Creating service modules for customising product/service systems by extending DSM

Tomohiko Sakao, Wenyan Song and Johannes Matschewsky

The self-archived postprint version of this journal article is available at Linköping University Institutional Repository (DiVA):

<http://urn.kb.se/resolve?urn=urn:nbn:se:liu:diva-138437>

N.B.: When citing this work, cite the original publication.

Sakao, T., Song, W., Matschewsky, J., (2017), Creating service modules for customising product/service systems by extending DSM, *CIRP annals*, 66(1), 21-24.

<https://doi.org/10.1016/j.cirp.2017.04.107>

Original publication available at:

<https://doi.org/10.1016/j.cirp.2017.04.107>

Copyright: Elsevier

<http://www.elsevier.com/>

Creating service modules for customising product/service systems by extending DSM

Tomohiko Sakao (2)^{a,*}, Wenyan Song^b, Johannes Matschewsky^a

^a Division of Environmental Technology and Management, Department of Management and Engineering, Linköping University, 58183 Linköping, Sweden

^b School of Economics and Management, Beihang University, Beijing 100191, China

Customising offerings effectively for customers' needs and wants, yet maintaining the provider's efficiency, is a challenging task. Modularisation is a key to achieve this, but insight on how to create modules for customising product/service systems (PSSs) is limited. This article proposes a new practical method that supports designers to create service modules by extending the DSM (Design Structure Matrix). The method has been applied to existing PSSs by an elevator manufacturer. It was found effective because it reduces complexity in customisation, and thus response time in service provision, as well as increases the chance of reusing previous designs.

Lifecycle, Modular design, Reconfiguration

1. Introduction

In order to create higher value for a variety of customer needs and wants [1], manufacturers often customise their offerings [2] and integrate services more and more with their products [3]. For instance, several dozen of interdependent services are often provided as a “menu” by a manufacturer on top of their products. This industrial trend presents providers with a number of challenges. First, in making a proposition that best suits a customer's needs and wants, ensuring the possible and feasible configuration of services is a time-consuming task, due to the interdependency of a large number of services and the resulting complexity. Second, when customers' requirements change during the lifecycle, reconfiguring an existing offering may be needed within a short response time, but is also time consuming due to the complexity mentioned above.

Modularity (e.g. [4]) is a key to achieve efficient customisation [2]. Structuring design and provision of product/service systems (PSSs) [3] throughout the lifecycle by taking advantage of modularity reduces the complexity and would lead to notable benefits, such as an easier overview of available options, easier communication within the provider, and a faster design and provision process according to Aurich *et al.* [5].

In literature, PSS customisation has been pointed out as an interesting research area [6] and methods for PSS customisation have emerged, especially recently. Ki Moon *et al.* [7] developed a service ontology to represent components in a module in product and service family design. A conceptual framework for the modular design of pure services was proposed [8]. In addition, a framework and a design process for PSS customisation was put forward [9]. Song *et al.* [10] adopted a modified service blueprint and fuzzy graph to create service modules of service activities and resources. However, most of the methods remain on a conceptual level, and practical methods to efficiently create modules for PSSs have yet to be developed for industry.

Therefore, this article aims to propose a new concrete and practical method to create modules for efficient PSS customisation. As a first step, service modularisation is targeted. For this aim, the article extends the traditional DSM (Design

Structure Matrix) [11] and verifies the method with a real case at an elevator manufacturer.

2. Problem formulation

This article targets companies providing a number of services for their products [12] according to a set of requirements from a customer. The term “service component” is introduced here. Components of physical products, which comprise parts of PSS modules, are defined by “dimensional, aesthetical, technological and functional characteristics” [1]. On the other hand, what is modelled as components of services is not equally obvious in the literature. Morelli [13] describes service components with respect to time, human interaction, and other (cultural or social) dimensions. Defining the concept of a service component is necessary to precisely describe the proposed method so as to address the service aspect of PSSs. Therefore, components of services are defined in this article as parts of resources for the concerned services. They are classified into **human resources**, **information**, and **service tools**. Human resources include, for instance, service technicians and on-line support staff. Information includes the service manual and information regarding product use history. The service tools cover both hard and soft tools, e.g. repair tools and analysis software.

