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Designing PSS Fleets - Consideration of the Product Architecture

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Abstract

By transforming from a manufacturer into a PSS provider, the business model of a company changes. In particular with service-oriented business models, the importance of tangible products alters. Instead of selling products, PSS providers need product fleets that enable the provision of services. If the manufacturer of the product and the provider of the PSS fleet are identical, the products can be designed specifically for the PSS. This paper introduces a framework that supports the design of modular PSS fleets so that the product architecture is optimised for the requirements of the fleet.

Keywords: product-service systems (PSS), modularisation, fleet design, product architecture

1. Introduction

Due to long-lasting megatrends, the environment companies operate in is constantly changing. The growing demand for individualised products and an increasing cost pressure forces manufacturing companies to diversify their product range and offer a higher external variety (Krause et al., 2014; Krause and Gebhardt, 2018). To implement this higher external variety, existing products are combined with product-related services, so that companies are changing from manufacturers to solution providers (Isaksson et al., 2009) and can offer more personalised products (Tseng et al., 2010).

The combination of product and service elements, better known as Product-Service Systems (PSS), has been an established topic in academic research for many years. A wide variety of definitions exist in the literature, which in essence describe PSS as added value for the customer provided by tangible and intangible goods (Goedkoop et al., 1999; Tukker, 2004; Alonso-Rasgado and Thompson, 2006). Providers of PSS benefit through an increase in customer loyalty or the acquisition of new customers by implementing PSS-based business models (Isaksson et al., 2009; Alonso-Rasgado and Thompson, 2006; Reim et al., 2015). PSS also create challenges for companies, such as a sharp increase in complexity (Zou et al., 2018; Rennpferdt and Krause, 2020). To counteract this, modularisation of the PSS is often proposed in the literature (Dambietz et al., 2021; Rennpferdt and Krause, 2021).

Some of the PSS-based business models, especially the heavily service-oriented business models, require the tangible product as an enabler for the services (Rennpferdt *et al.*, 2021). To offer such service-oriented business models, the PSS provider requires a certain number of products to provide the services to the customer. The set of these products is called the PSS fleet.

Approaches for the development of fleets exist in the literature, but they do not consider the specific characteristics of PSS such as the combination of tangible and intangible components. Therefore, the goal of this paper is to outline an approach for the development of modular PSS fleets to enable the potentials of PSS in terms of complexity.

2. Methodology, background and research gap

In the following, the methodology of the paper and short summaries of the topics Product-Service Systems and fleet design are given.

2.1. Methodology

The methodology underlying the paper is based on the DRM approach by Blessing and Chakrabarti (2009). In Section 2, a summary of the relevant topics for the paper is given and the research gap, identified by a literature review, is described. This is followed by the presentation of a framework for closing the research gap in Section 3. The framework is based on existing methods found in the literature and has been adapted to close the identified research gap. Afterward, the proposed framework is applied to an industrial example of a laser processing machine to evaluate its applicability in industry. This is described in Section 4. The results of the evaluation are critically discussed in Section 5. Finally, Section 6 contains the conclusion and provides an outlook on further research topics.

2.2. Product-Service Systems and business models

A major drawback from PSS is the rising complexity the PSS-providers have to handle (Rennpferdt and Krause, 2020; Zou *et al.*, 2018). With the increase in product and service components and their dependencies, the management of this complexity becomes a major task for companies. An analysis of different publications related to complexity in PSS design showed, that the main complexity driver in the context of PSS is an increasing variety (Rennpferdt *et al.*, 2022). To deal with this increasing variety-induced complexity, the literature proposes the modularisation of the PSS (Rennpferdt and Krause, 2020; Rennpferdt and Krause, 2021). For the modularisation itself, a variety of methods and approaches can be found that each has advantages and disadvantages (Larsen *et al.*, 2018; Rennpferdt *et al.*, 2019; Dambietz *et al.*, 2021; Rennpferdt and Krause, 2021).
The different types of PSS and the corresponding business models are closely interconnected (Rennpferdt *et al.*, 2021). For example, the eight so-called archetypes of PSS according to Tukker are described by their underlying business models, e.g., *product pooling* or *pay per service unit* (Tukker, 2004). Figure 1 shows Tukker's PSS continuum in the centre, where on the right value is created mainly through the tangible product (product-oriented PSS) and on the left through intangible services (result-oriented PSS). The composition of a PSS or value creation is not discrete but a gradual one and is difficult to distinguish exactly.
In particular for business models on the right side of the continuum, which are characterised by a high level of services (Tukker, 2004), tangible products are needed as enablers to provide the services (Rennpferdt *et al.*, 2021). Figure 1 visualises the product and service architecture of the PSS-family in relation to the PSS continuum. In the boxes labelled *1* and *2* are the product, architecture is shown on the left and the service architecture on the right whereby the three levels correspond to those of the Service Blueprint (Rennpferdt *et al.*, 2021). Box *1* in Figure 1 visualises a product-oriented PSS, in which the customer requirements are addressed by adapting the tangible product architecture.
In this paper, the result-oriented business models are of particular interest (see box *2* in Figure 1). From the customer's point of view, the services are primarily relevant when offering result-oriented business models and serve to differentiate the company from its competitors. The characteristics of the product,

