# Exploring modularity in servitization

– A theoretical development of the servitization matrix

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## Abstract

The strategic role of service in has been increasingly acknowledged by product manufacturers, as well as the research area of servitization. Successfully adding service to product can benefit manufactures with extended revenue stream and enhanced customer relationship. However, the transition process from a product-seller to a service-provider is not straightforward. With customer requirements being progressively more sophisticated, and technologies continuously advancing, it is likely that the complexity of the product and service system will gradually rise. Failing to cope with the complexities may lead to service paradox, i.e. undermined financial performance.

Striving to provide recommendations to solve the system complexity from an architectural perspective, this thesis exams how modularity manifests in the product-service offerings of the manufacturer. Being related to systematic decomposition and recombination, utilizing modularity in the design of product and service can reduce complexity and increase flexibility. This thesis provides the theoretical ground for the servitization matrix that distinguishes between the architectures of products and services.

Using two cases from the smartphone industry, this thesis demonstrates the effects of modularity and integrality on the orientation of the product-service offerings. This thesis posits that the focus of standard service on modular product is to deliver the best-preferred product-service offerings to customers by increasing module variety and process efficiency. For manufacturers with standard services added to integral products, the focus is to increase the volume of the standardized offering through replication and applying personalization in the delivery process.

# Table of contents

**List of figures**



**List of tables**

# 1 Introduction

Manufacturing firms are directing increased attention to the service domain, and the proportion of service in their offerings to customers has been rising. The shift towards services is generally characterized by manufacturing firms innovating and delivering services (e.g. Gebauer et al., 2012a; Kindström and Kowalkowski, 2014), primarily as a strategic consideration to sustain revenue growth (Kowalkowski, Gebauer and Oliva, 2017; Wise and Baumgartner, 1999). For example, car manufacturers are offering maintenance package subscriptions, rental services, and corporate fleet management services. It has been acknowledged that services can contribute to profit growth for manufacturers, as well as increase customer satisfaction and loyalty (Eggert et al., 2014). The complexity of servitization has been elevated by increasingly sophisticated customer requirements for customization and the pursuit of operational efficiency (Cenamor et al., 2017). With extending to downstream of the value chain comes increased customer contact, which requires careful management in fulfilling customer requirements, both on the configuration of product and service bundle and the process of product and service delivery.

As suggested by Simon (1962), one solution to the increased complexity is by decomposing the system into subsystems. In the decomposition process, by standardizing the connection between subsystems and specifying the tasks for every subsystem, the system complexity is reduced and managed by the subsystems. When the system is decomposed into to the smallest distinct portions that carry certain functions, the modules of the system is found. However, the lowest level that a system can be decomposed into varies from system to system. Such notion has been conceptualized and measured in degree of modularity. Generally speaking, modularity incorporates the separation of an object into constitutive components. The potential of modularity in facilitating cost-efficient operations while addressing the increasing customer demand heterogeneity has been acknowledged in both product and service modularity literature (Carlborg and Kindström, 2014). The notion of modularity can also be considered from an opposite perspective, i.e. the process of building and assembly. Having decomposed the system and identified the constitutive modules, by following the communication rules at the point of where the module is connected to the subsystem at the corresponding level, a different module can be designed and substituted into the system. In this way, the overall system is renewed, which manifested by the functions of the new module.

The practice of mass producing a large variety of modules for the purpose of creating freedom and flexibility to substitution lies in the core of mass customization. Mass customization creates customized offerings by selectively combine the modules that fulfils customer needs. It is a cost-effective approach to balance production efficiency from standardization and customer responsiveness in customization by exploiting the flexibility of modularity (Pine, 1993).

In order to understand the potential role that modularity might have in decomposing complex systems and involving the customization aspect into servitization, certain method to combine different aspects of product and service architectures, where modularity embeds, is needed.

Building on existing theoretical and empirical research on servitization and modularity, this thesis is delimited by the three following factors. First, the thesis has adopted an architectural perspective of servitization. Other perspectives of servitization, such as regarding servitization as a process of organizational change and a business model, are out of scope for this thesis. Second, with regard to the modularity concept, the decomposition level in this thesis has primarily focused on the product and service bundle level, as well as the product and service component level. The industry level and company level of modularity have not been addressed to. Third, the research method employed in this thesis is qualitative method with illustrative case studies. The quantitative aspect of modularity has been left out.

With the delimitations being considered, the next following sections introduce the research question, research philosophy and methodology of this thesis.

## 1.1 Problem statement

The objective of this research is to contribute to the understanding of the role of modularity in servitization. This thesis follows a pragmatism philosophy and starts with the problem:

*How does modularity manifest in the architecture of integrated product and service offerings of servitized organizations?*

Recognizing the differences of architectures, the research question can be decomposed into the following subordinated research questions:

1. *What are the characteristics of modular and integral products and services that should be considered by servitized organizations?*
2. *What are the possible types of integrated product and service offerings that an organization could offer, considering the varied product and service architectures?*

The research aim of this thesis is to explore the possible product service offerings, and how modularity affects the product-service configurations. This thesis investigates specifically into the architecture of products and services, and distinguishes between modular and integral architectures.

Research can be regarded as a process through which certain results are found in a systematic way, and the methods used in a research have implications on the justifications of results obtained and associated limitations (Saunders et al., 2016). In this study, 'The Research Onion' (Figure 1) has been used as a scheme to structure the methodology for answering the research question. It provides a structured approach to guide the design of this thesis and guides the flow of carrying out the thesis.

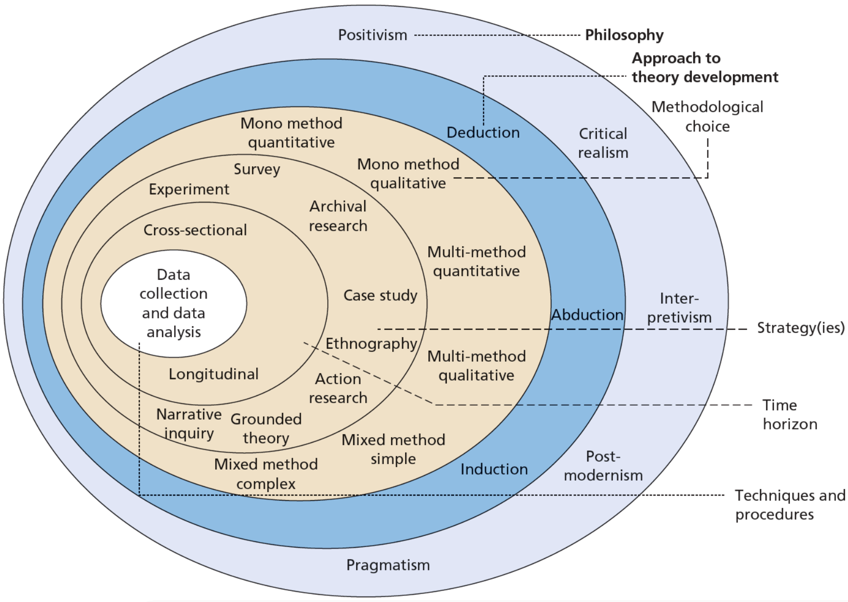


*Figure 1 The research onion.*
*Source: Saunders et al. (2016, p. 124)*

### 1.1.1 Research philosophy and methodology

The position of the researcher is the starting point of the research process, since the interpretation of results is influenced by the knowledge and mental perceptions of individuals

(Saunders et al., 2016). The philosophical and theoretical assumptions are the base of a research, which impact the subsequent choices during the process of carrying out a research. Such fundamental role of the research philosophy manifests itself as the outer layer in the research onion in Figure 1.

In the effort to explore possible servitization strategies, this thesis follows a pragmatism philosophy, in that it acknowledges that the relevance of different concepts is dependent on whether they support the real-world practices (Saunders et al., 2016). Pragmatism philosophy recognizes the contextual effects of theories and research findings on actions. Starting with the problem of servitization configuration and its interaction with product and service architecture, this thesis uses theories in servitization, product architecture, and product and service modularity literature as instruments of guiding practical strategy formulation in the context of servitization. Following the pragmatist philosophy, the thesis adopts a qualitative research design.

The research choice of pragmatism research philosophy determines the three assumptions in the philosophy of social science: ontology, epistemology and axiology. Ontology concerns the nature of reality. A subjectivism perspective recognizes that reality is the output of social and cognitive processes, whereas objectivism assumes separation and distinctiveness between individuals and reality (Eriksson and Kovalainen, 2016). Under the philosophy of pragmatism, this thesis takes the subjectivist stance and assumes that the business world is complex, rich, and full of flux of processes and practices. The "reality" of the business world is the practical consequences of ideas, and decisions are based on the perceptions of different socially constructed contexts, consequently contributing to varied organization performance.

Epistemology concerns the assumptions about knowledge, such as what constitutes acceptable knowledge and quality data (Saunders et al., 2016). Given that the social phenomena are constantly fluxing and revising due to the continual interactions between actors, a subjectivist research investigates certain situations in detail in order to gain knowledge of the reality (Saunders et al., 2016). The epistemological assumptions of pragmatism recognize the contextual meaning of knowledge, and focus on problem solving and implications for future practice. In this thesis, the product and service architecture perspectives are chosen to be analyzed to understand servitization. It reviews the existing literature for servitization and modularity, describes cases for servitization, and contributes to the theoretical building of the servitization matrix.

Axiology concerns the role of values within the research process, especially the values and beliefs of the researcher that influence the research process (Saunders et al., 2016). The axiology assumptions of pragmatism philosophy indicate that the research is driven by the values of the researcher, in other words, the research begins from and sustains from the enquiries and questions of the researcher. In the interpretation of the data collected, especially in deciding the architectures of the products and services, my personal perceptions, judgements, and values will inevitably influence the process. My role is to seek to understand the realities of servitization through my observations and analysis of architectures of the products and services.

