source of information. This step provides the basis for the prioritisation and selection of activities to be included in the service offering. It consists of three sub-steps that are described herein.

#### *Sub-step 2A – Selection of key operational value elements*

This sub-step involves several stakeholders of the target equipment, to be selected based on the findings from sub-step 1B and among those with responsibility or knowledge on the equipment operation. The expected outcome is a list of operational value elements reached by consensus or including all elements suggested by the stakeholders, in case consensus cannot be reached. A set of prompted elements are provided to support stakeholders' reflections on possible operational value elements for this equipment. Following Rosqvist et al. (2009) approach, we introduce a value tree (Figure 2) that builds on elements proposed by Macchi et al. (2014) and incorporates a wider view of value dimensions related to service provision (Ali-Marttila et al. 2015), environmental and social elements (Negri et al. 2016) and operational dependability factors (Crespo Marquez 2007). The elements are classified in four categories:

- process value elements, which are those related to the performance of the manufacturing process in which the equipment is integrated;
- equipment value elements, for those elements related to the single piece of machinery under study;

- environmental value elements, for the elements related to environmental damage reduction that are not directly connected to the consumption of resources in the manufacturing process (which are included in the first category);
- personnel value elements, for those related to staff linked to the target equipment, the manufacturing process and the maintenance intervention.

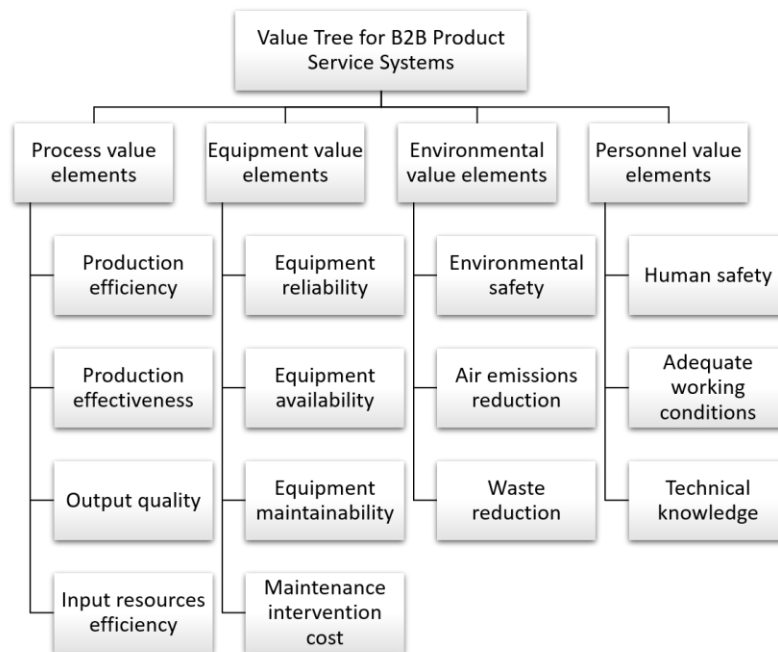


Figure 2. Value Tree of operational value elements for B2B PSS offerings

### *Sub-step 2B – Rating of operational value elements*

The prioritisation process builds on a multicriteria analysis technique that allows the inclusion of multiple stakeholder responses and supports complex prioritisation processes.

Methods and techniques for requirements analysis and prioritisation in the PSS engineering literature include Quality Function Deployment (QFD), TRIZ, Analytic Network Process (ANP), Analytical Hierarchy Process (AHP), and pairwise comparisons (Cavalieri and Pezzotta 2012). These methods usually support the customer perspective in PSS design

methods (Qu et al. 2016) and in some instances are used in combination, e.g., ANP-QFD method (Fargnoli and Haber 2019; Geng et al. 2010).

The selected technique for this step is AHP which is used in its rating mode, as done previously by Macchi et al. (2014) for the value assessment of e-maintenance platforms. In this mode, the AHP model is built for a range of degrees assigned to an attribute that will then be given a score according to their relative importance. The model proposed considers each value element as an attribute and uses a set of rating degrees defined as low (L), medium (M) and high (H) for each of them. The application of the rating AHP results in an integrated value score ( $V_{ij}$ ) of each operational value element (i) for each rating degree (j).

The stakeholders to be involved in the rating AHP should have different but complementary views of the target equipment, its relevant processes and the manufacturing plant. Their responsibilities may range from production and maintenance management, to plant management and service delivery. The rating AHP can consider the views of various stakeholders by calculating the simple average of value scores or a weighted average if adequate in case different degrees of equipment knowledge need to be taken into consideration. Considering the case of N stakeholders and n operational value elements, the integrated value score is calculated as shown in Equation 1:

$$V_{ij} = \frac{(\sum_k^N V_{ijk})}{N} \quad \text{[Equation 1]}$$

Where:  $i=1 \dots n$

$j= \{L, M, H\}$ , corresponding to rating degrees low (L), medium (M) and high (H)

$k=1 \dots N$

### *Sub-step 2C – Value-driven FMEA*

This sub-step uses a variation of the Failure Modes and Effects Analysis (FMEA) technique to interpret customer value at the equipment operation level, specifically by linking equipment functions to impacts on the operational value elements.