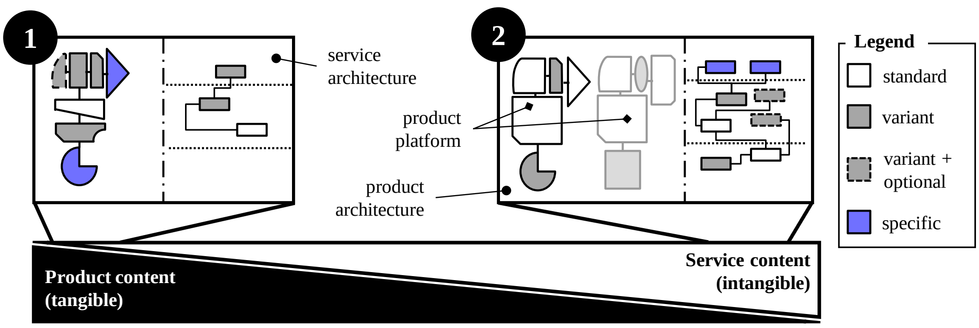

Figure 1. Product and service architecture for different types of Product-Service Systems

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on the other hand, are becoming less important. Here, the modularisation of the PSS represents a major lever for the sustainable reduction of complexity. Modularising the product and service architecture can enable flexibility where it is needed for the provision of these business models, and at the same time reduce variety where it is not needed, e.g., by developing standardised product platforms that can be used in one or more product families and fit the different service modules needed (see *2* in Figure 1). On the product side, in particular, the modular architecture can be adapted to be optimally aligned with the company-specific boundary conditions of the PSS provider, thus unlocking the potential of modular product architectures in all life phases (see (Hackl *et al.*, 2020; Greve *et al.*, 2022)).

2.3. Fleet design

Fleet design and optimization have long been an important area in operations research. With a focus on optimizing networks and product fleets to achieve higher efficiency and greater economic success. This is achieved by selecting the optimal combination of available products that can be procured (Jara-Díaz *et al.*, 2020; Fagerholt, 1999). In these models, the product is usually static and varies along with some key variables like transport capacity or speed. With this, it is possible to determine which combination of these individual factors is best suited to achieve the optimal solution. Therefore, a collection of products is combined into a fleet because they as an amalgam generate the best solution. This means that a collection of products is created to make the optimal fleet.
From the perspective of product development, it would make more sense to develop a product that is designed so that it would be the optimal product in the fleet. This rarely happens because manufacturers of products and operators of the fleet differ in most cases e.g., in aviation or car rental.
This no longer applies for use or result-oriented PSS, because the PSS provider manufactures the products and operates the PSS. In this case, the PSS that is developed should be designed so that it is the optimal product to be operated in a PSS fleet (Schneider *et al.*, 2020).
To achieve this four major aspects have to be considered when optimizing a product for use in a PSS fleet. These areas are shown in Figure 2. All the areas shown are influenced by the design of the product performing the work in the PSS. The modules can be connected directly as shown or indirectly through the other modules, to represent these influences. Therefore, alterations of the product impact the costs generated within each of the shown modules. The costs generated in the different modules can then be reattributed to the individual components of the PSS allowing for a redesign of the product to optimize the costs of the overall PSS fleet.

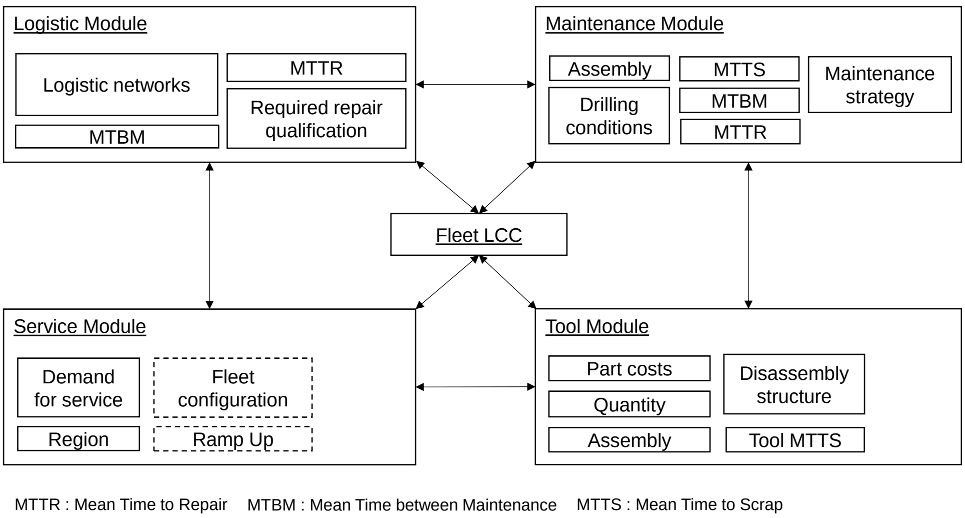

Figure 2. Framework for PSS fleet design (Schneider *et al.*, 2021)

2.4. Identified research gap

Traditional fleet design is mostly limited to optimising the composition of a fleet, e.g., different aircraft types, so that deployment times and utilisation are optimised. However, this optimisation is always limited to the composition of the fleet from existing product variants of (several) manufacturers. The

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transformation from manufacturing companies to PSS providers creates the opportunity to develop tailored products to be used in a PSS fleet. This is not yet sufficiently covered by existing methods.
Furthermore, the increasing complexity in PSS is an important aspect. The complexity is caused by a high variety of product and service components. It can be managed by modularisation, although existing approaches for modularisation do not take into account the special boundary conditions of PSS fleets, e.g., that the product is only needed as an enabler to offer services. However, this represents great potential in terms of standardisation and complexity reduction, especially on the product side.
In summary, there is a need for a framework that allows the development of specifically adapted product architectures for the usage in PSS fleets and at the same time enables the reduction of variety and thus the variety-induced complexity.