### 1.1.2 Reasoning approach

According to Saunders et al. (2016) and the second layer of the research onion in Figure 1, there are three main approaches in theory development. Deduction and induction are the two common reasoning approaches used in research, with the former logically derives the conclusion from a set of premises, and the latter logically fills the gap between the conclusion and the observed premises. A third approach is abductive reasoning, which combines deduction and induction. It identifies patterns, develops a framework, then tests the theory with the data collected subsequently (Saunders et al., 2016).

This research uses the abductive method. An abductive research is appropriate for theory development, which explores a phenomenon by the collection of data for theme identification and explanation of patterns, leading to the generation of new theories or modification of existing ones (Saunders et al., 2016). This thesis begins with identifying the servitization strategies of specific companies that have different product and service architectures, which are then theorized and positioned into the "servitization matrix" by Hsuan et al. (2012). The theory is then elaborated through a comparison case study with two cases from the smartphone industry. The outcome of the case study is to explain and build up the conceptual framework of servitization.

Data for the case study is collected from the smartphone industries and companies' websites where available to identify themes and patterns for the framework, and is subsequently used to induce the qualitative indicators and aims to develop a typology of servitization strategies. Other sources including news, magazine article and developers' conference are also used to acquire relevant data.

### 1.1.3 Research design and research strategy

Following the pragmatist philosophy, the thesis adopts a qualitative research design to obtain the understanding of servitization and modularity. The thesis is explorative in nature, with the purpose of clarifying the understanding of the impact of modularity in the product and service offerings of servitization and extending the understanding of the servitization matrix by Hsuan et al. (2012) through case studies.

The rationale for using a case study strategy is that it can generate insights into real-world servitization practices, leading to detailed descriptions of the servitization phenomenon and theory development (Saunders et al., 2016). To obtain in-depth enquiry of servitization and see the replication of the findings, the research strategy of this research is a multiple-case study. According to Yin (2014), the selection of cases should serve the purpose of analysis, including a literal replication (for similar results) or theoretical replication (for contrasting results). The cases selected in this thesis are focused on theoretical replication, with two phones with opposite (i.e. integral and modular) product architectures being selected for contrasting results. In this thesis, the case study uses an embedded design, with each individual case study includes data collection and analysis. Data is collected from company websites and product and service catalogues that are available online.

## 1.2 Structure of the thesis

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| Chapter 1<br>Introduction and Methodology |
| Chapter 2<br>Literature Review |
| Chapter 3<br>Theoretical Framework |
| Chapter 4<br>Case Study |
| Chapter 5<br>Discussion |
| Chapter 6<br>Conclusion |

This thesis is composed of six chapters. Chapter 1 starts by introducing the research arears of modularity and servitization, with three delimitation factors being presented, and followed by presentation of the research question, and a brief discussion research philosophy and methodology used in this thesis. Chapter 2 reviews literature in servitization and modularity, and describes product and service architecture by comparing modular architecture with integral architecture. Chapter 3 utilizes the descriptions of product-service offerings in servitization literature and the characteristics of product and service architectures in building the servitization matrix and proposing four possible typologies to describe servitized firms. Chapter 4 presents the two cases, Ara phone and Apple iPhone, and compares the product architectures as well as the added services. Following the cases, chapter 5 discusses the main findings and provides suggestions on business world. The thesis ends with a conclusion in Chapter 6.

# 2 Literature review

With the research object being exploring modularity in servitization and theoretically building the servitization matrix, this thesis reviews literature from servitization, product service systems, product modularity and service modularity.

## 2.1 Servitization

Innovative manufacturing firms are offering more than a pure product to customers. The changing characteristics of the competition landscape, especially the pressure from the growing demand of customer value and the goal of continuous profit growth are constantly influencing the strategies implemented by manufacturers (Gebauer et al., 2012b). The advance of technology and increased environmental concerns are continuously disrupting the global market, which inevitably affect the worldwide manufacturing operations (Avlonitis et al., 2014). Moreover, as the global competition of manufacturing intensified by the increased challenges from economies with relatively low production costs, a holistic approach to strategically offer a bundle of products and services has been increasingly adopted by manufacturers to sustain the competitiveness (Lightfoot et al., 2013).

### 2.1.1 Servitization and company performances

Servitization is related to providing an integrated package of product and service to customers. In broad terms, product and service are different in terms of tangibility, and service features intangibility, heterogeneity, inseparability and perishability (IHIP) (Spring and Araujo, 2009). Despite the distinct natures, service and product are closely related in business operations. In manufacturing firms, service can find its role in serving both internal and external customers with distribution, after-sales and factory activities, as well as acting as order qualifiers (Voss, 1992). The phenomenon of offering an integrated package of product and services has been depicted as 'servitization' by Vandermerwe and Rada (1988). They portrayed a three-stage process where the "bundle" provided by enterprises has evolved into a service-dominated package by selectively adding modules of services, support, knowledge and self-service to the goods. The modules can be standardized or customized, depending on the case-by-case circumstances, which makes servitization essentially a customer-driven approach that enables manufacturers to deliver both standardized and customized goods and services (Vandermerwe and Rada, 1988). Their concept of servitization as a bundle of different modules have implications on the applying modularity thinking to designing the service package. However, the nature of the service modules and the service bundles remains unclear.

Different terminologies have been used in the research area of servitization, such as “transition to service” (Oliva and Kallenberg, 2003), “service infusion” (Ostrom et al., 2010), and “service growth” (Kowalkowski, Gebauer and Oliva, 2017). This thesis follows the recent systematic review by Baines et al. (2017) and adopts “servitization” in referring to manufactures’ processes of establishing revenue stream from services. A systematic review of servitization by Lightfoot et al. (2013) identifies five related research communities: service marketing, service management, operations management, product-service systems (PSS) and service science. In operations management, servitization has been used to refer to the process during which manufacturing firms displace product offerings with integrated product and service offerings that deliver “value in use” (Baines et al., 2007). The process involves innovating in capabilities and process to facilitate the shift (Neely, 2009), such as reassigning a firm’s resource (Baines et al., 2009), redesigning firm vision and business model (Kowalkowski, Gebauer, Kamp, et al., 2017), and renovating company values into service-centric (Kindström and Kowalkowski, 2014).

Servitization has been referred to as competing through customer-centric value propositions and offering integrated products and services, and ultimately the company work towards the desired customer outcomes (Avlonitis et al., 2014). In recent years, there has been an increasing amount of literature on different perspectives of servitization, for example, the motivations for servitization (Raddats et al., 2016), and financial performances resulted from servitization (Gebauer et al., 2005; Neely, 2009; Visnjic Kastalli and Van Looy, 2013).

The motivations for servitization can be categorized into competitive, demand-based, and economic (Raddats et al., 2016). As observed by Vandermerwe and Rada (1988), competitive motivations regard product as the core resource and services as a point of differentiation, which enhance competitive advantage. Offering services also improve customer relationship, which can better defend the companies from competition. The demand-based motivations suggest that manufacturers provide services to respond to customers’ demand in cost-reduction and improved service quality (Raddats et al., 2016). In terms of economic motivations, manufacturers changes to service for increasing revenue and profit, building sustainable value stream, and extending revenue growth for products that reach maturity in the product lifecycle (Kowalkowski, Gebauer and Oliva, 2017). Recognizing the economic potential in integrating services into the products, Wise and Baumgartner (1999) exhort manufacturing firms to go downstream for pursuing higher margins and steady revenue streams from service, in other words, initiating an extended coverage of the value chain of the company.

Despite the promises of growth, competitiveness and profitability from servitization, for some manufacturers the transition from product manufacturer to service provider is far from straightforward. Gebauer et al. (2005) direct our attention to the outcomes servitization and termed the "service paradox in manufacturing firms"(Gebauer et al., 2005, p. 15), in which the projected financial returns of extended service business were failed to be achieved by servitized firms. Managing the operations of extended service tends to incur higher costs yet not necessarily yield higher returns, since services, such as providing maintenance and consulting, are generally more labor intensive than the practices of physical goods production. Moreover, to divert from the previous product-centric operations requires considerable management efforts and coordination between different departments (Gebauer et al., 2005). Following the notion of the service paradox, the case study by Visnjic Kastalli and Van Looy (2013) suggests a spiral relationship between the contribution to profits made by products and services. They observe that as the companies scale up their service offerings, a temporary steep increase in profitability would be firstly achieved at a low-level of service. Negative financial performances are observed with medium-level of service, and when the scale of services is large enough to reach economies of scale, a positive financial performance re-emerges (Visnjic Kastalli and Van Looy, 2013) . However, the exact level of service that a company should add needs further clarification. The empirically observed struggle of servitized firms have been categorized into servitization failure, i.e. unachieved projected financial benefits, and deservitization, i.e. decreasing or eliminating the service portion in the offerings (Valtakoski, 2016). The challenges of undergoing the servitization journey has been explored in a study by Martinez et al. (2010), which identifies some of the success factors to be service-oriented culture change, responsiveness in the delivery of integrated offering, capabilities in alignment of internal processes, strategic alignment and cooperation, and change in supplier relationships.