The FMEA technique consists of four actions: (1) the description of functions; (2) the description of functional failures; (3) the definition of failure modes; (4) the description of failure modes effects (McDermott et al. 1996). The FMEA technique has been previously used in PSS design to translate customer expectations from a functional analysis to the product perspective (Trevisan and Brissaud 2016; Maussang et al. 2009), to analyse risks associated with service delivery (Luczak et al. 2007), to define and analyse service delivery scenarios (Chiu et al. 2018; Chuang 2007) and to analyse failure modes of product components and service actors within a PSS service delivery system (Kimita et al. 2018).

The proposed value-driven FMEA resembles the use of FMEA technique within Reliability Centred Maintenance (RCM) methodology (Crespo Marquez 2007) in the first three actions. The novelty of the proposed variation falls into the determination of the failure effects which is done based on the operational value elements identified in previous steps. The fourth action defines the effect of each failure mode in terms of its influence in each operational value element, i.e., indicating whether it has a low, medium or high impact. Afterwards, each degree will be associated to the score obtained in the previous step, to quantify the impact according to customer-based prioritisation. This variation of the FMEA technique was developed ad-hoc for this value-driven method, with the specific purpose to integrate the effects analysis with the priorities given by customers; its validation is therefore done by its application to the industrial case described in next section 4.2.

Table 2 provides a template for the value-driven FMEA application to the target equipment, and the calculation of a score for each failure mode is shown in Equation 2.



Table 2. Template for value-driven FMEA

Target equipment (It can be considered as a whole or by component)	Required function (It indicates the purpose or mission of the target equipment or its components)	Functional failure (Total, partial or intermittent loss of the required function)	Failure mode (Visible or physical evidence of the functional failure)	Effect on operational value elements (E <sub>xi</sub> ) (It indicates whether the failure mode has a low, medium or high effect on each element)				Failure mode score (F <sub>x</sub> )
				Effect on operational value element 1	....	...	Effect on operational value element n	

For T failure modes associated to the target equipment, the failure mode score (F<sub>x</sub>) is calculated as:

$$F_x = \sum_i^n F_{xi} \quad [Equation 2]$$

Where F<sub>xi</sub> = V<sub>ij</sub> for j = E<sub>xi</sub>

$$x=1 \dots T$$

$$i= 1 \dots n$$

j= {L, M, H}, corresponding to rating degrees low (L), medium (M) and high (H)

E<sub>xi</sub>={L, M, H} , corresponding to the effect degree stated in Table 2 as low (L), medium (M) or high (H) of the x-th failure mode on the i-th operational value element.

### 3.3. Step 3 – Service Offering Definition

This step helps devising and evaluating alternative customised service offerings (SOs). The

definition of the alternative offerings builds on the portfolio and capabilities of the service provider. The evaluation uses the information and the scores for operational value elements and failure modes obtained in previous steps. This step consists of three sub-steps that are described herein.

### *Sub-step 3A – Portfolio Analysis for Service Offerings*

This sub-step helps the service provider to reflect on its own capabilities and build a set of SO alternatives based on its currently available activities and interventions for the target equipment. It requires knowledge on equipment specifications, as well as on operation and maintenance specifications. A service provider with extended experience or that is also the equipment manufacturer could perform this step on its own, with minimal input from the customer.

In B2B services, the activities within a performance-based SO may contain both direct and indirect maintenance activities. Direct maintenance activities are those closely connected to the execution of maintenance interventions, while indirect maintenance activities are those related to the planning, scheduling and controlling of the interventions, and to the application of maintenance engineering techniques or methods. Additional activities such as advice or consultancy are often offered to the customer to provide further improvements or support for its operations. In the case of experienced service providers, these activities may include audits, training, and support to implement standards and certifications.

The portfolio analysis is organised based on three aspects. The *first aspect* regards the operational conditions required to make viable the execution of the activity. For example, the execution of the direct maintenance activity ‘equipment conditions inspection’ can be relevant in cases in which the degradation parameters can be checked in fixed time intervals

that provide enough time to react before the failure happens. The *second aspect* concerns the intrinsic links between different activities, i.e. whether the activity needs to be preceded by another one and whether it enables subsequent activities that build on its results. Some dependency paths between activities can be envisaged, for example: a RAM analysis may require the knowledge obtained during corrective maintenance interventions; a preventive maintenance plan would benefit from applying the RCM methodology; equipment energy audits may need the knowledge from equipment inspection interventions. The *third aspect* regards the influence of the activity on the operational value elements, or other non-operational customer needs identified in Step 1. For example, a RAM analysis can be recommended in cases requiring high equipment reliability. This will help identify what additional activities from the service provider portfolio can be included in the offerings.

This analysis provides a comprehensive outlook of the service provider portfolio and indicates whether it covers appropriately specific customer operational requirements and other non-operational needs. It is the basis for building a set of SO alternatives and for evaluating them in next steps.