3. Consideration of the product architecture in PSS fleet design

Based on the literature review and empirical knowledge from industrial projects, a framework for the design of PSS fleets is presented in the first part of this section.

3.1. Proposed framework

In the case where a manufacturer himself becomes the owner-operator of a service-providing fleet in the PSS context, there may be product variants specifically adapted to the requirements of the fleet. This enables the product architecture to be adapted to the specific requirements of the product fleet and thus be optimised e.g., regarding costs. To maintain flexibility within the fleet and cover different business models and offer a wide range of functionalities, the authors propose a modularisation of the fleet's product variants. As discussed in Section 2, there are various methods for modularising PSS that do not sufficiently take into account the product architecture, but instead focus on analysing functional relations (Rennpferdt *et al.*, 2019; Rennpferdt and Krause, 2021). Therefore, the framework presented is based on the *Life Phases Modularisation for PSS*, which is based on the *Integrated PKT-Approach for the development of modular product families* (Krause *et al.*, 2014; Krause and Gebhardt, 2018). This approach combines advantages of different existing methods, e.g. considering functional and strategic module drivers, and is described in detail by Rennpferdt and Krause (2021). Next, the framework is presented schematically and the significant adaptations of the existing methods are described.

3.2. Variety-oriented design of PSS fleets

In the first step of the procedure, the internal variety of product and service components is initially reduced. To achieve this, the customer-relevant properties are linked with the variant resources and variant components. The connection is created via different levels and visualised in the Variety Allocation Model for PSS families (VAM) (Rennpferdt *et al.*, 2022). This method step is an adaption of the *Design for Variety method* according to Blees *et al.* (2010). Figure 3 shows the schematic architecture of the VAM. The focus of this research is set on the product domain but also considers dependencies between product and service domain.

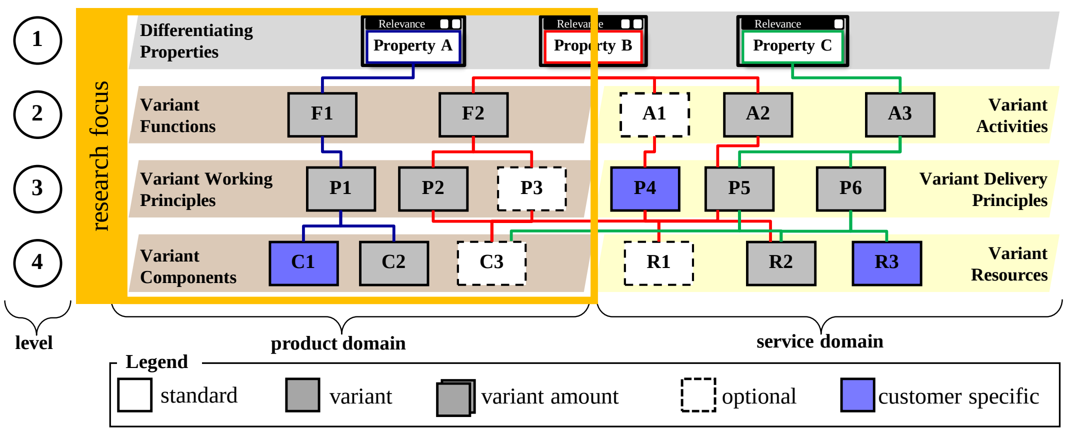

Figure 3. Variety-oriented design of PSS (Rennpferdt *et al.*, 2022)

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The visualisation of the variety in the VAM serves as the basis for a redesign of the product as well as the service architecture. In this context, especially in the design of PSS fleets, the goals are to assign the customer-relevant differentiating properties to the components in a one-to-one mapping, to decouple the product and service domains, and to create a standardised product platform as large as possible. This platform is the basis for the flexible adaption of the product for different tasks by combining the platform with different variant modules, which are defined in the next step of the procedure.

3.3. Life-phases modularisation of PSS fleets

Following the variety-oriented design, the modularisation of the product and service architecture follows in the second step. The *Life-phases modularisation of PSS fleets* is based on the *Life Phases Modularisation* according to Blees *et al.* (2010), which offers many advantages compared to other methods, such as the consideration of technical-functional and product-strategic module drivers, and has already been successfully adapted for the modularisation of PSS (Dambietz *et al.*, 2021; Rennpferdt and Krause, 2021).
Each life phase has its optimal modular architecture and from a product strategy point of view, there are various reasons for clustering components into modules. These reasons, so-called module drivers, are varying in every life phase and are dependent on the business model. When modularising PSS fleets, the approach presented by Rennpferdt and Krause (2021) must be expanded to consider fleet-specific module drivers for the *Usage* phase in particular. This is because the *Usage* phase is becoming more important for PSS. Figure 4 shows a selection of module drivers for different life phases.