Companies' decision of including specific components constitutes mapping based on a given requirement set, RS_k , which can be seen as designing in general. A company may select either all the service components C_i or none, as depicted by (a) in Fig. 1. This means provision of a standardized service offering as an option. A company may choose only part of components C_i as in (b). This can be regarded as tailor-made design according to RS_k . This is often the case in industry at present, and the number of components is often several dozen. This mapping is usually carried out manually. As the number of components increases, the burden on service designers increases exponentially. The solution proposed by this article is to decrease the number of elements to be chosen, where a set of modules is derived from a set of components before mapping RS_k to modules M_j is performed as in (c). This means customisation of offerings through modularisation aiming at reducing complexity. The problem to be solved by this article is how to make service

modules from given service components. Note that mapping from RS_k as such is beyond the scope of this article. Increasing the efficiency of the mapping is motivation for the method proposed.

Figure 1. Different ways of choosing service components according to a customer requirement set.

3. The method for creating service modules

3.1. Motivation to choose DSM as a foundation

DSM is a method intended for modelling, mapping and structuring relationships and interactions within elements of complex systems [11, 14]. Its properties and capabilities make it a fitting approach when aiming for enhanced structure, modularity and simplicity in PSS design: DSM allows for adjustment to the required level of detail and has previously been broadly applied in industrial companies [11]. Further, clustering algorithms offered as parts of DSM-oriented software packages support the aim of developing service modules. The flexibility of DSM also allows for adjustment of previous assessments in both depth as well as breadth [11], thereby ensuring that new developments can be added to existing knowledge, which in turn leads to high efficiency in competitive company environments.

DSM has been broadly applied to tackle design, operational and organizational challenges in industry, particularly in the case of "Product Architecture DSM Models" [11]. While examples exist showing different applications focusing on physical components, an approach for service modularisation is lacking at present.

3.2. Description of the steps

The five steps of the method are presented in Fig. 2 below.

Figure 2. Process of service modularisation.

Step 1: Describe customers' needs and wants

A variety of customers' needs and wants, which can be based on different PSSs, both existing and potential, are described.

Step 2: Determine level of granularity

In order to aggregate service components into complementary modules, a sufficient level of detail must first be determined. This is to avoid sub-optimization if an overly granular level is chosen, as well as to ensure the meaningfulness and fit of the different modules, which may be jeopardized in case the included components can be seen as modular themselves, thus defeating the purpose of the method. The appropriate level may not be as obvious for service components as for physical components.

The level of detail must be determined with respect to the service resources used, i.e. human resources, information, and service tools, as well as to realize the level of variety of the PSSs as described in Step 1. This is to be done in close communication with a cross-functional team involving relevant staffs from both service design and, even more importantly, service delivery.

A revision of the chosen level of granularity can be necessary as the following steps are carried out, as indicated by the iterative arrows in Fig. 2.

Step 3: Gather service components

A comprehensive overview of the available service components must be created, in coherence with the chosen level of granularity. Here, adhering to what was decided in Step 2 is absolutely key in order to not miss less apparent interdependencies in the following steps. Comprehensiveness in this step is also important to ensure the usefulness and effectiveness of the derived service modules in PSS design. Literature [11] suggest consideration of the following items when determining the scope of a DSM assessment:

- Boundaries of the system should be determined so that all relevant service components are included.
- The expected effort should be kept in mind for keeping the service modules up to date by updating the DSM diagrams.

Step 4: Assign interactions

When describing the interactions between service components, again the level of granularity must be determined. In a *binary* DSM, components can only influence one another, or not. Thus, no gradation of different levels of influence is possible. Other alternatives are *numerical* DSM with a ranking of interactions on a predefined scale, and a *composite* DSM, which allows not only a ranking of interactions, but also assigning more than one dimension to each interaction between two components.

Step 5: Create service modules

This step assesses all dependencies between the components in an effort to cluster those service components. The clustering adopts existing algorithms aiming to group components that have as many interactions as possible with each other into a module and have as few interactions as possible with components outside its module [15, 16]. Therefore, modules created have a higher degree of independence from each other, meaning a higher degree of modularity. In cases of composite DSM, modules can also be derived with a focus on a certain dimension; applicable dimensions may be functional adjacency, information transfer, and human interaction. Through this, service modularisation can be tailored more closely towards the needs of the service provider. Software-based support is available to increase the efficiency of the clustering (e.g. Cambridge Advanced Modeller [17] or DSMMatrix). Otherwise, clustering can be performed multiple times in order to achieve a sufficient complexity in the resulting modules. The necessity of a second clustering step depends on the level of granularity determined in Step 2, and can help in reflecting upon the decisions made there.