#### *Sub-step 3B – Service offering alternatives definition and evaluation*

The service provider needs to devise at least two different alternatives by bundling together the activities analysed in previous sub-step. These SO alternatives are evaluated using the integrated value scores ( $V_{ij}$ ) and failure mode scores ( $F_x$ ) calculated previously, to obtain a value score for each SO alternative (VSOs). This value score is compound by a value score associated to direct maintenance activities (VD), based on their contribution to avoid the occurrence or mitigate the consequences of the failure modes, and value scores associated to indirect maintenance activities (VI) and additional activities (VA), based on their contribution to the operational value elements desired by the customer. These value scores are calculated

as follows:

Given a number S of SO alternatives, compound by R direct maintenance activities, Q indirect maintenance activities and M add-on / additional activities,

$$VSO_s = VD_s + VI_s + VA_s \quad [Equation 3]$$

$$VD_s = \sum_r^R A_{xr} * F_x \quad [Equation 4]$$

$$VI_s = \sum_q^Q A_{iq} * V_{ijmax} \quad [Equation 5]$$

$$VA_s = \sum_m^M A_{im} * V_{ijmax} \quad [Equation 6]$$

Where,

$A_{xr}$  = binary value equal to 1 when activity r is included in the SOs for the x-th failure mode, 0 otherwise.

$A_{iq}$  = binary value equal to 1 when activity q is included in the SOs and is adequate for a degree of the operational value element i corresponding to the maximum score  $V_{ij}$  ( $V_{ijmax}$ ) obtained for that operational value element in the rating AHP, 0 otherwise.

$A_{iq}$  = binary value equal to 1 when activity q is included in the SOs and is adequate for a degree of the operational value element i corresponding to the maximum score  $V_{ij}$  ( $V_{ijmax}$ ) obtained for that operational value element in the rating AHP, 0 otherwise.

$V_{ijmax} = \text{Max}(V_{ij})$  for the i-th operational value element

$s=1 \dots S; r=1 \dots R; q=1 \dots Q; m=1 \dots M; x=1 \dots T; i=1 \dots n$

$j = \{L, M, H\}$ , corresponding to rating degrees low (L), medium (M) and high (H)

The value scores VSOs give an indication to both the service provider and the customer of

the extent to which each SO alternative brings value to the customer based on the identified customer requirements and priorities for the target equipment.

### *Sub-step 3C – Selection of performance measures*

This final sub-step helps to identify relevant performance measures to be employed in the performance-based service agreement.

Despite being acknowledged as a crucial element in the performance contracting literature, the definition and specification of performance is often a neglected or missing step in developing result-oriented PSS (Glas et al. 2018). Most result-oriented PSS focus on defined outcomes in terms of availability in broad terms (Batista et al. 2017), however actual outcomes are multi-faceted results from delivering capability (Smith et al. 2012). Addressing this gap requires codifying knowledge that connects inputs, e.g. customer requirements, with performance outcomes (Selviaridis and Wynstra, 2015) and providing clarity in the criteria or factors affecting the development of useful measures in PSS design (Brambila-Macias et al. 2018).

In this sub-step, the measures are determined according to the customer-based prioritisation of the operational value elements in the rating AHP done in previous step 2B. Suggestions for these performance measures are provided in the non-exhaustive but comprehensive list shown in Table 3. These indicators have been selected from existing indicators lists provided by both international standards (GRI Standards (2016) and EN 15341 (2007)), and scientific articles (Muchiri et al. (2011)), thus, building in performance measurement frameworks. The final choice of measures should be appropriate to the specific contextual features of the target equipment operation and the service delivery plans.

Table 3. Suggested performance measures for each operational value elements

<b>Operational value</b>	<b>Performance measure</b>	<b>Example of Units</b>
Production efficiency	Production rate	items / hour
	Lead Time	hours
	Work-in-progress	items
Production effectiveness	Actual production / planned production	%
	Manufacturing cycle time	hours
	Overall Equipment Effectiveness (OEE)	%
Output quality	No. defects or rework	items
	Quality rate	%
	Scrap production rate	%
Input resources efficiency	Energy consumption	MWh or KJ/hour
	Raw material consumption	Kg/hour
	Water consumption	L/hour
Equipment reliability	Mean Time Between Failures (MTBF)	hours
	Mean Time To Failures (MTTF)	hours
	Failure frequency	failures/year
Equipment availability	Availability	%
	Mean Down Time (MDT)	hours
	Mean Up Time (MUT)	hours
Equipment maintainability	Mean Time To Repair (MTTR)	hours
Maintenance intervention costs	Total maintenance cost	€/year
	Corrective maintenance cost	€/year
	Preventive maintenance cost	€/year
	Maintenance Intensity	€ /item
	Maintenance cost over manufacturing cost	%
	Equipment Replacement Value (ERV)	%
Air emissions reduction	Carbon footprint	CO <sub>2</sub> emissions/year
	Global warming	CO <sub>2</sub> eq. Kg/year
Environmental safety	Environmental damage caused by failures	%
	Environmental damaged caused by maintenance (or lack of maintenance)	%
	Potential environmental damage (near miss) caused by failures	%
	Environment-related non-conformities	%
Waste reduction	Solid-waste generation	Kg/year
	Wastewater generation	L/year
Human safety	Injuries caused by failures	%
	Injuries caused by maintenance (or lack of maintenance)	%
	Potential injuries (near miss) caused by failures	%
	Overtime done by maintenance personnel	hours/year or %