The performances of servitized companies have been further investigated and demonstrated with ample examples in a recent paper by Kowalkowski, Gebauer, Kamp, et al. (2017). Some successful examples of servitization include automotive parts supplier providing assembly services, water treatment equipment manufacture selling water-as-a-service to Africa, and pay-per-use business model by tire companies (Ibid). Meanwhile, the authors underline some manufacturers' action of terminating services, such as spin-off of service-focused departments. These studies indicate the process for servitization is not a simple process with guaranteed positive outcomes, and an understanding of how to configure the added service would be beneficial to assist the servitized firms in achieving growth opportunities. In addition, most studies in the field of servitization have mainly focused on industrial goods manufacturers, leaving a research gap to investigate into a wider range of industries such as consumer goods (Gebauer et al., 2012b). A large number of researchers investigating successful practices of servitization have been demonstrated with examples from capital intensive equipment manufactured by large corporations, among which the most cited examples including train and flight simulator manufacturer (Davies et al., 2007). It would be interesting to investigate into companies from other industries that have gone through or plan to initiate the process of adding services their offerings.

To sum up, the literature has acknowledged servitization as a way of manufacturing building up the competitiveness and extend revenue stream by going downstream in their value chain. However, several research gaps can be identified. Services in general incorporate higher customer contact and the heterogeneity of customer needs are recognized during the service process, compared with products. The promising revenue stream and competitive benefits have been thoroughly discussed in servitization literature, yet the recognition of customer heterogeneity appears to have received limited attention. Recognizing the role of customization in servitization would be a promising direction. In addition, there remains a paucity of the understanding of the composition of service packages and the factors that are related to the configurations. The generalization of servitization into other industries, such as consumer goods, would be beneficial in enriching the discussion. The following sections will firstly present three models that describe the transition process, followed by discussions about servitization strategies.

### 2.1.2 The transition model from products to services

In the literature of servitization process, two-dimensional frameworks are revealed to be prevalent (Kowalkowski et al., 2015). Companies can be positioned on continuums of product- and process-focused operations, standardization and customization in offering designs, and transactional and relational integrations with customers (Kowalkowski et al., 2015). The concept of product-service transition was proposed by Oliva and Kallenberg (2003), which is based on a recurring pattern identified from a sample of eleven machine manufacturing companies. The transition process has been assumed as a smooth process, with the importance of services increasing gradually, as displayed in Figure 2. The services are focused on the installed base of the product, which refers to the total number of the durable manufactured products currently in use (Ibid). The authors further conceptualize the transition processes of service development into a four-stage model: product-related services consolidation, market entry to the installed base service, IB service offering expansion, and end-user's operation taking-over. The transition process has been depicted as a sequential and systematically planned process. Along with the transition process, the service orientation transforms from product-focused to end-user's process-focused, and the customer relationship changes from transaction-based towards relationship-based (Ibid). Companies start from basic IB services (e.g. machine installation), then chooses either maintenance services (e.g. preventive maintenance) or professional services (e.g. spare parts management) path, and finally transforms into operation services and becomes a solution provider (Ibid).

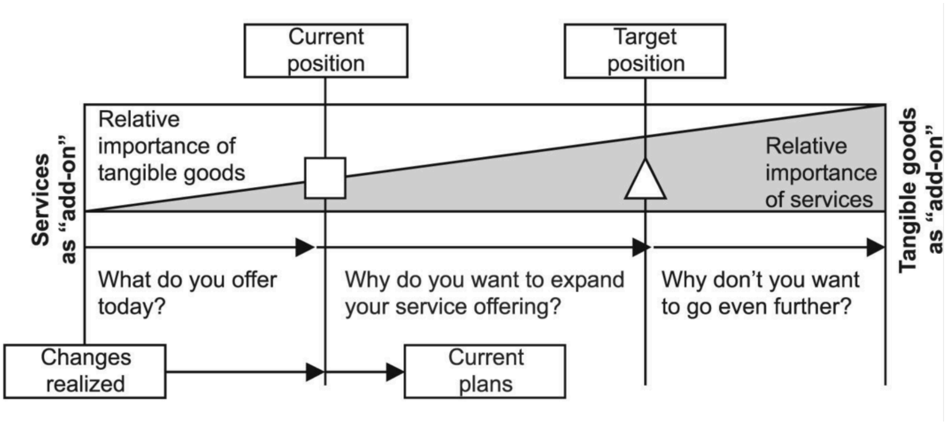


*Figure 2 The product-service continuum*
*Source: Oliva and Kallenberg (2003)*

The model focuses exclusively on the capital equipment industry where the notion of installed base is commonly accepted. Yet in other industries, especially in industries without IB, the transition process might be different. Moreover, the notion of IB tends to assume that product ownership has been transferred from the manufacturer to end-users, which might limit the possibility of offering other type of services, such as leasing and renting, as well as systematic designs of integrated products and services. The concept of product-service system takes a more systematic approach in designing the product-service offerings, which will be discussed in the next section.

### 2.1.3 Product-Service System concept

Product-service system (PSS) can be regarded as a value proposition where the functionality of a product is extended by integrating services into product offering (Baines et al., 2007). Steered by a service-led strategy, the emphasis on 'sale of product' would be shifted into 'sale of use', where customers pay for using an asset instead of ownership. Accordingly, the customers benefit from restructured costs and eliminated risks of asset ownership. Manufacturers would better differentiate themselves from product-based offerings of competitors by providing unique solutions while retaining asset ownership for enhanced utilization.

A PSS is perceived as "a marketable set of products and services, jointly capable of fulfilling a client's need" (Goedkoop et al., 1999, p. 18). The ownership structure is usually changed, and the physical product can be accessed through leasing and rental (Mont, 2002). The corresponding cost structure could also be changed, with more variable costs to the customer and the provider bears more fixed costs. From a more general perspective, PSS could be regarded as a system with integrated products and services that are capable of delivering value in use (Baines et al., 2007; Tukker, 2004). The key elements of a PSS include product, service and system (Goedkoop et al., 1999). A product is a tangible commodity manufactured to be sold and meet customers' needs (e.g. an engine of aircraft). Services refer to activities that are carried out with an economic value on a commercial basis. The activities are essentially intangible and do not result in ownership (e.g. maintenance and repairing). A system is a collection of products and services and the relationship between them, such as the network and infrastructure.

The PSS community emphasizes on exploiting product-service offerings' ability to improve economic and environmental sustainability, which values asset utilization and performance (Lightfoot et al., 2013). PSS has been regarded as a specific type of business model and a special case of servitization, which requires fundamental change of customers' perception of product ownership and manufacturers' organizational reconfiguration for risk adjustment. Servitization and PSS have been regarded as two overlapping concepts, since they both refer to business models of offering integrated products and services (Lightfoot et al., 2013). The notion of servitization has been primarily used in the research field of operations management whereas PSS is more related to engineering and sustainability field (Baines et al., 2009). This thesis follows the operations management field and adopts the terminology of 'servitization' while using the Tukker (2004)'s categorizations of integrated product and service system as a starting point of theory building.

As mentioned previously, the concept of PSS originated in Northern Europe and has been closely associated with the discussions about sustainability and environmental impact. Focusing on changing the consumption pattern into use of product, PSS has been proposed as an innovative business model that could reduce environmental impact of businesses while improving competitiveness (Manzini and Vezzoli, 2003; Mont, 2002, 2004). The 'system' of PSS is mainly concerned with total environmental impact. A functional-focused PSS enables customers to purchase a desired function, result or solution without the need for owning the focal product. The product provides technical functions to customers while services ensure the availability of those functions. Consequently, as suggested by the sustainability literature, material flows of PSS in production and consumption would decrease, resulting in reduced impact on the environment. Manzini and Vezzoli (2003) view PSS as a strategic design method for product and system integration that enables the systematization of existing technologies, leading to innovative configurations of stakeholder relationship, facilitating sustainability in the long term while retaining economic feasibility and social benefits for today. This is evident in the case of Vigga, a Danish start-up company offering a PSS that designs, produces, distributes and recycles baby wear. Users subscribe to a series of clothes deliveries as the baby grows, and the clothes that have been outgrown would be collected, washed and sent to other subscribers by Vigga (Vigga, n.d.). Leasing baby clothes maximizes the use of the product, substantially reduces the waste in the textile industry and promotes sustainability.

Despite the promising resource-efficient outcomes depicted by the sustainability literature, the diffusion of sustainable PSS is found to be limited. Two possible reasons can be identified. First, companies' core business become diverted away from the design and manufacture of the core product. In some industries, the design of the product is essential to the uniqueness and network power (Tukker and Tischner, 2006). Second, in some contexts where product ownership generates intangible value, such as the esteem of owning a stylish car, a PSS without asset ownership might hamper perceived customer value. Compared with traditional product-oriented services, leasing, renting and other types of PSS with less accessibility and more prescriptive instructions on how to behave seem to leave customers with little freedom over the asset (Tukker, 2015).

In summary, PSS is an integrated set of product and services that deliver value-in-use to customers. The distinctions between product and services in the package seem to be blurred, and the typical forms of PSS involves no ownership of the product. The PSS community has underlined the potentials for achieving sustainability and circular economy. The section below combines the servitization and PSS concepts and presents the categorizations of PS offerings.

### 2.1.4 Servitization, PSS and PS offering categorizations

As indicated previously, being both related to product and service integration, the concepts of PSS and servitization overlap to a large extent, and PSS has been regarded as a special case of servitization. Figure 3 demonstrates the relationship between the two concepts proposed by Baines et al. (2007).

