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# Product and service modularization for variety management

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**Abstract**

Due to the increased diversity in customer requirements, many manufacturers are in the process of evolving from mass production to mass customization (MC) whereby products and services are tailored to specific customer needs. Even though MC strategy was described decades ago, its implementation within industry is hindered by the partial understanding of its underlying philosophy and operational drivers. A central question to be dealt with for a successful MC implementation is how to balance between products and services variety and their induced complexity. Modularity is one of the commonly used means for dealing with such as question. While this concept has been widely discussed in product design and operations management literature at large, its applicability to service or product-service systems is only poorly addressed. This paper addresses the question of how to deal with the service modularity and how this can be exploited jointly with product modularity to modularize an offering, in a way to increase offering variety and improve internal company performance.


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*Keywords:* Mass customization; Variety management; Modularity; Product and service system

## 1. Introduction

In the last twenty years mass customization (MC) has been put forth as a possible business strategy for operation management to meet market diversity [1]. However, enterprises' endeavours to implement MC are not always fruitful, due to the partial understanding of its underlying philosophy and operational drivers [2]. Yet, the shift to offering a solution of both product and service, companies will need to diverse their offerings considering the peculiarities of such integrated solutions coupling tangible with intangible elements. However, diversifying the offer is usually correlated with an increasing internal complexity of the production system and of the whole supply chain


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of the company. A major challenge for MC companies is then to mitigate internal complexity while ensuring a variety level capturing as many customer preferences as possible. Modularity is one of the commonly used means for dealing with such as question. The basic idea is to group product components together following some criteria so as to increase offering variety while mitigating induced complexity [3]. While this concept has been widely discussed in product design and operations management literature at large, its applicability to service or product-service systems is only poorly addressed [2].

This article describes a method for modularizing and integrated offering of both product and service by using Design structure matrix (DSM). Section 2 provides a brief overview of mass customization and modularity literature. Section 3 describes the general steps for modularizing the product and service offer. Section 4 focuses on an illustrative example for showing the first steps of the method. Section 5 discusses the research perspectives.

## 2. Literature review

From its very beginning introduction as a business strategy, MC has modified considerably the value proposition for MC companies and customers, generating additional benefit to both of them. Pursuing MC allows corporations to supply their customers with personalized merchandise, which are created with near-to-mass production potency [4]. This is owed to the rapid growth of flexibility in manufacturing and the configuration tools for the customers [1]. MC seeks to be an economically viable strategy, as some companies can benefit from the increasing prices of the goods. Although service has been mentioned since the very MC beginning, in most of the literature MC is only applied to mere products.

Recent trend in the manufacturing industry to shift to integrated product and service offerings requires rethinking how MC applies to these offering also known as Product Service Systems (PSS) [5]. PSS combines a physical product with an additional tangible service and will lead to a higher benefit for the client and reduce environmental impacts [6]. PSS changes the way of designing and selling physical products to designing and selling both product and service system together [6]. However, using PSS for some enterprises faces some challenges relating mainly to the heightened complexity induced by integrated tangible products with intangible services, the shorter product and service lifecycles and the rapidly increasing customer needs [7]. In other words, the complexity inherited from product variety is likely to increase further by adding services to the offering. The coexistence of product and services in a diversified offering requires coupling different resources (human, equipment, etc.) to manage (usually) perishable products and unperishable services.

Modularity was acknowledged as an efficient means to overcome the variety induced complexity, thus fostering MC success [7]. Modularity has been applied before in product development [8]. Some researchers started to focus on the development of modularity in service [9]. Other research works are focused on the effect of service modularity on service customization [10]. Although several researches were focusing on product and service modularity separately less researches existed that discuss the modularity that covers both product and service together i.e. PSS [11]. Li et al. [12] discussed the relationship between product and service and how these can meet customer’s physical and service requirements. Another recent research focused on identifying a modularization method that is based on defining the functional requirement of PSS and how to classify them into different clusters that will ease the customization design to cope with the individual requirements [3].

Several methods were proposed to modularize the offer such as Quality Function Deployment (QFD), Modular Function Deployment (MFD) and Design Structure Matrix (DSM). DSM is a method intended for modelling, mapping and structuring relationships and interactions within elements of complex systems [13]. DSM allows for adjustment to the required level of detail and has previously been broadly applied in industrial companies [14]. Further, different algorithms are applied to DSM to cluster its elements such as genetic algorithm [15]. Genetic clustering algorithm reduce the time required for the algorithm to find a good clustering result [16]. The k-means clustering was adopted for DSM based modularization by defining a proper entity representation, a relation measure and an objective function [17]. DSM has been widely applied to tackle design, operational and organizational challenges in industry, particularly in the case of “Product Architecture Models” [5]. However, while examples exist showing different applications focusing on physical components, an approach for service modularization is lacking at present [5].