<b>Operational value</b>	<b>Performance measure</b>	<b>Example of Units</b>
Adequate working conditions	Maintenance personnel on continuous improvement tasks	%
Technical knowledge	Multi-skilled maintenance personnel	%
	Average resolution time	hours

Note: Units of time have been considered in hours or years in the Table; other units, e.g. minutes, weeks, may be more relevant depending on the context and equipment operation.

#### **4. Application case study**

The value-driven method for designing PSS has been applied in a field case involving both a service provider and a customer. The main objective of the case was to apply the method to design performance-based services for several equipment installed in the manufacturing plant owned by the customer.

The service provider is a dedicated service unit within a large equipment manufacturing company. It has extensive experience in providing B2B services, including performance-based services, and they were looking for a new methodological approach to systematise their service offerings. Previously, they developed their service offering proposals based on senior service staff observations and expertise in an ad-hoc manner for each customer. The customer is a manufacturer of instrumentation devices for the B2B market. The two companies had previously worked together, however without using any co-creation approach for service development, and they were revisiting their service agreements. The close relationship between the companies, being already engaged in a long-term agreement, helped to minimize the common issues of lack of trust and reluctance in data sharing, highlighted by Brax and Jonsson (2009) and Guo and Ng (2011). Thus, this case provided an excellent scenario for testing the value-driven method.

#### ***4.1. Application approach***

The case application was developed together with both companies during a six-month period. We defined the intervention for the application of the proposed method by building on action research and intervention research principles (Hatchuel and David, 2008; Coughlan and Coughlan, 2002). This collaborative approach helped ensuring the applicability of the method in industry (Vasantha et al. 2012) and the validity of the practical knowledge which results from the relationship among the intervention intention, the problem-context and the solution-impact evidence (Auernhammer, 2020).

The value-driven method was strongly supported by both companies that dedicated time and staff to participate in the research activities. One staff member of the service provider was deployed in the customer site, worked closely with the lead researcher, and acted as enabler and key source of information. Data made available for the researchers included internal communications and reports from both companies, archival records containing plant layout, detailed equipment information and the value stream mapping conducted in the plant. Direct observations were made during two full day visits to the production plant. These visits included seven focused interviews with production area supervisors, production manager, maintenance manager, and plant manager. Besides, there were additional seven meetings with the key staff member of the service provider for data analysis and reflection on findings after each step. This allowed to react and adapt the intervention as the method application progressed. At the end, the case results were presented to the companies independently to gather their impressions and feedback regarding the method itself, the implementation approach, their perceived benefits and relevance of results. Conducting independent meetings to present the results allowed the participants from each of the companies to speak freely about their experience and therefore we reduced biases in their reflections and reported benefits.



## ***4.2. Application of Step 1***

The information needed in Step 1 was collected using the guiding questions proposed in Table 1. Non-confidential information related to sub-steps 1A and 1B is summarised next.

The customer holds a prominent position in its market share and its main competitive advantage is the high quality and accuracy of its products, which are considered niche. The manufacturing processes are organized as a job shop with four main production areas. The manufacturing plant has automatized the most delicate steps along the production process by installing five robotized workstations in two of the production areas. The production processes do not involve hazardous materials. Environmental and safety standards are implemented in the whole plant. Machining processes and robotized areas are properly protected in closed and isolated spaces with warning alerts in case of unsafe or risky conditions during the operation. The plant was working at around 60% of their maximum capacity during the observed period. The product demand is quite volatile, with a large amount of requests considered special orders.

This step was performed for all machinery in the plant, as the service agreement that the companies have in place covers all of them. The analysis helped creating groups of machines with similar characteristics and / or functions that could be grouped together. Seven groups of equipment were defined for the application of the value-driven method. The results for one group of equipment named 'welding machines' are reported in this article. This group of machines perform similar welding processes within one production area and have similar operational characteristics; they constitute a sufficiently homogeneous group for the analysis. They are located in an area of high value-added processes with a quality control performed once the piece is outside this production area. Therefore, quality defects in early processes cannot be identified. Further information gathered (not reported here due to confidentiality)

included machine age, renovation plans, machine redundancy, process bottlenecks, quality control frequency, and machine working conditions.