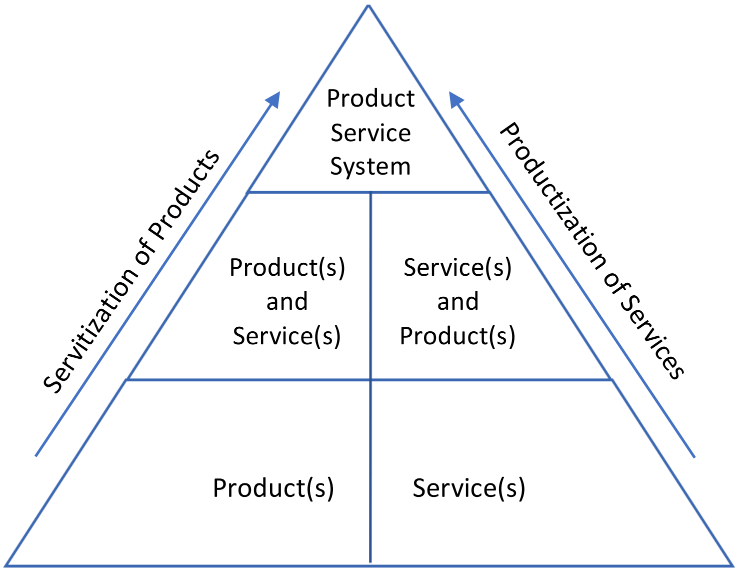


*Figure 3 Evolution of the Product Service System Concept*
*Source: Baines et al. (2007)*

According to the model, the common path towards a PSS starts from the tangible products or intangible services that a company has already offered to the market. At certain point as the competition intensifies, companies would be tempted to maintain competitiveness on the market by starting blending services or products into their offerings to customers. Servitization relates to innovation of capabilities and process of an organization, and it refers to the transformational process where a company shifts from product-centric to service-centric business model (Baines et al., 2009; Kowalkowski, Gebauer, Kamp, et al., 2017). Correspondingly, productization of services is the evolution of adding product components into a service. Spring and Araujo (2009) propose that productization could facilitate service providers in scaling up services (e.g. restaurants opening new branches through franchising) and manage services during peak times when capacity is difficult to change (e.g. student counselling service offering leaflets for stress-handling during exam periods). Other benefits of productization include increased operations efficiency for the service provider, as well as allowing customer to easily understand and assessing the service prior to purchase (Jaakkola, 2011). Furthermore, a tangible product could assist enhance user-experience of the service. For instance, Amazon Echo, a smart speaker produced by Amazon, interacts with users through voice control and assists in users' everyday tasks through Amazon's intelligent personal service – Alexa.

The convergence of the two trends that considers a product and a service as a single offering is termed as PSS, which has been positioned on a spectrum with pure products and pure services as the two ends. Figure 4 illustrates the product-service spectrum by Tukker (2004), which depicts three major types of product-service (PS) offerings that categorizes eight archetypal models.

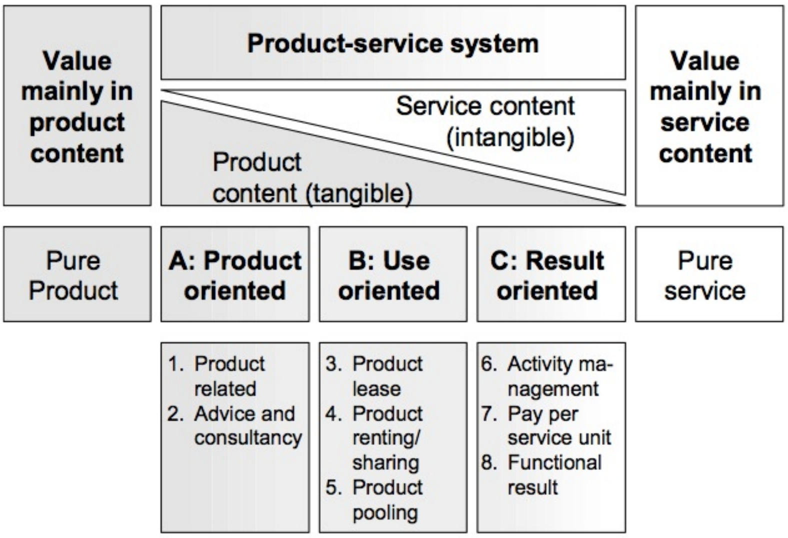


*Figure 4 Main and subcategories of PSS*
*Source: Tukker (2004)*

Different categorizations of PSS exist in literature, and prevalent reviews (e.g. Baines et al., 2007; Lightfoot et al., 2013) acknowledged previous researchers' support on three types, namely product-oriented, use-oriented, and result-oriented PSS. A product-oriented service offering provides supplementary services to current products that is delivered in a conventional manner. The ownership of product transfers from the manufacturer to customer, with the business model primarily focused on sales of the product. According to Tukker (2004), one subcategory is *product-related service* that supports the use of the product, such as contract for routine maintenance. The other type of service is offering *advice and consultancy*, where customers are provided with advice on the efficient use of product. An example of product-oriented services is that IKEA offers old furniture disposal service to customers. The old furniture is removed and disposed by IKEA when delivering the order of new furniture to the customer, who is charged for the amount of furniture serviced by the disposal service. Another example could be the agreement of retrieving healthcare equipment between the supplier and hospital when the equipment becomes obsolete (Reim et al., 2015). Such services create customer value through reduced work in searching and handling transactions with other parties, which might simultaneously induce the customer to upgrade and purchase new products and services. For manufacturers, the extended customer contact builds up customer relationship, and leads to additional opportunities for economic gains. Baines et al. (2007) suggest that the motivation of the service added lies in increasing the durability of the product owned by the customer, and the design of products should consider product lifecycle, with easily replaceable parts being recommended.

In contrast to selling products, a use-oriented PS offering sells the use or availability of a product. Products are positioned central in the business model. The ownership of the product remains with the company, and the availability of the product is sold in different forms. Tukker (2004) distinguishes three subcategories according to the amount of access that users have, namely single, sequential, and simultaneous use. A *product lease* agreement usually grants a particular lessee unlimited access to the leased product. The lessor retains control of the product and is responsible for maintenance and repair. In *product renting or sharing* activities, the product is used sequentially by different users, who are provided with periodic access to the product. Furthermore, product usage could be maximized through *product pooling*, where a single product is accessed by multiple users simultaneously. As noted by Baines et al. (2007), manufacturers might consider creating a PSS that maximize the use of a product and extend the lifetime of the components, for example, using improved design and quality parts.

The result-oriented product-service offering is a prevalent form of PS offering within literature. The provider sells a result or capability that has been agreed with the customer beforehand. The customer receives a customized mix of products and services and the provider receives payment based on the outcomes. Three subcategories are proposed by Tukker (2004). The first type is *activity management/outsourcing*, where the client outsources part of an activity to a third party, such as cleaning and catering activities. The second type is *pay per service unit*, where the customer buys the output of the product based on the level of use. One example is the pay-per-print model adopted by copier producers, who charge the customers according to the usage of the printing service. The last type is *functional result*, where the provider has the complete freedom in how the result is delivered. Total-Care by Rolls-Royce could be an example of delivering the outcome of maximized engine flying time. As having been discussed, the result-oriented PSS has the most promise towards a sustainable and circular economy.

Tukker's categorization depicts a continuum of product and service and the eight types of product-service offerings are grouped and positioned from left to right. From the first to the last type, with services taking up increasingly important role, the share of tangible content decreases, indicating a reduced reliance on product as the core component of the PSS. When reaching the right end of the continuum, the value of PSS is predicted to be virtually placed on services. Although being one of the prominent paradigms of illustrating different forms of PSS, some drawbacks has been identified by scholars. A critique is that the model focuses on describing traits and giving examples of PSS offerings, with some intrinsic values, such as cost and quality, being left out (Lightfoot et al., 2013). The categorizations would be valuable in facilitating an organization position itself, yet provides limited assistance in competitive strategy development and operation configurations. This model echoes with Oliva and Kallenberg (2003) and both suggest that as servitized firms gradually increase the available service packages, customer relations become intimate and long-term based, and eventually the traditional manufacturing companies become a pure service organization. However, the "service transition" assumption along a product-service continuum has been challenged by the literature. Kowalkowski et al. (2015) propose that companies are seeking balance between expansion and standardization, while managing the co-existence of different roles.

With regard to the categorization of servitization, the models by Oliva and Kallenberg (2003) and Tukker (2004) attribute different focus on the dimensions of describing the PS offerings. According to Gaiardelli et al. (2014), the transition model by Oliva and Kallenberg (2003) focus on the categorizing the potential paths where the companies could position themselves during the process of transiting from product seller to service provider, by distinguishing between two dimensions: the orientation of the services (i.e. from product-oriented to end-user's process-oriented services), and the types of customer interaction (i.e. from transaction-based to relationship-based services). By contrast, the model by Tukker (2004) distinguishes the three type of PS offerings on three dimensions: product ownership, the use of product, and the involvement of the customers (Gaiardelli, Resta, et al., 2014).

To sum up, servitization and PSS are two similar concepts used in two domains of research. Manufactures initiate the servitization process by providing PS offerings to customers, and might eventually establish a system of PSS. Both the models by Oliva and Kallenberg (2003) and Tukker (2004) depict the process as continuums of transition which the value added by services continuous increases. Such transition model has been challenged by other servitization literature, which will be discussed in the following section.

### 2.1.5 Servitization strategy

A number of authors have suggested strategies that assist firms' transition alone the line from products to services. For example, taken a business strategy perspective, Rabetino et al. (2016) portray a detailed strategy map for manufacturers undertaking servitization, with the financial return as the goal at the top and supported by activity systems of customer, internal operations and learning perspectives. Servitization has also been studied in the organizational change domain, for example, the framework by Baines et al. (2017) considers context, process and content aspects which facilitate servitization. Gebauer et al. (2007) suggest three types of services for companies seeking to progress on the transition line by Oliva and Kallenberg (2003): after-sales service provider, customer support service provider, and development partner. This categorization is further enriched by Gebauer et al. (2010), which focus on how service strategies correspondents with organizational design factors in manufacturing firms, and suggest five types of service strategies: customer service strategy (e.g. delivery services), aftersales service provider (e.g. spare parts), customer support service provider (e.g. preventive maintenance), outsourcing partner (taking over customer's operating processes) and development partners (R&D-oriented services). The strategies, however, seem to lack of a method of defining and configuring the services that constitute the service bundles.