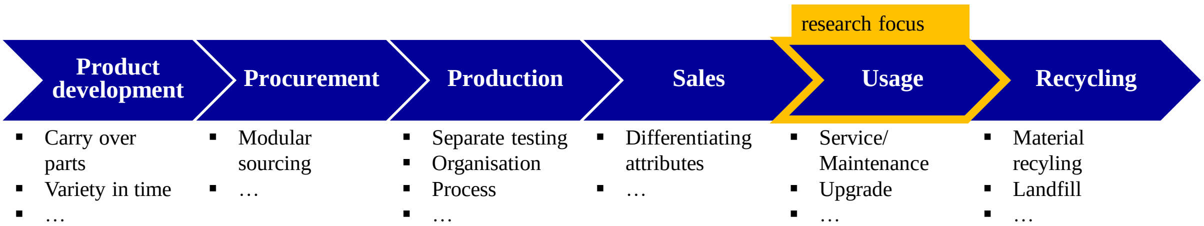

Figure 4. Life-phases and corresponding module drivers (Erixon, 1998; Blees *et al.*, 2010; Krause and Gebhardt, 2018)

Several module drivers were identified from the literature in the context of *Design for Life-Cycle* and complemented with new fleet-specific module drivers. The module drivers are listed in the table below.

Table 1. Relevant module drivers in the context of PSS fleets

Module driver	Description	Reference
Upgrade	Components must be clustered to be easily replaceable regarding a possible upgrading or extension of the product after the sale.	[1, 3, 8]
Maintenance	Components must be clustered to be physically separable for reasons of maintenance.	[1, 3, 4, 6]
Repairability	Components must be clustered to simplify the repair or improve the repair quality.	[5, 6]
Functionality	Components must be clustered to enable or extend functionalities.	[2]
Serviceability	Components must be clustered to improve serviceability and reduce service costs.	[7]
Process	Components must be clustered that are needed to offer certain processes or functions of the PSS fleet, e.g., components needed for drilling or milling.	New
Data	Components must be clustered that use or process the same data in the PSS fleet, e.g., components needed to track usage time in a Pay-per-Hour PSS.	New
Provision	The components must be clustered to provide the PSS fleet, e.g., components related to a service platform.	New

[1] (Blees *et al.*, 2010) [2] (Chang *et al.*, 2013) [3] (Halstenberg *et al.*, 2015) [4] (Go *et al.*, 2015)
[5] (Umeda et al., 2008) [6] (Zhang *et al.*, 2011) [7] (Newcomb *et al.*, 1996) [8] (Erixon, 1998)

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These module drivers are used in network plans to cluster the components into modules for every life phase. In a network plan, that is developed for each life phase, the module drivers are linked to the PSS-components via module driver characteristics, that specify the more general described module drivers. PSS-components can be either tangible (e.g., mechanical components) or intangible (services) and are needed to offer the PSS. Based on these connections, experts from every life phase discuss and evaluate the network plans for their life phase and define a module architecture. The individual module architectures are then harmonized over each life phase to form a company-wide module architecture.

There can be contradicting reasons to cluster components within a life phase and across life phases so that the evaluation of the developed module concepts is very important. In traditional business models, the aim is often to reduce the manufacturing cost to remain competitive and sell more products. In the context of PSS fleets, the aim is different: The product is not sold but generates continuous revenue. Since the PSS provider is often responsible for maintenance, especially in very result-oriented business models, it is important that e.g., maintenance costs remain as low as possible over the entire product life cycle. For this purpose, higher manufacturing costs are acceptable. Furthermore, a frequent goal of PSS providers is that the PSS fleets can be used flexibly. Therefore, it can also be useful to oversize certain functionalities and thus cover a wide range of applications. To evaluate this, approaches from traditional fleet management can be used, e.g., to calculate the needed fleet size or downtimes for different concepts.

4. Industrial case study

After the generic description of the developed approach, it is applied to an industrial example of mobile laser processing machines. The manufacturer is an SME and its goal is to access new market segments through PSS-based business models. Instead of selling highly customised stationary laser processing machines, the company plans to offer mobile machines that can be used in the customer's workshop for a short-term period. In addition, various services packages shall be offered so that customers only have to pay for the functional result and e.g., no longer deal with the maintenance of the machines. Different types of laser-based processes are to be offered. Customers should be able to choose between *welding*, *engraving*, and *cladding*. Considering the limited resources available to the company, the PSS fleet should be as flexible as possible. This is to ensure that downtime of the fleet is kept to a minimum.

To enable this new business model, a PSS fleet is needed that requires the development of corresponding product architecture concepts. With the help of the presented approach, different concepts were developed and afterward evaluated with company experts, e.g., the Head of Research and Development. A summary of the application and the obtained results are presented in the following.

4.1. Variety-oriented design of the laser processing machines

For the three applications of *welding*, *engraving*, and *cladding*, product variants from three separate product families of the product line *Mobile Machines* are needed. As the machines have different laser sources, optics, linear guides, and other components, partly optional (depending on the application) they are handled as three separate product families. In the context of variety-oriented design, concepts are to be developed for merging the three product variants into one PSS fleet. Figure 5 shows an excerpt of the VAM for the initial situation. It is evident that almost all components are variant and the customer-relevant properties influence multiple components, which significantly increases the variety (Rennpferdt *et al.*, 2022). For instance, the customer-relevant product properties *Precision* and *Processing* speed are relevant for all use cases, *welding*, etc. only for the respective task.