### ***4.3. Application of Step 2***

The production area supervisor and the production manager were interviewed individually to define the operational value elements. No discrepancies were observed between their views on operational value elements for the target equipment which were the following: equipment reliability, equipment availability, production effectiveness, output quality, technical knowledge, environmental safety and human safety. Afterwards, the production manager, the maintenance manager and the plant manager participated in the rating AHP to prioritise these value elements. Table 4 shows the results obtained as an average of their individual responses. They all mentioned that environmental and human safety were vital priorities that couldn't be compared with other value elements and it was decided to remove them from the rating process and assign a score 1 for the rating degree "high" of the equipment under study. The pairwise comparisons for the rating AHP were done for each person in an individual interview. Authors' previous experience indicate that inconsistency levels can get predominantly higher, and in some cases achieve unacceptable levels, when comparing five or more criteria and the person doing the comparison does not have previous experience with the AHP method. To mitigate this, a methodological modification was introduced at this stage. During the interviews, the respondents were first asked to place small cards, each of them representing a selected operational value element, on a table according to their relative position of importance respect each other. They replied to the pairwise comparison questions after the visualisation exercise with the cards. It worked well and the inconsistency indexes were acceptable, i.e., lower than 0.1, for all comparisons and respondents.

Table 4. Summary of value scores for the equipment group ‘welding machines’

Selected operational value elements	Value scores for the operational value elements according to the rating degrees( $V_{ij}$ )			Overall value score for each operational value element ( $V_i$ )
	Low	Medium	High	
Equipment Availability	0.0147	0.0577	0.1569	0.2293
Production Effectiveness	0.0116	0.0302	0.0840	0.1258
Output Quality	0.0368	0.0418	0.3426	0.4211
Equipment Reliability	0.0183	0.0331	0.1254	0.1768
Technical knowledge	0.0049	0.0241	0.0180	0.0470
Environmental Safety	0.0000	0.0000	1.0000	1.0000
Human Safety	0.0000	0.0000	1.0000	1.0000

Note: SuperDecisions software (<https://www.superdecisions.com/>) was used for the AHP pairwise comparisons. Inconsistency index was acceptable, i.e. lower than 0.10, for all answers.

Then, the value-driven FMEA was performed together with two maintenance staff of the production site. It was applied using a high-level definition of the failure modes for the equipment group, without going into the component or subcomponent level. Regarding environmental safety, there was no effect for the equipment respect to any of the failure modes, while one of the failure modes could potentially affect human safety regarding loss of safe working conditions. Table 5 shows the value-driven FMEA.

Table 5. Value-driven FMEA for the equipment group ‘welding machines’

Required function	Functional failure	Failure mode	Effect on operational value elements, Exi (Vij, j= Exi)							Failure mode score (F <sub>x</sub> )
			Equipment Reliability	Equipment availability	Production Effectiveness	Output Quality	Technical knowledge	Environmental Safety	Human Safety	
Perform the welding process according to production standards	F1: Machine doesn't start welding	One of the components is broken	High (0.1254)	High (0.1569)	Medium (0.0302)	Low (0.0368)	Low (0.0049)	No (0.00)	No (0.00)	0.3542
	F2: Welding out of production standards	Welded piece is outside specification limits	Low (0.0183)	Low (0.0147)	High (0.0840)	High (0.3426)	Medium (0.0241)	No (0.00)	No (0.00)	0.4837
	F3: Machine setup is not appropriate for welding this material	Quality loss that comes out in subsequent operations	Medium (0.0331)	Low (0.0147)	Medium (0.0302)	High (0.3426)	High (0.0180)	No (0.00)	No (0.00)	0.4386
Act as a screen between welding area and production area	F4: Not proper isolation	Isolation system is broken	High (0.1254)	High (0.1569)	Low (0.01156)	Low (0.0368)	Low (0.0049)	No (0.00)	Yes (1.00)	1.3356

#### ***4.4. Application of Step 3***

The portfolio analysis was performed with inputs from the service provider staff, with contributions from the maintenance manager of the customer production site. Direct maintenance activities considered appropriate for this equipment are corrective and preventive maintenance interventions, and inspections of equipment condition and of output quality. Due to the operational context in which these machines operate, condition-based predictive maintenance interventions were not considered immediately feasible. Instead, time-based preventive maintenance interventions were included within the available interventions as collected historical data allows calculating the equipment failure rate. Indirect maintenance activities were selected based on possible benefits on the operational value elements with higher importance for the equipment, the overall customer needs, and their links to direct maintenance activities. High human safety, equipment availability and reliability, and output quality were associated to performing criticality analysis, RAM analysis, and designing FMECA-based maintenance plans. Additional activities that could be offered were the following: revamping study, energy efficiency audit, training for production and maintenance personnel. These were identified based on the customer needs and requirements analysis performed in Step 1. These activities were bundled into six alternative SOs. Table 6 presents the activities included in each SO as well as their scores obtained using equations 3-6 described in sub step 3B.

The value score for the direct maintenance activities (VD) considered that corrective maintenance interventions do not prevent the functional failures occurring and therefore for SO1 and SO2 this score is zero. For the subsequent SOs, based on the service provider staff expertise, we considered for the value score of direct maintenance activities (VD) that output

quality inspections prevent functional failures F2 and F3, and that both preventive interventions and equipment condition inspections address functional failure F2.