It has been suggested that the types of services an organization offers to the customer would influence the decisions in choosing servitization strategy and building related capabilities, and Sousa and Silveira (2017) distinguish between basic service and advanced service, based on the means of value co-creation. Basic service (BAS), including maintenance, product installation and provision of spare parts, supports the basic product functionality with limited customer interaction. Value co-creation is restricted to the availability of basic functions that embedded in the product, which is similar to product-oriented services (Ibid). Compared with the standardized BAS, advanced service (ADS) is related to both use-oriented and result-oriented services, which encompasses significant interactions with customers and value co-creation lies in meeting specific customer needs through the adaptation of products and services (Ibid). The findings of Sousa and Silveira (2017) reveal some servitization trajectories that are different from the transition model by Oliva and Kallenberg (2003), which depicts the transition process as a continuum with one position taken by the company at each time. In contrast to the transition process, some servitized organizations adopt a balanced share of BAS and ADS, where BAS is necessary for expanding market penetration and ADS serves to provide higher level of service to customers (Sousa and Silveira, 2017).

The findings by Sousa and Silveira (2017) supports the three trajectories of servitization proposed by Kowalkowski et al. (2015), namely availability provider (i.e. offering a bundle of products and services that are product-oriented), performance provider (i.e. specific offerings to achieve customers' value-in-use), and industrializer (i.e. long-term agreements or contracts to capitalize on accumulated knowledge to create resource-demanding offerings). Moreover, Sousa and Silveira (2017) suggest that through adding different modules of services could a company take up the different strategic roles in servitization. For example, by adding use-oriented service modules to the basic product-based services, an organization can take up the role of availability provider. With performance-oriented modules added to the BAS, an organization can become a performance provider. As for industrializer, offering BAS in a large amount and scale can achieve the strategic goal quickly. The distinctions between BAS and ADS and the configuration of service packages by combining different types of service modules hint the potential role of modularity in PS offerings configuration.

Table 1 summarizes of aforementioned servitization strategy models. It appears that all the models have described PS offerings with the three types of PS offerings: product-oriented, use-oriented, and result-oriented. Some models (i.e. Gebauer et al., 2007; Oliva and Kallenberg, 2003; Tukker, 2004) assume a gradual and deliberate transition process from one type of offerings to another, while the other (i.e. Kowalkowski et al., 2015; Sousa and Silveira, 2017) acknowledge the process as ad hoc, where multiple positions and types of PS offerings are possible for companies, depending on the company capabilities and types of services provided. Some literature has hinted the role of modularity in configuring PS offerings, which will be discussed in the following section.

*Table 1 Summary of some servitization models*

| **Author(s)** | **Proposed servitization strategies** | | |
|---|---|---|---|
| Tukker (2004) | Product-oriented PS offerings | Use-oriented PS offerings | Result-oriented PS offerings |
| Oliva and Kallenberg (2003) | Basic installed base service | Maintenance service & Professional service | Operational service |
| Gebauer et al. (2007) | After-sales service | Customer support service | Development partner |
| Kowalkowski et al. (2015)<br>Sousa and Silveira (2017) | Industrializer<br>• Large amount of BAS | Availability provider<br>• BAS + use-oriented service | Performance provider<br>• BAS + performance-oriented service |

### 2.1.6 The potential for modularity in servitization

The former section discussed five categorizations of servitization strategies, which differentiate the different PS offerings primarily from the orientation of the offerings (i.e. product-, use-, service-oriented) from the perspective of the manufactures. One aspect seems to be missing is the recognition of customer individuality. Featuring IHIP, services usually require higher customer contact, and to provide quality services, the variations in customer demands require vigilant management attention. The process of capturing customer heterogeneity is rather complicated, which generally requires transitions to relationship-based transactions, process oriented services, and result-oriented offerings (Gaiardelli, Songini, et al., 2014). In addition, as technologies continue evolving, such as the application of artificial intelligence to learn the customer preferences and continuously adapt the PS offerings, the nature of products and services would be inevitably more complex, which further pose challenges to companies' capabilities for designing and providing integrated PS offerings.

The impact of product and service complexity on servitization has been recognized in some literature. Raddats et al. (2016) maintain that manufacturers with different degrees of product complexities follow varied motivations for servitization. They propose a product categorization model that distinguishes between non-complex products and complex products and systems (CoPS), with the latter being further decomposed into complex products and systems. CoPS is defined as complex product offerings or systems with highly customized components, which are use-oriented and result-oriented in nature. On the other hand, the 'non-complex products' are rather loosely referring to the products which does not meet the characters of CoPS, leaving the exact features of non-complex products undefined. A better categorization of products could be proposed by investigating further into the nature of complex or non-complex architecture of a product or system through the lens of modularity by decomposing the complexity into constitutive subsystems and components.

With regard to the efforts to recognizing customer individuality, providing customized product and services in on a large scale and with an efficient manner could be the solution. Mass customization, as proposed by Pine (1993), provides a way to answer customer needs in a cost-efficient manner, and the best way to achieve mass customization is through creating modular components, from which a variety of products and services can be configured.

The interests in applying mass customization by modularity in servitization has been rising. Frandsen (2017) reports that the presence of service modularity is growing among manufacturing companies, and service modularity's role in decoupling the service complexities is promising. In managing business operations processes, modularity has been regarded as source of strategic flexibility that allows rapid response using the combinations of existing modules (Sanchez and Mahoney, 1996). Rabetino et al. (2016) find that servitized companies build a portfolio of modular products and services for the goal of scaling up of a solution and achieving production agility. The flexibility of modularity has also been exploited in the design of product and service systems. From a case study of an elevator company, Song and Sakao (2017) reveal that by incorporating modular processes into the design of an integrated PS offering, the service provider can increase design efficiency by reusing modules, as well as achieve optimized customization through modifying the existing offerings. Additionally, Salonen et al. (2017) adopt a strategic learning perspective in exploration of new models while exploiting the existing services, and highlights the role of an servitized organization in integrating the modular service offerings in the supply network. These findings imply that the flexibility in product and service configuration using standardized modules can benefit companies with efficiency in production while recognizing customer individuality in servitization.

Although the literature has realized the benefits of modularity in servitization, there have been few investigations into modularity from product and service architecture perspective. Recognizing this gap, this thesis strives to dismantling the complexity of product and service systems, describing the characteristics of product and service, and proposing possible ways to configure PS offerings and servitization strategies. The following sections review the modularity literature, from which the characteristics of modular and integral product and services are derived.

## 2.2 Modularity

The changing needs and preferences of consumers, such as consumers' lifestyle upgrading in developing countries resulted from an elevated level of income, and the advance of technologies in production and processes, are posing challenges for managers to navigating the increasingly complex business world. Other than being price-focused only, consumers are also attributing values in the intangible part of the purchasing activities, such as the comprehensive services associated with a product and the possibility of customization. Starr (1965) recognizes the trend in consumers demanding for maximum number of possible choices of product varieties, and identifies modular design and production of interchangeable parts, which allow for a maximum number of combinatory ways, as a response to the heterogeneous customer demands. In such context, the concept of modularity provides an approach to manage complex products and processes effectively through decomposing a complex task into smaller tasks that can be managed independently while serve the functionality as a whole (Baldwin and Clark, 1997).

The concept of modularity originated in the general complex systems theory by Simon (1962). Simon (1962) suggests that the complexity of an organizational structure is closely related to the interdependencies between elements and the interfaces in the subsystems. By decomposing the hierarchical systems into substitutive subsystems, the complexity of the system can be effectively reduced. Previous literature has interpreted modularity from different perspectives, including product modularity, process modularity, organization modularity, and service modularity (Bask et al., 2010). The following sections will firstly briefly discuss the four perspectives, then product and service modularity will be highlighted as the level of analysis used in this thesis.

### 2.2.1 Defining modularity: five dimensions

Scholars from a wide range of disciplines have studied modularity in different contexts (Frandsen, 2017). Five dimensions have been discovered existence in the research area of modularity: components and systems, degree of coupling, interfaces, commonality sharing and platform (Voss and Hsuan, 2009). Viewing from the system perspective of modularity suggests that virtually all complex entities could be regarded as systems, and the structures of most systems are hierarchic that could be subsequently decomposed into sets of subsystems (Simon, 1962). A system can be defined at industry, organization, and product level (Schilling, 2000). A complex system consists of various components that engage in interactions with others and act accordingly, and a nearly decomposable system, as defined by Simon (1962), denotes weak yet not necessarily negligible interactions among the subsystems. Following on this notion, Sanchez and Mahoney (1996) see modular systems as being decomposable with loosely coupled components, featuring a high degree of independence that has been intentionally created by standardizing interface specifications. The components are primarily recognized as the physical components in a product architecture, and it could also refer to the basic process that composes a service architecture.

Modularity has also been viewed in terms of degree of coupling. Schilling (2000) perceives modularity as a continuum outlining the extent to which the components of a system that are allowed to be separated and recombined. The possibility of disaggregating and reconfiguring are contingent on the tightness of coupling between the components, and the freedom of mixing and matching promised by the modular design rules (Schilling, 2000). Degree of coupling indicates the tightness of connection and the degree of interdependence among the constitutive components and related interfaces (Voss and Hsuan, 2009). The degree of coupling underlines the extent to which the design changes of one component would consequently require changes of other components. A high degree of coupling is created when a component is dependent on the interactions with many other components to perform a function. With a number of interfaces involved, the components are highly interdependent in a tightly coupled structure, which are often found in integral architectures (Mikkola, 2003b). A modular architecture features loosely coupled components carrying out specified and allocated tasks that can be substituted individually.