The literature investigation shows that there is a lack in the research addressing MC in PSS context. It supports also the idea that modularity is a potential driver for succeeding MC implementation in PSS domain. Some methods such as DSM show a potential for being applied for modularizing PSS offering to cope with variety and complexity.

## 3. General steps for modularizing product and service

### *3.1. Rationale of the method*

This section presents a method for modularizing an integrated product and service offering. The rationale of the method is to reinforce the modularity of a set of products and services through generating, evaluating, and comparing different modularity scenarios. The aim is to efficiency use the modularity as a driver for managing the variety of a PSS offering. The method consists of four steps namely, product and service identification, building DSM, clustering, and evaluation. Figure 1 describes briefly those steps, which will be detailed in the next paragraphs.

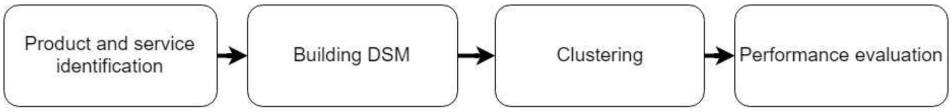



Figure 1. Steps for PSS modularity

### *3.2. Product and service identification*

The first step is to identify services and products that the company will be able to offer. Identifying products and services provides a raw input for the subsequent step, namely building DSM. Thus this input should be refined according to the industrial context; in this sense two main strategies have been identified to be useful for refining products and services identification resulting in various structuring:

- Considering both service and product as a pre-modularized before integrating them together. This means that each of the service and the product are already clustered into service packages and product modules, respectively.
- Breaking the products and the service down into components. Product components that can be derived from the Bill of Material (BOM). In the case of service, there are two levels of decomposition, either breaking the service package down into a list of services, or decomposing the services into activities.

Although these strategies depend upon the existing offering of a given company, using some of them contribute towards generating various modularity scenarios, thus opening up further drivers for managing offering variety.

### *3.3. Building DSM*

This step aims to characterize the relationships between the refined inputs from the previous step: products modules, service packages, components. In other words, after collecting the entire product and service information and refining their structuring, a DSM can be built. As discussed before, there are two ways for building up the DSM; first, considering service packages and product modules (Fig. 2a), alternatively, breaking down services and products into components (Fig 2b). So far, the method does not recommend any of these structuring, it however suggests that both shall be analyzed and evaluated in the subsequent steps.

In addition, there is more than one way to build a DSM. One approach will be is the binary DSM which is just used as a notation of 1 and 0 to define whether there is a dependencies between two given elements of DSM or not. Another type of DSM is the numerical DSM in which the degree of dependency could be used to measure how strong is the relationship between elements [18] . The dependency is measured using can range from 1-3 where 1 is considered as high dependency, 2 is medium dependency and 3 is low dependency [18]. We will use in this article the binary DSM. The cells of the DSM are ruled by the following criteria:

- Two services (or service component) are related (one in their crossing) if they:
  - Share the same lifecycle phase of the product.
  - Fulfil the same customer need (functional encapsulation).
  - Share the same resources, skills or activities.
- Two product modules (or components) are related if:
  - Share some technical interface.
  - Fulfil the same customer need (functional encapsulation).
- A product module (or component) and service (or service component) are related if:
  - They fulfil the same customer need.

Building the DSM using different criteria will result in different dependencies between DSM elements, thus different matrixes and modularity scenarios. The selection of the criteria could be refined upon clustering and evaluation which enlighten the decision maker on the performance of the modularity scenarios.

| | Product module 1 | Product Module 2 | Product Module 3 | Service Package 1 | Service Package 2 | Service Pckage 3 | Service Package 4 |
|---|---|---|---|---|---|---|---|
| Product module 1 | ■ | | | 1 | | 1 | |
| Product Module 2 | | ■ | | | 1 | | |
| Product Module 3 | | | ■ | 1 | | | 1 |
| Service package 1 | 1 | | 1 | ■ | | | |
| Service package 2 | | 1 | | | ■ | | |
| Service package 3 | 1 | | | | | ■ | |
| Service package 4 | | | 1 | | | | ■ |