The value score for the indirect and additional activities (VI and VA, respectively) considered whether the proposed activities contribute to achieving the operational value elements desired for this type of equipment. The relation between these activities and the value elements was done based on the expertise of the service provider staff. For example, personnel training and conducting a revamping study for this equipment was considered to have a positive contribution towards three of the selected operational values: equipment availability, production effectiveness and output quality.

Table 6. Overview of service offering alternatives for the equipment group ‘welding machines’

<b>Service offering</b>	<b>Direct maintenance activities</b>	<b>Indirect maintenance activities</b>	<b>Additional activities</b>	<b>VD</b>	<b>VI</b>	<b>VA</b>	<b>VSO</b>
SO1	Corrective interventions	Criticality analysis	None	0.00	2.28	0.00	2.28
SO2	Corrective interventions	- Criticality analysis - FMECA-based maintenance plan - RAM analysis	- Training personnel - Energy efficiency audit	0.00	6.20	5.96	12.16
SO3	- Corrective interventions - Output quality inspections - Preventive interventions	- Criticality analysis - FMECA-based maintenance plan - RAM analysis	None	1.41	6.20	0.00	7.61
SO4	- Corrective interventions - Output quality inspections - Preventive interventions	- Criticality analysis - FMECA-based maintenance plan - RAM analysis	- Training personnel - Energy efficiency audit - Revamping study	1.41	6.20	8.67	16.28
SO5	- Corrective interventions	- Criticality analysis	- Training personnel	1.89	6.20	4.87	12.96

	- Output quality inspections - Preventive interventions - Equipment condition inspections	- FMECA-based maintenance plan - RAM analysis					
SO6	- Corrective interventions - Output quality inspections - Preventive interventions - Equipment condition inspections	- Criticality analysis - FMECA-based maintenance plan - RAM analysis	- Training personnel - Energy efficiency audit - Revamping study	1.89	6.20	8.67	16.76

Note: Corrective interventions do not prevent the negative impact of the failure mode on the operational value elements, therefore, the VD score in SO1 and SO2 is null.

Once the scores were calculated and presented to the companies, they decided to take SO4 due to its balance between value-add and service offering cost. The cost for the customer of acquiring each alternative are not discussed nor presented here; however, this was taken into account in their final selection of the service offering. Future plans were discussed regarding an upgrade to SO6 in the long term, due to envisaged improvements based on SO4 activities and plans to enable equipment condition inspections in a systematic way in this production area. This progression between offerings identified by the companies uncovered the modularity possibilities available due to the capabilities of the service provider. The applied method enabled modularity and progression between offerings to be made visible during the co-creation process. This was an unexpected result of the intervention (Oliva, 2019) which extended the conceptual scope envisaged for the value-driven method.

Based on their high priority (Table 4) and the potential impact of failure modes on them (Table 5), the operational value elements driving the selection of performance measures for the service agreement were human safety, output quality and equipment availability.

Identified possible measures to include in the service agreement are then the following: injuries (and near miss) caused by failures; rework percentage, scrap production rate, MTTR, and MDT. These measures were subsequently discussed by the companies to be integrated into the service agreement between the two companies.

## **5. Discussion**

Building on the background presented in section 2, the value-driven method was developed with the following features: i) technical and customer knowledge as the basis of the approach; ii) customer value at the centre of the service design method; iii) co-creation and value-driven engineering approaches to inform the method development. The collaborative research with the case companies was then conducted as an intervention or application case that observed the principles of free academic investigation, e.g., free interviewing, confidentiality, controlled design and creation of new empirical material, and of joint and continuous monitoring (Hatchuel and David, 2008). In our case, the monitoring was done by the senior researcher in the team and the service provider executive manager who oversaw the implementation of the steps.

The value-driven method was developed with intrinsic flexibility in a threefold way: (1) allows iterations between steps and adaptation to changing factors affecting the machinery, e.g. changes in the value elements prioritisation due to changes in the production process can be introduced and calculations of scores revisited accordingly; (2) can be applied to different units of analysis, e.g. a single equipment, a group of equipment and a portfolio made of different groups of equipment in the production site, (3) can be applied at different levels of detail, e.g. failure modes can be more or less detailed depending on the defined unit of analysis for the performance-based services. The latter was explicitly discussed with the service provider staff during the application of the method. Regarding iterations during this



application case, they occurred between sub-steps 1B and 2A (due to discussions about operational value elements prompting the reorganisation of equipment groups in one specific production area), and within Step 2, particularly between sub-steps 2A and 2B (due to participants realising one pre-selected value element was not relevant as thought when doing the rating AHP). Regarding the applicability to different units, the application case study covered seven machinery groups from three different production areas within the plant, although only the analytical results of one group are presented here for simplicity. This served as replication of the application of the method, which increases validity of practical knowledge (Auernhammer, 2020) and provided confidence in its applicability to different equipment types.