Interfaces link the components with embedded design protocol for interactions, and it is defined by Ulrich (1995, p.419) as "the scheme by which the function of a product is allocated to physical components". The standardized interface specifications of a modular architecture create embedded coordination through loosely coupled component designs (Sanchez and Mahoney, 1996).

The notion of commonality sharing extends the focus of product architecture into multiple products or a product family, within which the same version of certain component is commonly shared (Voss and Hsuan, 2009). This concept echoes the concept of substitutability by Mikkola (2003b), which denotes the extent to which the same components can be used across the product family. The sharing of standard components would lead to economies of scale, and economies of scope could be achieved by sharing unique components (Voss and Hsuan, 2009). Other advantages include accelerated speed of product development and shortened lead times (Voss and Hsuan, 2009). Salvador (2007) discusses the definition of modularity in terms of component separability, i.e. using standard parts across a variety of products, and component combinability, i.e. maximizing the variants of output from a set of components. Separability indicates that the product configuration of a variant could be first built in modules and subsequently assembled for the final product. Combinability implies that different products are produced at a minimized level of modularity differences.

Featuring easily interchangeable modules, a modular architecture lays the foundation of developing an extensive portfolio of offerings by leveraging a platform approach (Cenamor et al., 2017; Mikkola and Skjøtt-Larsen, 2006). In a board term, the concept of platform encompasses the shared intellectual and material assets across a product family (Krishnan and Gupta, 2001). Examining from a product architecture perspective, platforms incorporate the components, subsystems and interfaces shared by a stream of products (Mikkola and Skjøtt-Larsen, 2006). A variety of products can be developed and manufactured in a flexible and efficient manner by sharing components and production processes across platforms (Robertson and Ulrich, 1998), serving the requirements of users in respective market segments. With a modular product architecture, product flexibility and changeability are built, leading to a robust product platform and subsequently successful product families.

Product families include collections of products sharing the same assets, and within each product families, platforms are used to balance the choices between commonality sharing and differentiation (Halman et al., 2003). Companies are motivated to adopt platform development based on the benefits of: product cost reduction, enhanced NPD efficiency, and increased flexibility in product launching (Halman et al., 2003; Muffatto, 1999). For example, Philips launched a platform for Dental Care business that realized an average cost reduction of 53 percent through mass-production of shared common components, while achieving expanded product variety with shortened lead times (Sanchez, 2004).

Concluding on the five dimensions of a product architecture, modularity is defined as "*the scheme by which interfaces shared among components in a given architecture are standardized and specified to allow for greater reusability and commonality of components among product families*" (Voss and Hsuan, 2009, p. 543). The emphasis on managing the variability of outputs through mixing and combining parts during in assembly has been depicted as the core of mass customization (e.g. Mikkola, 2007; Da Silveira et al., 2001). In addition to focusing on increasing the commonality across product variants within a product family, operations management research have also highlighted the flexibility of designing loosely coupled production system (Salvador et al., 2002). It appears that in the modularity literature there is a consensus that product modularity is closely related to the standardization and substitution. Therefore, this thesis defines product modularity as *the use of standard components to configure varied outputs through mix and matching across product families.* This definition assumes the concepts of standardized interfaces and loose coupling among components.

The production and marketing of modular products appear to influence the knowledge and information processing structure of an organization, which has been described in mirroring hypothesis (Baldwin, 2008). The task structures are determinants of the communication and information exchange pattern (Fixson, 2005). The standardized and fully-specified interfaces in a modular product architecture creates the information structure which would consequently bring together the loosely coupled parts of a modular organization. The departments of developing product components would coordinate in a self-organized and efficient manner through specialized processes for knowledge creation and application, alleviating the needs of cross-interface management (Sanchez and Mahoney, 1996). Therefore, the mirroring hypothesis postulates that organizations that develop modular products tend to have a modular structure. In addition, the empirical findings by Jacobs et al. (2011) suggests that an increase in product architecture modularity results in increased process modularity, which would then contribute to operations agility.

To sum up, modularity refers to decomposing complex system into distinctive components. Modular architecture allows for freedom of disaggregation and recombination of components, which is captured in degree of coupling. With standardized components and interfaces, components can be shared across product families and used for a variety of product configurations. Focusing on product modularity level, the next section describes product architecture and the characteristics of two types of products with opposite types of architectures.

### 2.2.2 Product architecture: modular and integral

Product architecture, viewing from a nominal perspective, considers the number and types of components to be used, and the interfaces between components of a product (Fixson, 2005). A product design perspective of modularity exams the architecture, components and interfaces of a product. According to Ulrich (1995), the architecture of a product specifies the schemes of functionality allocation of a product, including 1) the arrangement of functional elements; 2) the mapping of functional elements to individual physical components; and 3) the specifications of the interfaces where the interactions of components are created. The purpose of describing a product architecture is to define the basic building blocks, or the modules, and the interactions between the components through interfaces (Sanchez, 1999).

A module consists of a group of components that could be adjusted or switched without destructing the overall systematic functionalities (Bask et al., 2010), in other words, it features interdependence between the elements within a module and independence across different modules (Baldwin and Clark, 2000). This thesis defines a module as *an interchangeable collection of components in a system that serves a specific function*. This definition embraces the decomposition of the overall functionalities into individual components and the assumption of standardized interfaces.

Modularity in product has been interpreted from various perspectives. Some authors have focused on the impact of modular product architecture in assisting the new product design (NPD) within a firm (e.g. Baldwin and Clark, 1997; Mikkola, 2006; Mikkola and Gassmann, 2003; Ulrich, 1995). Others have highlighted the relevance of interfirm product modularity and component outsourcing based on standardized interfaces (e.g. Mikkola, 2003a; Schilling, 2000). Despite the distinctions, most of the products are positioned between the two extremes of perfectly modular and integral architectures (Schilling, 2000; Ulrich, 1995).

Following the abovementioned definition of product architecture by Ulrich (1995), distinctions between modular and integral product architectures could be drawn. A modular product architecture encompasses one-to-one mapping from product functionality to physical components, with specified and decoupled interfaces in between. The components are highly independent such that one component can be easily changed without affecting the other components. For example, the components of PCs such as hard disks and keyboards can be relatively easily changed without undermining other components and overall performance.

Compared with the modular architecture, an integral architecture features a different way of mapping (many-to-one or one-to-many) and less clearly specified interfaces, and the physical parts are generally tightly coupled (Campagnolo and Camuffo, 2010). The functional elements of the product architecture are generally carried out using more than one components. Due to the interdependence, the change of one component will inevitably affect other components. The integral architectures are designed with the goal of either to achieve the highest level of performance under the constraint of costs, or to meet the minimum performance constraint at the lowest costs (Sanchez and Mahoney, 1996). Such optimization is created by combining multiple functional elements (Mikkola, 2003b). In addition to being performance- or cost-optimized, an integral product with closely coupled components would usually be more compact than comparable modular products, resulting in better aesthetic features. For example, Apple Inc. is well-known for designing stylish consumer electronics with high performance. Since the first 1984 Macintosh model to the later model iMac, Apple's desktops adopt a highly integral architecture, with CPU and monitor hosted in a single unit. In contrast, the conventional desktop PCs use a modular architecture that regards CPU and monitor as two separate modules. An integral design reduces the need for signal transmitting between modules through cables, resulting in an all-in-one appearance that is compact and sleek. However, as the nature of integral architecture promises, it would be virtually impossible for regular users to change or upgrade different parts of the iMac in isolation, whereas the modular-designed PCs require relatively less effort to change the obsolete parts at the users' preferences.

In this section, modular and integral product architectures have been explained. With the one-to-one mapping from functions to physical components, modular architectures allow for changing components in isolation. By contrast, integral architectures usually score better in terms of performance and aesthetics, as a result of the integrated and complex functionality mapping. The section that follows moves on to highlight the advantages of adopting modular product architectures.

### 2.2.3 Advantages of modular product architecture

Pursing modularity in manufacturing processes have many benefits, and flexibility and adaptability are among the most mentioned ones. The decomposition the total function into distinctive modules creates standardized and substitutable modules, which promise flexibility, economies of scope and scale, cost reduction through platform strategy, and potentials for mass customization.

Using a modular product architecture, manufacturers can receive the benefits of flexibility in product configuration, new product development process, as well as choices in choosing suppliers. Product variants can be created through mixing and matching of existing modules in an efficient manner (Sanchez and Mahoney, 1996) while responding to customer requirements (Mikkola, 2007). In terms of new product development, the example of the computer industry adopting modular designs by Baldwin and Clark (1997) demonstrates that the ability to experiment with different modules is essential to react to the high technological uncertainty, as well as to encourage innovation in design. The competence to quickly respond to market and technology changes through new combinations of components would subsequently contribute to organization flexibility (Baldwin and Clark, 1997; Garud and Kumaraswamy, 1995). In supply chain management, modularity product architectures are found to extend the choices in choosing and switching suppliers, and lays considerable potential in collaborating with suppliers (Mikkola, 2003a).

With a flexible architecture, it is likely that costs related to manufacturing, substituting, and developing new components will be reduced. By breaking down functions into modules, the products could be designed with substitutable components, which leads to economies of substitution (Garud and Kumaraswamy, 1995). The economies of substitution are realized when selectively retaining and reusing certain components incurs less costs than creating a complete new system design. The retention of components leverages the knowledge of existing components and saves costs through routinized production (Garud and Kumaraswamy, 1995). In addition to reduced manufacturing costs, the well-specified interfaces in modularity enables flexibility in choosing suppliers and outsourcing of technologies and processes, which saves switching costs and transactions costs (Baldwin, 2008). In addition, loosely coupled interfaces reduces complexity and uncertainty in the production process, which lowers the chances for failures and production costs (Fixson, 2005).