| | Product component 1 | Product component 2 | Product component 3 | Service 1 | Service 2 | Service 3 | Service 4 | Service 5 | Service 6 |
|---|---|---|---|---|---|---|---|---|---|
| **Product component 1** | ■ | 1 | | 1 | | 1 | | | |
| **Product component 2** | 1 | ■ | | | 1 | | | 1 | 1 |
| **Product component 3** | | | ■ | 1 | | | 1 | | |
| **Service 1** | 1 | | 1 | ■ | 1 | 1 | | | |
| **Service 2** | | 1 | | 1 | ■ | | | 1 | |
| **Service 3** | 1 | | | 1 | | ■ | | | 1 |
| **Service 4** | | | 1 | | | | ■ | | |
| **Service 5** | | 1 | | | 1 | | | ■ | |
| **Service 6** | | 1 | | | | 1 | | | ■ |

Figure 2. (a) DSM with product module & services package; (b) DSM with service and product components

### *3.4. Clustering*

In this step, the DSM will be rearranged to be able to find a clustering where modules minimally interact with each other while components within a module maximally interact with each other. Several clustering algorithms can be used to find the best products and services clustering [19]. Cost minimization is considered as one of the first clustering objectives in which each DSM element is placed in an individual module and components are then, coordinated across modules to minimize the cost of being outside or inside the module. Yet, hierarchical and k-means clustering algorithms have been widely used and their efficiency is witnessed in many research works. However, the selection of the algorithm is not imposed by the method. Trying different clustering algorithms will lead to generating different modularity scenarios of the PSS and comparing them to end up with the best ones.

### *3.5. Performance evaluation*

The final step of the method consists in measuring the performance of modularity scenarios using several indexes. These indexes measure the ability of a set of components to perform a module as well the capability of the modules to perform well. The indexes will be used as a theoretical check for the performance and the efficiency of the modules themselves, which will help in identifying the best way in modularizing the PSS offer based on the criteria chosen for each step.

## 4. Illustrative Example

This section, briefly illustrates the proposed method and particularly the first steps. The illustrative example is inspired by a research project aiming at designing an industrial cleaning solution. The cleaning process is ensured by an autonomous robot supported by a set of maintenance, installation and training services. The final customer is in the meat transformation industry, however the idea of the project is to extend later on to other sectors, and thus the variety of the offering and the modularity are important questions.

### *4.1. Product and service identification*

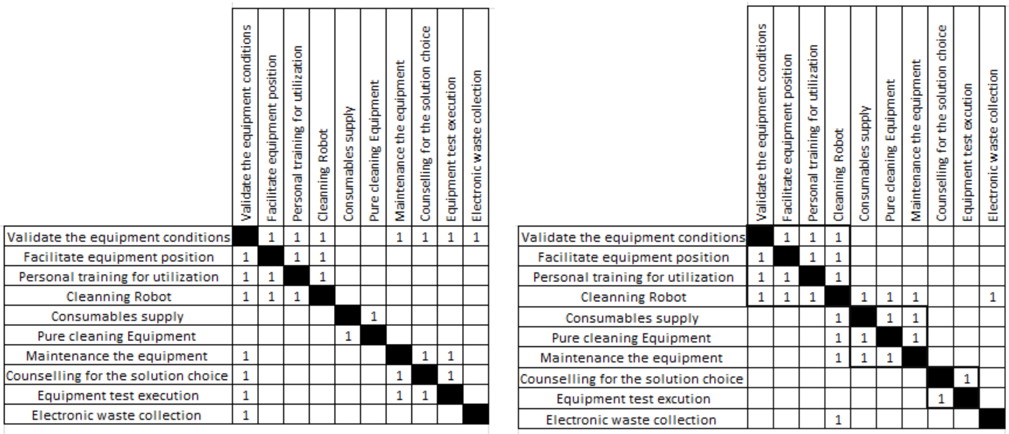
In this example we will have one product which is the cleaning robot and several services that are integrated with it to create a PSS offer for the customer. The company (PSS provider) already defined a list of services based on what customer need. Those services can be treated as service components of the offer. The services are as shown in Table 1.