Methodologically, the value-driven method addresses important elements of PSS design and development applied to result-oriented PSS. Steps 1 and 2 provide a systematic way of identifying and managing customer needs and requirements, which is fundamental for the successful development of PSS offerings (Song 2017). Particularly sub-steps 1A, 1B and 2A deal with understanding customer needs and translating them into operational requirements, while sub-steps 2B and 2C support requirements prioritisation and analysis of interdependencies and trade-offs. Thus, addressing the challenges uncovered by Nilsson et al. (2018) for requirements management in PSS developments. Additionally, the method assumes that the target equipment is already preselected and agreed between both companies in a preliminary step; however, it also allows for revisiting this while conducting the analysis proposed in Step 1 that can help to discuss the service scope. In our application case, a set of machinery was preselected for the performance-based service and Step 1 discussions helped redefining and confirming the scope with the customer based on technical knowledge. Last but not least, it is worth remarking that the direct involvement of staff from the service provider and the customer in the analysis of customer needs and its translation into equipment

level requirements can contribute to their cultural shift towards a stronger customer-orientation. This change to operational practice is crucial for successful servitisation transformations (Clegg et al. 2017) and was also observed in our research work, particularly strengthening the already extant relation between service provider and customer.

Step 2 is a core part of the method, as it elicits the operational value required from equipment performance in its operating context. The value tree for operational value elements includes technical, environmental, economic, and social value elements that companies can use to define their equipment requirements. These prompts enrich the discussion and support the integration of environmental and social dimensions in PSS design, which is recognised as a research need (Kjaer et al. 2019; Annarelli et al. 2016; Tukker 2015). Thereafter, the application of rating AHP technique helped to understand prioritisation based on insights from three different internal stakeholders of the manufacturing plant (production manager, maintenance manager and plant manager). The rating AHP, used previously in Macchi et al. (2014), worked well to bring insights from these stakeholders without the computational effort required by other techniques like ANP (Fargnoli and Habert, 2019). Another frequent issue with these techniques is the lack of effectiveness when comparing a large number of attributes (Geng et al. 2010). In this regard, the visual representation of value elements done by interviewees during the AHP pairwise comparison was effective to keep acceptable levels of the inconsistency index, even when more than five elements were compared and the interviewee did not have previous experience on the method. This modification in the data collection for AHP pairwise comparisons could be replicated in other studies. Eventually, the proposed value-driven FMEA was developed to support the understanding of the effect of functional failures on the operational value elements selected and prioritised by the customer for the equipment, for example Table 5 shows that two functional failures (‘welding out of standards’ and ‘machine set up not appropriate for material’) have a high effect on one of the

operational value elements ('output quality'). This is a novel use of the FMEA respect to previous uses of this technique for PSS design.

Step 3 helps analysing the portfolio and capabilities of the service provider, devising service offering alternatives and evaluating those respect to customer needs and priorities. This puts technical knowledge and providers' capability at the core of the service offering development, which are key factors for successful service delivery (Datta and Roy 2011). The potential for taking a modularity approach emerged when working on sub-steps 3A and 3B with the service provider staff. Although initially planned to create competing service alternatives, we noticed that the application of certain direct maintenance activities required the implementation of other indirect activities as a prerequisite (e.g. preventive interventions needed the development of a FMECA-based maintenance plan done either in advance or as part of the service package) or required specific resources or technologies available at the customer plant facilities (e.g. condition-based interventions couldn't be considered for this plant due to their operational constraints at the time of our research work). Considering these constraints in the definition of SO alternatives uncovered that the method enables the definition of both modular and progressive service offerings, adapted to the customer requirements and its operational context. Thus, this work contributes to understanding how modularity enables a high degree of customisation (Khanra et al. 2021) and enhances the PSS development (Qu et al. 2016). To this regard, it is worth remarking that our method enabled to accommodate and make visible the modularity possibilities that were part of the capabilities of the service provider in our application case. This capability for modularity was key in the SO alternatives definition and evaluation.

Finally, in Step 3, and its last sub-step, the proposed approach deals with the complexity of advanced services in terms of multi-dimensional value elements and performance measures. It provides a structured way to identify the relevant measures to use

in the service agreement based on the context of the service and the operational requirements from the equipment. Thus, helping to address the lack of attention to performance measures, beyond availability measures, in performance-based PSS offerings (Glas et al. 2018; Batista et al. 2017), and improving requirements traceability along the design process (Trevisan and Brissaud 2016).

Both companies reported benefits obtained when applying the value-driven method. Firstly, the customer personnel highlighted two main benefits. Firstly, they obtained better knowledge of the service offering content, its links with their own strategic and operational context and, ultimately, the reasoning behind the inclusion of specific activities into the service offering alternatives. The plant manager mentioned that the method application helped them to make a more informed decision being aware of what sort of activities would be performed for their equipment, and the envisaged consequences of those activities in their production operations. This sort of support can help building a trust-based and fruitful collaboration between the service provider and its customer (Visnjic et al. 2017; Brax and Johnson, 2009). Secondly, the application of sub-steps 2A and 2B for their machinery was considered of great value for them, as it brought a new perspective to analyse their production areas and enhanced their understanding of the operational requirements needed from their machinery. It was seen as a stand-alone service that they would pay for, independently of any service agreement, and before engaging in any performance-based service. Secondly, the service provider personnel reported gaining a greater understanding of the customer requirements for the production equipment and processes than before using the proposed method (previous approach was based on senior staff observations and expertise). Regarding their own internal needs and capabilities, they found the portfolio analysis step helpful to reflect on activities available and applicable to the customer case, to create pathways by grouping activities into SO alternatives that could suggest a developmental pathway to the