Modular product architecture has also been viewed as a complement or prerequisite to set up the platforms that supports the configuration of product variants (Mikkola and Skjøtt-Larsen, 2006; Muffatto, 1999; Sanchez, 2004). The automobile industry is featured with modularity and platform manufacturing. As a modular product, cars share components across models from the same platform. For example, Volvo Cars has built two automobile platforms, the Scalable Product Architecture (SPA) for full-size cars and Compact Modular Architecture (CMA) platform for mid-size cars, which enable all the cars to be built with modular vehicle architectures (Volvo Cars, 2015). Using platforms benefit Volvo with the flexibility in devising a variety of models, innovation in components, and economies of scale using streamlined production processes.

The flexibility in architecture modularity also lays the grounds for mass customization, which fulfils the idiosyncratic needs of customers while maintains efficiency and low costs in production processes (Schilling, 2000; Starr, 2010). Mass customization is related to providing customized products and services in an agile and quick responsive manner (Da Silveira et al., 2001). By applying single standard components in configuring a variety of products and services, mass customization benefits companies with increased output and shortened throughput in the production process (Pine, 1993). Modularity provides a means to repetitive production and standardization for scale production, and customization is achieved through the combination of modules (Duray et al., 2000). In addition to economies of scale at component level, using common components creates economies of scope across product lines (Pine, 1993; Sanchez, 1999). Modular product architectures enable the use of modular product platforms, which provides the opportunities of reusing standard designs and share common components across product families (Løkkegaard et al., 2016).

The modular headphone system by AIAIAI is a good illustration of mass customization through modularity. Introduced in 2015, the modular headphone TMA-2 is composed of four standard modules: headbands, speaker units, ear pads and cables, with multiple options to for each of the parts that can be swapped with ("TMA-2 Modular Headphone System | AIAIAI Headphones", n.d.). The configurations of the headphone can be created through mix-and-match of parts and customized to produce different sound profiles according to customers' preference. In addition to configure an entirely customized headphone, customers have the options to choose from a range of preconfigured models and special editions collaborated with musicians. Another service is to recommend headphone configurations by analyzing the customers' music profile from Spotify playlist data ("TMA-2 Discovery | AIAIAI Headphones", n.d.). By mixing-and-matching the components of the modular headphone, a large number of product variants can be created and configured effortlessly to meet customer needs.

Given the appealing advantages, limitations of modular product architectures should not be ignored. Modular systems are significantly more challenging to design than interconnected systems, since to specify and design the inner process require significant knowledge and clear definition of design rules (Baldwin and Clark, 1997). Competitors' imitation of new products could be hardly prevented, yet with a modular architecture it might be more difficult to protect the design of the specified functions and components. The independencies between components and subsystems reduces structural complexity, making it relatively easy for competitors to decipher (Pil and Cohen, 2006). In contrast, for an integral product, the embedded architectural complexity might make it more difficult to be reserve engineered than a modular architecture with standardized interfaces and components.

To sum up, the advantages of product modularity is closely related to flexibility and adaptability, which lead to operational, economic, and competitive benefits. A modular architecture allows for substitution of components, which is fundamental to platform strategy and mass customization. Economic benefits are brought by scale production and efficient reuse of modules across product configurations and platforms. The potential related risk is competitors' imitation and deciphering of the architecture. The next section will present the characteristics of modular and integral product architectures.

### 2.2.4 Characteristics of modular and integral product architectures

#### *2.2.4.1 Use of standard and unique components*

According to Mikkola (2006), standard modules refer to existing components in the product architecture of a company, and unique modules are components introduced to the firm or being created for the first time. The concept of standardization is an inseparable attribute to a modular architecture. Modularity creates the possibility to repetitive use and production of standard modules (Duray et al., 2000), whereas for a more customizable product, unique components are required to contribute to product-specific aspects (Mikkola, 2006).

Both modular and integral products provide the customers with possibilities of customization, although the degree and costs vary. The benefits of modularity in reducing production costs while maintaining the possibility of offering tailored products to customers have been acknowledged in mass customization literature. Scale and scope production could be achieved through substituting standard modules that are mass produced, leading to high volume output, and a high number of product variants. For an integral product, it may require specific process and tooling to create unique product that is usually low volume. Moreover, the integral nature of architecture requires adjustment of more than one components to achieve an improvement in functional performance (Mikkola, 2003b), Therefore, for a modular product, the number of standard components used is high, and for an integral product, a relatively high number of unique components will be found.

#### *2.2.4.2 Mass customization and product variety*

While the generic business strategies can vary from a differentiator to mass producer, companies find themselves on a continuum of standardization and customization (Lampel and Mintzberg, 1996). One strategy of recognizing board customer needs is mass customization, which exploits the flexibility of modularity in product and service architectures (Pine, 1993). Mass customization enables companies to achieve customer responsiveness at high volume production in a cost-efficient manner.

Depending on the manufacturing process, mass customization can serve different purposes in pull- and push-manufacturing systems (Mikkola, 2007). In a pull (engineer-to-order) system, customer specifications are influential to the fabrication of a customized product, and the degree of customization is reflected by the point of customer involvement in the product cycle (Duray et al., 2000). By contrast, a push (make-to-stock) strategy focuses on the manufactures' design decisions and ability to control the product architecture for customization (Mikkola, 2007). The focus in this thesis is the push strategy and the related possibility of product mass customization.

As modular architectures enable easily disassembly and recombination of components, new configurations and a large number of product variants can be easily produced without tremendous changes in other components. In a push strategy, the firm has the control over the amount of customization available to the customers by deciding the components used for customization (Mikkola, 2007). When considering the value chain of a manufacturing company, five main stages can be identified: new product development (NPD), production, assembly, distribution, and customer (Mikkola, 2007). The balance between productivity and flexibility can be achieved by deciding the position of customer order decoupling point (CODP). CODP is related to the stage where customers order is received and the customized goods can be designed and manufactured accordingly, and four frequently used types are: engineer-to-order (ETO), make-to-order (MTO), assemble-to-order (ATO) and make-to-stock (MTS) (Fogliatto et al., 2012). In mass customization, the order decoupling point occurs at downstream of the value chain, which allows postponing customization and standardizing production process before the order decoupling point (Mikkola, 2007). Companies achieve productivity in operations from the point before CODP in the value chain, while maintaining necessary flexibility from the activities after CODP (Rudberg and Wikner, 2004). Acknowledging the important role of customer involvement in mass customization, Rudberg and Wikner (2004) distinguishes CODP on two dimensions to describe engineer-related and production- related customizations, and the degree of customization is decided by the position of the CODP.

As suggested by Rudberg and Wikner (2004), to fully achieve mass customization in practice, it is essential to use modularity architecture and flexible production system to integrate customer involvement with the cost-effective production system. A modular product has the high potential to be mass customized, whereas for an integral product, it is literally impossible to mass-customize by combing constitutive components. A large variety of the modular product can be configured by combining different standard components. As for the degree of customization, for a modular product, the CODP can occur at the downstream of the value chain, implying the possibility to apply the value-add activities based on forecast and use ATO. Such position of CODP also allow for higher degree of customization by combing selected components. By contrast, for integral products, the production is usually MTS and customers are only given the choices to few product varieties that cannot be configured and customized individually.

#### 2.2.4.3 Use of product platform and components sharing

Platforms incorporate the organization of components and interfaces of a product architecture, and platform strategy is the means to achieve mass customization (Mikkola, 2007). Through strategically partitioning the product architecture into common components and varying components, an organization could implement mass production, reducing production costs while attaining a significant number of product variations (Sanchez, 2004). The extent to which the product families are standardized and customized are subject to the configuration of the platform, which includes how the technology are configured and how the interfaces are designed among the subsystems products (Mikkola and Skjøtt-Larsen, 2006). In a modular product architecture, the functional elements are decoupled, enabling the separation of common components to be shared across the platform, and unique components that are maintained exclusively for certain product lines. Therefore, a modular product appears to have a high number of components that are shared across the product family. Whereas for integral products, the coupled functions made it difficult to share the components for the product family, therefore, a low number of product family and component sharing is expected.

#### *2.2.4.4 Summary*

Table 2 sums up the characteristics and portrays of integral and modular products at two opposite ends of the continuum. Modular products use a large number of standard components, and the loosely coupled modules underlines a high potential for mass customization through mixing-and-matching at the assemble stage. The degree of customization is high, with CODP occurs at the assemble stage for configuring customized products. The product family are quite common and components sharing are abundant. By contrast, an integral product incorporates a small number of standard components that can be substituted. The coupled components and less specified interfaces result in low possibility for mass customization. Components sharing across product family tends to be less obvious or in a small scale.

*Table 2 Characteristics of product systems.*
*Adapted from Hsuan et al. (2012)*

| Characteristics of product systems | Integral products | Modular products |
|---|---|---|
| No. of standard components | Low ⟷ | High |
| Possibility for mass customization | Low ⟷ | High |
| Degree of customization | Low ⟷ | High |
| No. of product variants | Low ⟷ | High |
| Components sharing across product family | Low ⟷ | High |

In this section, the product architecture and modularity has been defined. Modularity benefits companies with flexibility in components production and product variants configuration.

Modularity also allows for mass production of components, from which customization can be achieved cost-efficiently by mixing-and-matching. The characteristics of modular and integral products have been described and compared. The section that follows moves on to consider the other pillar of PS offerings – the services.