Depending on the application, the laser source must be adapted, as welding requires a higher power than engraving. However, welding and especially cladding require a lower level of precision (affects the linear guides and thus Frame Z). In addition, one or more powder tanks and a powder supply for the optics are needed for cladding. This requires a different cast basis so that the powder tanks can be attached. Furthermore, a wide variety of optics are required for beam focusing.

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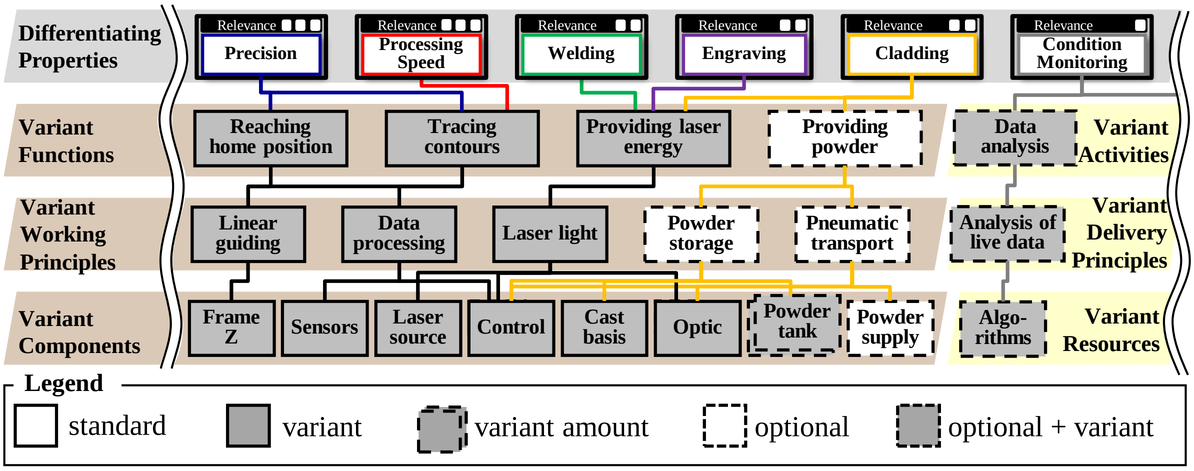

Figure 5. Excerpt of the VAM of the three product families

Starting from the initial situation, concepts for a variety-oriented PSS fleet are developed. Figure 6 shows an excerpt of one of the developed concepts. The *cast basis* is oversized so that it can be used for all applications. It includes the mountings for the *powder tank* and can accommodate a wide range of *laser sources*. In the context of traditional business models, this idea would be rejected for cost reasons. However, by looking at fleets, standardising the *cast basis* is a valid possibility to create a platform for the machines in the PSS fleet. The *powder tank* and *powder supply* are offered as an option for cladding. All components can be mounted on a standardised *cast basis*. To cover different business models, the *sensors* are always installed and can thus collect the required data. For the control, a distinction is made between *Hardware (HW)* and *Software (SW)*. The control hardware is standardised and always installed. The necessary variety is created by adapting the software accordingly. The linear guiding system is also over-dimensioned so that it is capable of all attributes of *Precision* and *Processing speed* for all applications. Different processing speeds can be enabled via the *control s (SW = Software)*. To achieve this, the optional components should be designed in such a way that they contain not only the mechanical components but also electronic components or integrated circuits.

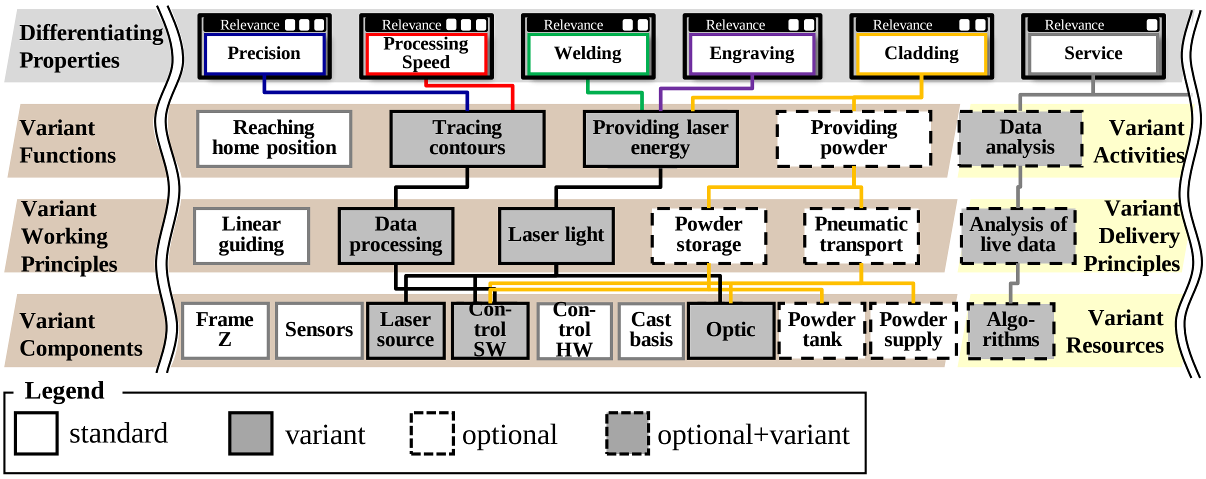

Figure 6. Excerpt of the VAM of the variety-oriented PSS fleet

4.2. Modularisation of the laser processing machines

Modularisation is applied after the variety-oriented design. This is illustrated below in Figure 7 using the example of the life phase *Usage*.