Table 1: Service structuring

| Requirement analysis phase | Deployment phase | Operation phase | Retirement phase |
|---|---|---|---|
| – Counselling for the solution choice<br>– Equipment test execution | – Validate the equipment in real use conditions<br>– Facilitate the equipment position and navigation<br>– Personal training in the equipment utilization | – Consumables supply<br>– Corrective and preventive maintenance<br>– Pure cleaning of the equipment | – Electronic waste collection |

### *4.2. Build DSM*

After identifying and structuring products and services, the DSM is built. An illustrative example of DSM based on the cleaning robot example is used and is shown in Fig. 3a. The used criterion for characterizing the relationships between services and the product is functional encapsulation. Common lifecycle phase is the criterion used in addition for characterizing the relationships between services.



| | Validate the equipment conditions | Facilitate equipment position | Personal training for utilization | Cleanning Robot | Consumables supply | Pure cleaning Equipment | Maintenance the equipment | Counselling for the solution choice | Equipment test execution | Electronic waste collection |
|---|---|---|---|---|---|---|---|---|---|---|
| Validate the equipment conditions | | 1 | 1 | 1 | | | 1 | 1 | 1 | 1 |
| Facilitate equipment position | 1 | | 1 | 1 | | | | | | |
| Personal training for utilization | 1 | 1 | | 1 | | | | | | |
| Cleanning Robot | 1 | 1 | 1 | | | | | | | |
| Consumables supply | | | | | | 1 | | | | |
| Pure cleaning Equipment | | | | | 1 | | | | | |
| Maintenance the equipment | 1 | | | | | | | 1 | 1 | |
| Counselling for the solution choice | 1 | | | | | | 1 | | 1 | |
| Equipment test execution | 1 | | | | | | 1 | 1 | | |
| Electronic waste collection | 1 | | | | | | | | | |

| | Validate the equipment conditions | Facilitate equipment position | Personal training for utilization | Cleanning Robot | Consumables supply | Pure cleaning Equipment | Maintenance the equipment | Counselling for the solution choice | Equipment test excution | Electronic waste collection |
|---|---|---|---|---|---|---|---|---|---|---|
| Validate the equipment conditions | | 1 | 1 | 1 | | | | | | |
| Facilitate equipment position | 1 | | 1 | 1 | | | | | | |
| Personal training for utilization | 1 | 1 | | 1 | | | | | | |
| Cleanning Robot | 1 | 1 | 1 | | 1 | 1 | 1 | | | 1 |
| Consumables supply | | | | 1 | | 1 | 1 | | | |
| Pure cleaning Equipment | | | | 1 | 1 | | 1 | | | |
| Maintenance the equipment | | | | 1 | 1 | 1 | | | | |
| Counselling for the solution choice | | | | | | | | | 1 | |
| Equipment test excution | | | | | | | | 1 | | |
| Electronic waste collection | | | | 1 | | | | | | |

Figure 3. (a) Simple DSM; (b) DSM manual clustering

### *4.3. Clustering*

The manual clustering resulted in three main modules, highlighted with the bold frames in Fig. 3b. One of the modules (upper left hand side) including the product and the three other ones include services. Although the clustering was done manually for illustration purpose, some inferences can be derived. For instance, the module including the product comprises also some services from deployment phases while other service modules belong to subsequent phases. Consequently such a clustering might be relevant to the case of a product oriented PSS where a module of a sold product with a set of services can be offering at the beginning of the contract, and several other optional services could be offered later on. Likewise, other criteria could be used to generate further modularity scenarios consistently with the decision maker requirements.

## 5. Discussion

Within the limit of the current paper, only a brief illustration of the method is presented. The evaluation will not be discussed here as the performance indexes are still to be studied and their shortages shall be addressed to cover the scope of the method, e.g. impact of modularity on offering variety, impact on complexity and internal performance, link to flexibility. This said, several promising research perspectives are still to be investigated. First, a full case study is likely to provide further insights into the relevance and operationalization of the method. This implies going through product and service structuring, building DSM and clustering, evaluating and providing recommendations, and collecting decision maker feedback. Second, the link between modularity and variety and between modularity and performance should be made explicit so as to consider these dimensions during modularity scenarios assessment. Current indexes used for evaluating modularity scenarios may be used but do not cover such a whole scope of the assessment. Third, another important dimension underlying mass customization and variety management namely commonality, is likely to positively impact on the decisions on modularity. In other words, trying to increase commonality while modularizing an offering, is likely to reinforce the economies of scales of the company. The oxymoron of variety and commonality provides a potential area of investigation, particularly in the field PSS.

## 6. Conclusion

This article proposed a new method for generating and comparing different modularity scenario of PSS. The starting point of the method is the existing product architecture and potential or already offered services. The method helps in identifying the relationship between products and services resulting according to different criteria, resulting in different DSM alternatives. The clustering and performance evaluation supports the comparison of the modularity scenarios and provides a valuable support for the decision makers on variety management.

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