customer and to formalise their competencies for service provision. This contributes to the organisation of internal operations of the service provider and dealing with internal variety for the service provision, which are areas for further work for the flexibility theme identified by Brambila-Macias et al. (2018). Additionally, the proposed way to define the service offering alternatives into three categories (direct maintenance, indirect maintenance and additional activities) was considered helpful to the service provider in two ways: (1) to visualise the developmental route available to the customer, and (2) to increase visibility of the add-on / additional activities and their value-adding potential; as otherwise, the customer may not consider them. They reported that previously the information on the wealth of possible activities and how they relate and build on each other was not easy to convey to the customer, and they felt this was a limitation to their intake. Overall, their perception was that engaging with the customer in the application of the proposed method was a positive experience, supported their long-term relationship and help them clarify and materialise different sets of service agreements.

## **6. Conclusions, limitations and future research directions**

Research on PSS design is still in its early stages and mainly characterised by exploratory studies (Annarelli et al. 2016), by limited instances of studies applying prescriptive approaches (Baines et al. 2017) and by lack of considering both customer and service provider viewpoints in PSS design studies (Xin et al. 2017). This work advances this research field and presents a prescriptive approach to support the effective development of performance-based PSS offerings. The proposed method was tested in an industrial case with a well-established service provider and one of its customers from the manufacturing sector. This represented a unique contextual setting to conduct our research intervention through collaboration with both companies. Customer views and outcomes are often neglected in

servitisation studies (Kohtamäki et al. 2019), especially when the customer is a manufacturing company itself (Baines et al. 2017). This work addresses this research gap and gives voice to the customer in our empirical setting.

The scope of the application case was the equipment located in the customers' manufacturing plant, organised in seven groups. The application of the method in this specific research setting achieved encouraging results based on feedback received from the participating companies, and this, together with the application itself, serves as proof of concept (Oliva, 2019). Further replications of the method in different settings will increase the validity of the practical knowledge obtained in this case (Auernhammer, 2020).

This work provides a step forward to support performance-based PSS design processes within the context of performance-based services in manufacturing equipment. The value-driven method incorporates technical, strategic, and operational knowledge based on the specific equipment and its setting in the customers' plant, supports the integration of sustainability aspects at operational level, and features flexibility, modularity and adaptability characteristics. The proposed approach enables the development of performance-based PSS with and for the customer, by integrating joint actions within the proposed steps and by considering customers' operational requirements pervasively throughout the entire value-driven method. By focusing on a prescriptive approach for the detailed design of a performance-based PSS, this work complements studies done at business model and conceptual design levels for this type of PSS offerings, such as the prescriptive framework for transitioning to a PSS business model proposed by Adrodegari et al. (2017).

Limitations of this research regard its single application case in a specific research setting and not having explicitly considered the economic side of the service offerings. The method currently does not address the cost analysis for the provider or payment options for the service offerings. It relies on the service provider being able to make the economic

assessment and to complement the method with a price associated to the service offerings and a charge scheme based on the selected performance measures. The service provider in our case has extensive experience in industrial services and excellent service costing and operational capabilities. This, however, may not be the case for all performance-based service providers and requires further investigation. Further research could address this by adopting a cost modelling or estimation approach based on equipment life cycle costing (Sakao and Lindahl 2015; Settanni et al. 2014) and total cost of ownership models (Roda et al. 2020, Bonetti et al. 2016).

Further research is also required to leverage on technological innovations; this could be developed in two ways. The first way is to explore the role of technological innovations in industrial services. For example, remote monitoring technology (RMT), Internet-of-Things (IoT) and Prognostics and Health Management (PHM) can potentially enhance value creation in servitised offerings (Suppatvech et al. 2019; Grubic 2018; Teixeira et al. 2013). This is partly taken into consideration within Step 3 of the proposed value-driven method, as the service provider could include condition-based and predictive maintenance activities in the SO alternatives. To further support their choice, research is needed on the value-adding functionalities of these technologies to result-oriented PSS and on their viability and adequacy based on the expected contribution to customer value and the readiness of customer processes.

The second way is to understand the potential improvements in adaptability and flexibility that technologies such as big data and artificial intelligence (Wang et al. 2021; Song 2017) can bring to the proposed value-driven method for performance-based services. Expected future work is then required to investigate how a data-driven approach can support the development and the implementation of result-oriented PSS based on our proposed method. This could include four types of data (Zambetti et al. 2021): product data, operations

data, enterprise data, and contextual data. Thus, supporting the automation of requirements elicitation (Wang et al. 2021) and the adaptability of PSS configuration to evolving customer contexts and feedback from the use phase (Cong et al. 2020; Grubic 2018)

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