In the network plan shown, the applicable module drivers from Table 1 are listed on the left-hand side. One or more module driver characteristics were identified for each of the named module drivers. For

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maintenance, the characteristics *cleaning joints* and *powder refill* are examples of the maintenance work required during operation. For the module driver *upgrade*, the characteristic *laserpower* is identified, as this should be adapted in usage depending on the customer's demands. For *process* respectively *function*, the characteristics correspond to the three different applications. When linking module driver characteristics and PSS-components, it is noticeable that there are many contradictory module driver assignments, e.g., for the components *Control SW*, *Control HW*, *Optic*, and *Laser source*.

When defining the modules, the objective for the usage phase is to ensure the most flexible use of the PSS fleet possible. For this purpose, the components are clustered into modules in such a way that a standardised platform is created. This platform can be configured for the different use cases by adapting a few variant modules. The documented decision for a module architecture on the right shows the platform of standard modules and the small-scale variant modules for adapting the platform for different applications. For example, the *laser module* can be adapted according to customer requirements and the optional *cladding module* can be added for cladding if required.

As a network plan is generated for each product life phase, the module preferences of the individual life phases still have to be harmonised with each other. For this harmonisation of the module architectures, the *Usage* life phase is critical. This is especially valid in the context of user-oriented and result-oriented PSS because low costs for the PSS provider in the usage phase are important to maximize profit from the PSS fleet. For this, slightly higher manufacturing costs of the products can be accepted.

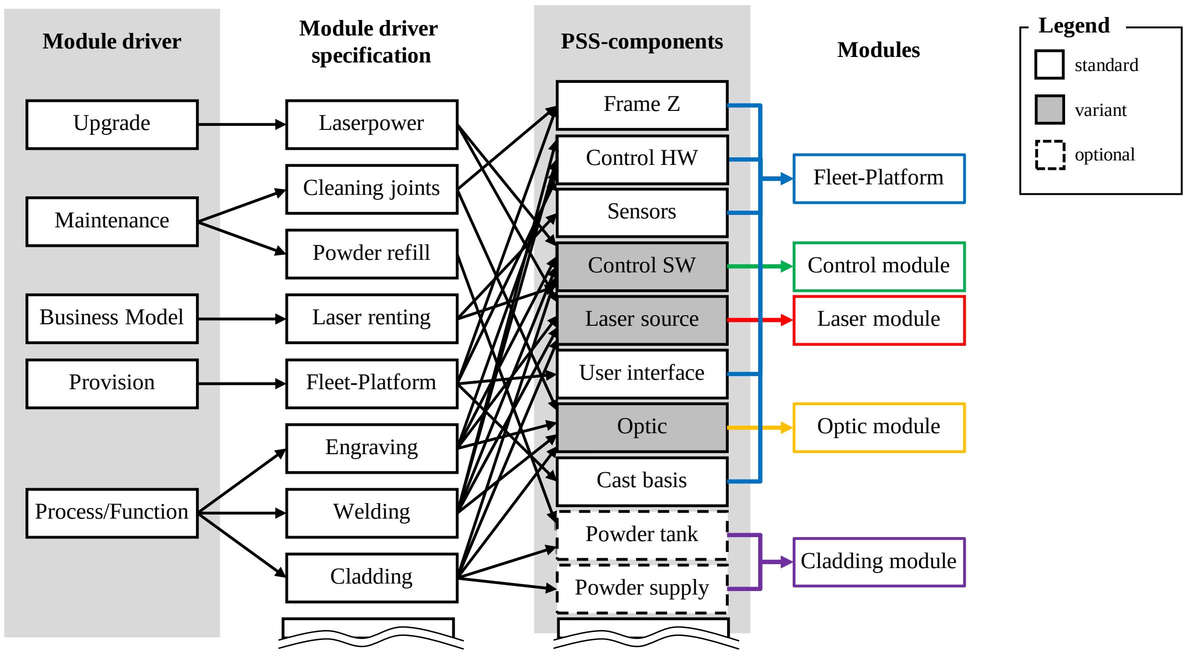

Figure 7. Network plan for the life phase *Usage* for the PSS fleet

5. Discussion

The developed framework and the results of the case study were discussed and evaluated with the company. Here, the visualisations were praised in particular, as they were well suited for identifying starting points for the redesign of the product architecture. The visualisation of the existing variety can be used to improve communication in interdisciplinary teams. It visibly documents which components are needed for which tasks and how this affects the variety. Together with the design guideline to implement a platform strategy, this supports the development of a product variety specifically adapted to the PSS-based business models.

Newly identified module drivers for fleet modularisation were also highlighted as benefits. The concept of module drivers was already used by the company in previous modularisation projects. However, it was not used in the fleet context. By expanding this product-strategic approach and taking it more into account in modularisation, further potentials of the PSS-based business models can be unlocked.