4. Empirical findings from a real case at an elevator provider

4.1. The target provider and their PSSs

The target company is elevator manufacturing company M. Company M is a leading manufacturer in eastern China which provides different types of elevators including passenger/freight elevators, hospital elevators, escalators, and elevator monitoring systems. Besides elevators, Company M offers different kinds of elevator-related services for their customers, such as remote monitoring, maintenance, repair and spare part supply. Company M customises their PSS offerings according to its customer needs and wants. Company M had situations depicted as (b) in Fig. 1, and also had used modularisation in an ad-hoc manner, mainly based on the organisational structure of their departments.

4.2. Results of applying the method

In Step 1, customers' needs and wants were listed; e.g. shorter response time in service and better information given in the use phase. In Step 2, based on the outcome of Step 1, the granularity was carefully determined so as to obtain meaningful components and modules from the method. In Step 3, service components were identified based on the outcome of Step 2 as in Table 1.

Table 1

Company M's elevator service components identified (excerpt).

#	Service components	#	Service components
1	Remote monitoring system; T	27	Remote support engineer; H
2	Elevator running data; I	28	Maintenance trainer; H
3	Maintenance data; I	29	Elevator service tools; T
...		30	Failure detection instruments; T

Note: H, I, and T denote human resources, information, and service tools, respectively.

In Step 4, the binary approach was applied, and binary interactions between different components were created. In Step 5, those components were clustered into modules as shown in Fig. 3. Here, the Cambridge Advanced Modeller was used. As a result, the 30 components were clustered into 6 modules, of which only three are shown in Fig. 3 due to the space limitation. The complete 6 modules were *remote monitoring & diagnosis*, *customer care*, *maintenance*, *spare parts supply module*, *emergency repair*, and *supporting tools & resources*.

	"Remote monitoring & diagnosis"						"Emergency repair"			"Supporting tools & resources"		
	Remote diagnosis system	Remote inspector (system)	Elevator fault alarm system	Maintenance data	Remote monitoring system	Elevator running data	...	Failure detection instrument	Remote support engineer	MRO knowledge database	The 3rd party service partner	Elevator-related information
Remote diagnosis system	1	1	1	1	1	1	...	1	1	1	1	1
Remote inspector (system)	1	1	1	1	1	1	...	1	1	1	1	1
Elevator fault alarm system	1	1	1	1	1	1	...	1	1	1	1	1
Maintenance data	1	1	1	1	1	1	...	1	1	1	1	1
Remote monitoring system	1	1	1	1	1	1	...	1	1	1	1	1
Elevator running data	1	1	1	1	1	1	...	1	1	1	1	1
...	...	...	...	...	...	...	...	...	...	...	...	...
Failure detection instruments							...	1	1	1	1	1
Remote support engineer							...	1	1	1	1	1
MRO knowledge database							...	1	1	1	1	1
The 3rd party service partner							...	1	1	1	1	1
Elevator-related information							...	1	1	1	1	1
Repair personnel							...	1	1	1	1	1
Elevator service tools							...	1	1	1	1	1
Maintenance manual							...	1	1	1	1	1
Maintenance trainer							...	1	1	1	1	1

Figure 3. DSM of Company M's elevator service components (excerpt).

Note: three shaded areas in the matrix mean modules 1, 5, and 6 created.

4.3. Analysing results from the method

Interactions of service components were effectively used; e.g., the 3rd party service partner has interactions with the components in the Maintenance module, but it is not clustered into the Maintenance module – it is in the module of Emergency Repair. The reason is that in this way, it has fewer interactions (8) with components outside the module. If the 3rd party service partner were grouped into the Maintenance module, it would have 9 connections with other service components outside its own module. The 3rd party service partner in the Emergency Repair module creates a higher degree of modularity than in Maintenance. Although the clustering algorithm itself is outside the scope of this article, the results acquired comply with the functionality expected from the DSM clustering.