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A limitation of the approach is that it is primarily intended for redesigning existing PSS. Furthermore, the effort for implementing the method depends on the scope of the PSS. In the case of large value networks, especially modularisation, which considers all stakeholders, can require a lot of resources. The support in deciding for or against specific concept ideas was not yet rated as sufficient. From the company's point of view, there is a lack of information on the impact of concept ideas on costs, especially in the *Usage* phase. The manufacturing costs can usually be estimated relatively well, whereas the costs over the entire life cycle of the fleet are not known. Support for objective cost estimation and evaluation is desirable.

6. Conclusion and outlook

This contribution presented the state of the art in fleet design, PSS, and business models. Using this as a basis, the need for methods that support the development of products for usage in PSS fleets was shown. Especially in highly service-oriented business models, the tangible product only serves as an enabler for the provision of services. This allows these products and their product architecture to be redesigned in a way that they are tailored to the requirements of the PSS fleet. To bridge the identified research gap, a framework was developed that involves variety-oriented product design and modularisation of the PSS fleets. The framework was successfully applied to an industrial example and evaluated. It was shown that the approach enables benefits for companies and unlocks new potentials regarding the product architecture of PSS. However, there are also some limitations. In future work, the framework shown should be enhanced by a detailed cost analysis. For an objective evaluation of different alternative product architecture concepts, the effects on the entire life cycle should be known. Especially the life cycle costs are of relevance here, as these are the basis for the pricing of services within the framework of results-oriented business models.

References

Alonso-Rasgado, T. and Thompson, G. (2006), “A rapid design process for Total Care Product creation”, *Journal of Engineering Design*, Vol. 17 No. 6, pp. 509–531. http://doi.org/10.1080/09544820600750579

Blees, C., Kipp, T., Beckmann, G. and Krause, D. (2010), “Development of Modular Product Families: Integration of Design for Variety and Modularization”, in Dagman, A. and Söderberg, R. (Eds.), *NordDesign 2010: Proceedings of the 8th biannual conference NordDesign* 2010, *DS*, Product and Production Development, Chalmers University of Technology, Göteborg, pp. 159–170.

Blessing, L.T. and Chakrabarti, A. (2009), *DRM, a Design Research Methodology*, Springer London, London. http://doi.org/10.1007/978-1-84882-587-1

Chang, T.-R., Wang, C.-S. and Wang, C.-C. (2013), “A systematic approach for green design in modular product development”, *The International Journal of Advanced Manufacturing Technology*, Vol. 68 No. 9-12, pp. 2729–2741. http://doi.org/10.1007/s00170-013-4865-5

Dambietz, F.M., Rennpferdt, C., Hanna, M. and Krause, D. (2021), “Using MBSE for the Enhancement of Consistency and Continuity in Modular Product-Service-System Architectures”, *Systems*, Vol. 9 No. 3, p. 63. http://doi.org/10.3390/systems9030063

Erixon, G. (1998), “Modular Function Deployment - A method for product modularization”, PhD Thesis, The Royal Institute of Technology, Stockholm, Sweden, 1998.

Fagerholt, K. (1999), “Optimal fleet design in a ship routing problem”, *International Transactions in Operational Research*, Vol. 6 No. 5, pp. 453–464. http://doi.org/10.1111/j.1475-3995.1999.tb00167.x

Go, T.F., Wahab, D.A. and Hishamuddin, H. (2015), “Multiple generation life-cycles for product sustainability: the way forward”, *Journal of Cleaner Production*, Vol. 95, pp. 16–29. http://doi.org/10.1016/j.jclepro.2015.02.065

Goedkoop, M.J., van Halen, C.J., Te Riele, H.R. and Rommens, P.J. (1999), “Product Service systems, Ecological and Economic Basics”, *Report for Dutch Ministries of environment (VROM) and economic affairs (EZ)*, Vol. 36 No. 1, pp. 1–122.

Greve, E., Fuchs, C., Hamraz, B., Windheim, M. and Rennpferdt, C., et al. (2022), “Knowledge-Based Decision Support for Concept Evaluation Using the Extended Impact Model of Modular Product Families”, *Applied Sciences*, Vol. 12 No. 2, p. 547. http://doi.org/10.3390/app12020547

Hackl, J., Krause, D., Otto, K., Windheim, M. and Moon, S.K., et al. (2020), “Impact of Modularity Decisions on a Firm’s Economic Objectives”, *Journal of Mechanical Design*, Vol. 142 No. 4. http://doi.org/10.1115/1.4044914

https://doi.org/10.1017/pds.2022.113 Published online by Cambridge University Press