In the results, service skills, experience and knowledge are considered aspects of human resources, and packaged accordingly into a module which will facilitate accurate and efficient service dispatching. In previous service dispatching without using the method at Company M, the maintenance engineer, repair personnel, remote support engineer, and service quality tracking personnel were all considered homogeneous service engineers without acknowledging their expertise and special experience. However, after modularisation with the proposed method, the service engineers are classified into different types and integrated into different modules. This will help to enhance the service dispatching accuracy and efficiency. This could be regarded as a benefit of the method in practice considering human resources for packaged modules. Although it is possible in theory to do so in case (b) of Fig. 1, it tends to be avoided to decrease the component number and thus effort.

Some components are clustered in the different modules as they are usually considered to be. In a previous manual modularisation at Company M, the component of Maintenance Data was usually incorporated into the module of Maintenance. This is because the Maintenance Data is generally considered one of the outputs of the module of Maintenance. However, by applying the proposed method, Maintenance Data is clustered into the module of Remote Monitoring & Diagnosis. In this way, the remote monitoring system can monitor not only the conditions of the elevator, but also the quality or result of the maintenance by analysing the maintenance data. Besides, the component of Elevator-related Information is generally incorporated into the module of Customer Care, due to its close relation to the customer. In the proposed method, Elevator-related Information is clustered into the module of Emergency Repair, because the basic information of the elevator (e.g., elevator location and type) interacts within Emergency Repair and is indeed a critical input of the Emergency Repair. These examples imply benefits of the method modularising systematically based on interactions.

When using one or multiple selected service modules in customising and then providing PSSs, each module needs to be equipped with sufficient resource to be able to stand alone. This implies a possible redundancy of the resource embedded in multiple modules and thus redundancy for the provider as a whole, similarly to DSM when applied to physical products. However, a trade-off relation should be emphasized between this possible redundancy and the inefficiency of manual customisation. It may be expected to provide outweighing benefits from the efficiency in a number of cases in practice.

4.4. Feedback on the method from Company M

Service managers in Company M were invited to evaluate the method and results. They consider the modularisation results from the method more reasonable, because service components

with strong interdependencies are clustered into a module. Different from this method, their previous modularisation in Company M was based on the business department paying less attention to the interdependencies between different service components. Service managers also feel that the new modules will help them to optimise the use of service resources, and reduce the waste of time and energy in service design and delivery. According to the managers, other benefits of using the method at Company M include: easier customisation, more frequent reuse of design cases, easier and quicker backtrack of the cause of a problem, and faster response in service.

5. Discussion

The method was found effective for service modularisation based on the verification with a PSS case in industry. The number of obtained modules was substantially decreased from that of components input into the method, and the created modules were sensible to the practitioners. Benefits from using the method, such as a faster design and provision process in PSS customisation, are, in many cases, expected to outweigh the effort needed to carry out the method.

The method was found practically useful. According to the practitioners, it especially brings, in a standardised and scientific manner, reasonable modularisation that may be different from how a company modularises service components in practice at present. Relevant cases in industry may involve more service components than found in this article. However, the method is still applicable to an increased number of service components, and the modularisation benefits become larger due to the exponentially increased number of combinations. Concerning implementation at a manufacturer, the method is advantageous because DSM is relatively well acknowledged in industry and supporting software of DSM is widely available.

The proposed method targets service resources as components, and excludes service activities (e.g., failure detection activity) from the components. Another method for service modularisation [10] targeted both as components. An advantage of this new method is reduced complexity: it is possible to omit the dimension of activities, and decrease the number of components. All the service activities originate from service resources, in line with the service modelling method by Arai *et al.* [18], and therefore the proposed method does not leave out the constituents for services as compared to the existing method [10]. As another advantage compared to that method [10], this new method requires less mathematical knowledge of users. Yet, investigating the benefits of extending the method, e.g. the modelling scope, is a good subject for future work.

The method is also academically new, as it extends DSM to be applicable to a domain of service modularisation by defining service components. The discussion of how service modularisation was performed concretely (in Section 4.3) also advances scientific insights in literature. Thus, knowledge of service modelling is advanced. This knowledge is a prerequisite to address product and service modularisation in a parallel and integrated manner for PSS modularisation.

6. Conclusion and future work

This article proposed a new practical method to create service modules from service components as resources (human, information, and service tools) for efficient customisation of PSSs by extending DSM. Thus, it contributes through the extension of DSM into the realm of services. The method was verified by service modularisation for PSSs at a manufacturer. In addition, the article provided some new concrete insights for service modularisation as discussed in Section 5.

Future work will include; 1) extending the method for PSS modularisation and 2) investigating the pros and cons of different modelling methods (both as stated in Section 5), as well as 3) verifying use of the two other alternatives in Step 4 with a case.

Acknowledgements

The work described in this paper was supported in part by the Mistra REES (Resource Efficient and Effective Solutions) program, funded by Mistra (The Swedish Foundation for Strategic Environmental Research). This research was also partially supported by the National Natural Science Foundation of China (Grant No.71501006). The authors wish to express their deep appreciation to Company M for their support.

References

- [1] Hu, S.J., Ko, J., Weyand, L., ElMaraghy, H.A., Lien, T.K., Koren, Y., Bley, H., Chrysosolouris, G., Nasr, N., Shpitalni, M., 2011. Assembly system design and operations for product variety, *CIRP Annals - Manufacturing Technology* 60(2), p. 715–733.
- [2] ElMaraghy, H., Schuh, G., ElMaraghy, W., Piller, F., Schönsleben, P., Tseng, M., Bernard, A., 2013. Product variety management, *CIRP Annals - Manufacturing Technology* 62(2), p. 629–652.
- [3] Meier, H., Roy, R., Seliger, G., 2010. Industrial Product-Service Systems - IPS², *CIRP Annals - Manufacturing Technology* 59(2), p. 607–627.
- [4] Jung, S., Simpson, T.W., 2017. New modularity indices for modularity assessment and clustering of product architecture, *Journal of Engineering Design* 28(1), p. 1–22.
- [5] Aurich, J.C., Fuchs, C., Wagenknecht, C., 2006. Life cycle oriented design of technical Product-Service Systems, *Journal of Cleaner Production* 14(17), p. 1480–1494.
- [6] Durugbo, C., Tiwari, A., Alcock, J.R., 2011. A review of information flow diagrammatic models for product-service systems, *The International Journal of Advanced Manufacturing Technology* 52, p. 1193–1208.
- [7] Ki Moon, S., Simpson, T.W., Shu, J., Kumara, S. R. T., 2009. Service representation for capturing and reusing design knowledge in product and service families using object-oriented concepts and an ontology, *Journal of Engineering Design* 20(4), p. 413 – 431.
- [8] Løkkegaard, M., Mortensen, N.H., McAloone, T.C., 2016. Towards a framework for modular service design synthesis, *Research in Engineering Design* 27(3), p. 237–249.
- [9] Song, W., Sakao, T., 2017. A customization-oriented framework for design of sustainable product/service system, *Journal of Cleaner Production* 140(3), p. 1672–1685.
- [10] Song, W., Wu, Z., Li, X., Xu, Z., 2015. Modularizing product extension services: An approach based on modified service blueprint and fuzzy graph, *Computers & Industrial Engineering* 85, p. 186–195.
- [11] Eppinger, S.D., Browning, T.R., 2012. *Design Structure Matrix Methods and Applications Engineering Systems* MIT Press, Cambridge.
- [12] Sakao, T., Napolitano, N., Tronci, M., Sundin, E., Lindahl, M., 2008. How Are Product-Service Combined Offers Provided in Germany and Italy? – Analysis with Company Sizes and Countries -, *Journal of Systems Science and Systems Engineering* 17(3), p. 367–381.
- [13] Morelli, N., 2006. Developing new product service systems (PSS): methodologies and operational tools, *Journal of Cleaner Production* 14(17), p. 1495–1501.
- [14] Yassine, A., Braha, D., 2003. Complex Concurrent Engineering and the Design Structure Matrix Method, *Concurrent Engineering* 11(3), p. 165–176.
- [15] Thebeau, R.E., *Knowledge management of system interfaces and interactions from product development processes*, 2001, Massachusetts Institute of Technology.
- [16] Helmer, R., Yassine, A., Meier, C. *Module and interface identification and definition – a comprehensive approach using DSM*. in *Proceedings of the 9th International DSM Conference*. 2007. Munich: The Design Society.
- [17] Wynn, D., *Model-based approaches to support process improvement in complex product development*, 2007, University of Cambridge.
- [18] Arai, T., Shimomura, Y., 2004. Proposal of Service CAD System -A Tool for Service Engineering-, *Annals of the CIRP* 53(1), p. 397–400.