Halstenberg, F.A., Buchert, T., Bonvoisin, J., Lindow, K. and Stark, R. (2015), "Target-oriented Modularization – Addressing Sustainability Design Goals in Product Modularization", *Procedia CIRP*, Vol. 29, pp. 603–608. http://doi.org/10.1016/j.procir.2015.02.166
Isaksson, O., Larsson, T.C. and Rönnbäck, A.Ö. (2009), "Development of product-service systems: challenges and opportunities for the manufacturing firm", *Journal of Engineering Design*, Vol. 20 No. 4, pp. 329–348. http://doi.org/10.1080/09544820903152663
Jara-Díaz, S., Fielbaum, A. and Gschwender, A. (2020), "Strategies for transit fleet design considering peak and off-peak periods using the single-line model", *Transportation Research Part B: Methodological*, Vol. 142, pp. 1–18. http://doi.org/10.1016/j.trb.2020.09.012
Krause, D., Beckmann, G., Eilmus, S., Gebhardt, N. and Jonas, H., et al. (2014), "Integrated Development of Modular Product Families: A Methods Toolkit", in Simpson, T.W., Jiao, J., Siddique, Z. and Hölttä-Otto, K. (Eds.), *Advances in Product Family and Product Platform Design*, Springer New York, New York, NY, pp. 245–269. http://doi.org/10.1007/978-1-4614-7937-6_10
Krause, D. and Gebhardt, N. (2018), Methodische Entwicklung modularer Produktfamilien: Hohe Produktvielfalt beherrschbar entwickeln, Springer Vieweg, Berlin, Heidelberg.
Larsen, M.S.S., Andersen, A.-L., Nielsen, K. and Brunoe, T.D. (2018), "Modularity in Product-Service Systems: Literature Review and Future Research Directions", in Moon, I., Lee, G.M., Park, J., Kiritsis, D. and Cieminski, G. von (Eds.), *Advances in Production Management Systems. Production Management for Data-Driven, Intelligent, Collaborative, and Sustainable Manufacturing*, Vol. 535, Springer International Publishing, Cham, pp. 150–158. http://doi.org/10.1007/978-3-319-99704-9_19
Newcomb, P.J., Bras, B. and Rosen, D.W. (1996), "Implications of Modularity on Product Design for the Life Cycle", in *Volume 4: 8th International Conference on Design Theory and Methodology, Irvine, California, USA, 8/18/1996 - 8/22/*1996, American Society of Mechanical Engineers. http://doi.org/10.1115/96-DETC/DTM-1516
Reim, W., Parida, V. and Örtqvist, D. (2015), "Product–Service Systems (PSS) business models and tactics – a systematic literature review", *Journal of Cleaner Production*, Vol. 97, pp. 61–75. http://doi.org/10.1016/j.jclepro.2014.07.003
Rennpferdt, C., Dambietz, F.M. and Krause, D. (2021), "Business Models and Product-Service System Design - Introducing the Business Model Graph", *Proceedings of the IEEM 2021 Conference*, pp. 1102–1106. http://doi.org/10.1109/IEEM50564.2021.9672798
Rennpferdt, C., Greve, E. and Krause, D. (2019), "The Impact of Modular Product Architectures in PSS Design: A systematic Literature Review", *Procedia CIRP*, Vol. 84, pp. 290–295. http://doi.org/10.1016/j.procir.2019.04.197
Rennpferdt, C. and Krause, D. (2020), "Towards a Framework for the Design of Variety-oriented Product-Service Systems", *Proceedings of the Design Society: DESIGN Conference*, Vol. 1, pp. 1345–1354. http://doi.org/10.1017/dsd.2020.108
Rennpferdt, C. and Krause, D. (2021), "Life Phases Modularisation of Product-Service Systems", *Proceedings of the Design Society*, Vol. 1, pp. 1967–1976. http://doi.org/10.1017/pds.2021.458
Rennpferdt, C., Kuhl, J. and Krause, D. (2022), "Tools for the Variety-Oriented Product-Service System Design", in Andersen, A.-L., Andersen, R., Brunoe, T.D., Larsen, M.S.S., Nielsen, K., Napoleone, A. and Kjeldgaard, S. (Eds.), *Towards Sustainable Customization: Bridging Smart Products and Manufacturing Systems*, *Lecture Notes in Mechanical Engineering*, Springer International Publishing, Cham, pp. 798–806. http://doi.org/10.1007/978-3-030-90700-6_91
Schneider, J.A., Gatzen, M.M. and Lachmayer, R. (2020), "The Importance of Considering Fleet Size in te Lifecycle Cost Analysis of Product Service Systems", *Proceedings of the Design Society: DESIGN Conference*, Vol. 1, pp. 1365–1374. http://doi.org/10.1017/dsd.2020.284
Schneider, J.A., Wurst, J., Gruetzmann, I., Mozgova, I. and Lachmayer, R. (2021), "Implementation of Maintenance Strategies in the Life Cycle Costing of Product-Service Systems", *Proceedings of the Design Society*, Vol. 1, pp. 1827–1836. http://doi.org/10.1017/pds.2021.444
Tseng, M.M., Jiao, R.J. and Wang, C. (2010), "Design for mass personalization", *CIRP Annals*, Vol. 59 No. 1, pp. 175–178. http://doi.org/10.1016/j.cirp.2010.03.097
Tukker, A. (2004), "Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet", *Business Strategy and the Environment*, Vol. 13 No. 4, pp. 246–260. http://doi.org/10.1002/bse.414
Umeda, Y., Fukushige, S., Tonoike, K. and Kondoh, S. (2008), "Product modularity for life cycle design", *CIRP Annals*, Vol. 57 No. 1, pp. 13–16. http://doi.org/10.1016/j.cirp.2008.03.115
Zhang, J.X., Wang, W.W. and Cao, S.S. (2011), "Module Design Based on Life Cycle Design", *Advanced Materials Research*, 228-229, pp. 158–161. http://doi.org/10.4028/www.scientific.net/AMR.228-229.158.
Zou, W., Brax, S.A. and Rajala, R. (2018), "Complexity in Product-Service Systems: Review and Framework", *Procedia CIRP*, Vol. 73, pp. 3–8. http://doi.org/10.1016/j.procir.2018.03.319