### 2.2.5 Service architecture and modularity

The global economy has witnessed the uprising significance of services, together with increasingly diverging customer needs, which have resulted in the rising demand of efficient service processes with customized aspects (Bask et al., 2011). The service sector is predicted to continuously grow, at the same time the growing complexity of service systems requires effective methods to deal with service delivery and innovation (Løkkegaard et al., 2016). Delivering superior services to customers is on the agenda of all the service providers in the competitive landscape. It is especially relevant for manufacturers that are making effort to enter new competitive markets through servitization, to understand how to enhance value delivered to customers through combing services into products. The provision of services that is flexible and customizable to realize heterogeneous customer requirements in an efficient and standardized manner is the goal of service modularity (Pekkarinen and Ulkuniemi, 2008). The following sections will introduce service decomposition, interfaces and platform, as well as advantages of using service modularity in operations.

#### *2.2.5.1 Service decomposition*

The service modularity literature has been studied through different lenses. Decomposition level, platform thinking and customer perspectives are identified as the research topics by Brax et al. (2017). Similar to a product architecture, a service architecture encompasses the decomposition of system functionalities into individual elements, ranging from modular and integral (Voss and Hsuan, 2009), and the service interfaces, standards and technologies (Tuunanen et al., 2012).

With regard to the decomposition logic, a three-step process has been suggested by Eissens-Van Der Laan et al. (2016). First, the boundary of the focal system is to be defined in the dimensions of the service bundle and interactions between the customers and service provider. Second, the subsystems within the service offering are defined and the functional parts are identified. Third, the interdependencies between the modules are categorized (pooled, sequential and reciprocal) and minimized. By decomposing a service into distinctive parts, the degree of modularity of a service could be investigated under further scrutiny. This thesis will follow this decomposition logic in the case analysis. Voss and Hsuan (2009) propose four levels of service decomposition: industry, company and supply chain, service component, and service module.

The first level of decomposition is industry level, which considers value creation, division of labor, and value appropriation among multiple players, which are connected by the interfaces consisted of regulations and standards (Voss and Hsuan, 2009). For example, mortgage banking industry and investment banking can be viewed as modular financial instruments, which grant investors the freedom of mixing a portfolio from stocks, bonds and risk-free assets to match the expected return and risk. At service company and supply chain level, the organizational architecture of a company as well as the whole supply chain are the focus of analysis. With well specified and standardized interfaces, a modular organization can use subcontracting and outsourcing in a flexible manner while remain focused on the core processes (Pekkarinen and Ulkuniemi, 2008). The next level of disaggregation considers a set of service modules, in other words, a service bundle. For example, amazon prime offers a bundle of service modules including media streaming, e-books, and cloud storage space to subscribers ("Amazon Prime", 2017). At the service component level, the focus is on the basic building blocks. The service components can be regarded as the smallest and distinctive standardized processes that collectively provide a feature in the service. Similar to a product module, a service module could also be regarded as a building block in the service system, and features standardization, uniqueness, degree of coupling, and replicability (Voss and Hsuan, 2009). A service module can be defined as *"a system of components that offers a well-defined functionality via a precisely described interface and with which a modular service is composed, tailored, customized, and personalized"* (Tuunanen et al., 2012, p. 101). This definition highlights the role of standardized interface in connecting the different service modules, and lays the foundation for further customization. For example, the set of available pre-booked activities offered by tour operators can be considered as modules in a tour package, and customers can choose extra activities (i.e. service modules) through a manual sign up list (i.e. the standardized interface) (Avlonitis and Hsuan, 2017). For the purpose of analyzing service configuration in servitization, this thesis focuses on service bundle and service component levels.

#### 2.2.5.2 Service interface and platform

Interfaces prescribe the interactions between components or service providers. The various components that compose a final product are connected through interfaces, and in a modular product architecture the interfaces are standardized, enabling substitution and components exchange (De Blok et al., 2014). In service modularity, other than enabling components substitution, the interface is expanded to include people, information and governing gules for the information flow (Voss and Hsuan, 2009). For example, in the context of health care, when transferring patients from one care provider to another, well-defined guidelines and protocols are required to ensure proper handling, as well as to maintain the continuity of service module delivery (De Blok et al., 2014). Interfaces defines the flow of customers and interactions with service modules, as well as the information exchange between service packages (De Blok et al., 2014).

Platform thinking in services has been attributed to growing research attention, and a new service business model of becoming a platform provider has been demonstrated by companies such as Amazon and Airbnb (Brax et al., 2017). Platforms incorporate a set of subsystems and the interfaces in-between (Pekkarinen and Ulkuniemi, 2008). Through sharing service modules between platforms, companies benefit by increased flexibility and responsiveness in meeting customer requirements, as well as the ability to provide customized services at lower costs through volume production (Pekkarinen and Ulkuniemi, 2008). As maintained by Pekkarinen and Ulkuniemi (2008), leveraging on the same modular service platform, standard, mass-customized and tailored solutions can all be accomplished by selectively adding modules with unique features to the standardized interfaces.

Different frameworks of modular service design have been suggested by literature. For example, Voss and Hsuan (2009) propose a two-dimensional categorization that consist of the choices of the timing of service to be consumed and a consecutive consumption of a service component. When considering how a service is designed, Tuunanen et al. (2012) identify service module, service architecture and service experience as the three components in a modular service design. Recognizing the mass customization potential of modular services,  Bask et al. (2011) develop an matrix that combines degree of service modularity and degree of customization. A more comprehensive model proposed by Avlonitis and Hsuan

(2017) categorizes the sequence of service based on the position of a service encounter, i.e. before, during and after the service encounter. However, the models mentioned remain narrow in focus dealing only with service as the single component in an offering to customers. When considering servitization, product and service are integrated into the same offering, and the types of services remain to be further explored under the influence of the servitized product.

#### *2.2.5.3 Advantages of service modularity*

Incorporating customization into services is not an easy task. When the offering is overly customer-specific, the replicability of the service is hindered; lack of well-defined processes and service structure undermines operational efficiency and central planning (Böttcher and Klingner, 2011). Service modularity brings the benefits of mass customization, and the opportunity for outsourcing in the company level.

Implementing modularity in services can improve efficiency in service package configurations by reusing modules. The service bundle defines the content and the projected outcomes that customers will receive from the service. The configuration of the components in a service package should reflect the customer needs, where mass customization resulted from modularity plays a crucial role. When the service modules are clearly defined and connected with standard interfaces, individual service bundles can be created by combing the standardized modules that are mass produced (Pine, 1993), yielding economies of scale and scope (Voss and Hsuan, 2009). The service modules can be reused in creating and delivering a variety of service bundles, which accelerate the development cycle for new services (Böttcher and Klingner, 2011). Focused process improvement can be achieved by reinventing the specific components in a service package. Two methods of customization can be summarized from the service modularity literature. First, a menu of options is offered to customers, and the service employee combines appropriate modules that suits the customer specification in the service package (De Blok et al., 2013). A variety of service can be configured through combining a set of predetermined standard service components. The second method is by presenting customers a service prototype with the possibility to change the standard components and add unique modules in the service package (De Blok et al., 2013; Voss and Hsuan, 2009). When adding a modular lens to strategic planning, an organization could build competitiveness through: 1) the possession of unique service modules that are hardly imitable in the short run; 2) the ability to replicate the unique modules across multiple services or sites; 3) the possession of a degree of modularity to support customization and rapid NPD (Voss and Hsuan, 2009).

Service modularity on organization level enables outsourcing. To provide modular services, the organization design of service provider is expected to incorporate some degree of modularity with loosely coupled subsystems (Pekkarinen and Ulkuniemi, 2008). The loosely coupled company structure allows for flexibility in allocation of resources (such as service personnel) and capabilities in outsourcing some processes to other participants in the network (Bask et al., 2010; Rahikka et al., 2011).

To sum up, from a modularity perspective, services can be decomposed from different levels. A standardized interface governs the flow of customers and service modules, and by leveraging on platforms and sharing modules, both mass customization and tailored solutions can be accomplished. The next section obtains insights from service management literature with regard to the elements of service processes.

#### *2.2.5.4 The classic categorization of service processes*

The operations management literature has categorized the classic manufacturing process types into project, jobbing, batch, line and continuous process (Slack et al., 2015). The five processes can be plotted diagonally on a graph that demonstrates the correlation between product volume and variety. In service operations literature, different typologies have been proposed, and Silvestro et al. (1992, p. 67) describe six service dimensions as:

1. Equipment/people focus;
2. Customer contact time per transaction;
3. Degree of customization;
4. Degree of discretion;
5. Value added back office/front office;
6. Product/process focus.

The core element in delivering a service can be an equipment (e.g. ATM for cash withdrawing) or people (e.g. management consulting). In a high customer contact service system, the customer remains in the system for a relatively long period of time, comparing with a low customer contact service. For example, the initial public offering (IPO) service has a high customer contact. The investment bank usually works with the customer (the private company) for months to prepare for all the required documentations and evaluations. By contrast, currency exchange services in consumer banks can be quickly carried out in a standardized manner. In a highly-customized service, the heterogeneous customer needs are recognized and configuration of service delivery are adapted accordingly, while in a service with a low degree of customization, standardized and predetermined processes are prevalent. The degree of discretion is related to the judgement of front-office personnel and the ability to alter the service process. Such staff discretion can be related to the concept of personalization, which refers to the modification of interpersonal behavior to better response to the interactions with customers (Voss and Hsuan, 2009). When customer contact is crucial in delivering the service, the front-office staff would contribute to a larger proportion of value added than the counterparts in back office, making the service front-office-oriented. The last dimension differentiates between product- and process-oriented services, focusing on what the customer buys and how the service is delivered respectively.

Using the six dimensions of services, Silvestro et al. (1992) propose three typologies of service process: professional services, mass services, and service shops. Professional services, such as corporate banking and R&D services are highly customized, with relatively long customer contact time and low transaction volume. By contrast, mass services offer little customization, short customer contact time, and high transaction volume. Examples include public transport and newsletter delivery. The service that lies in-between the two extremes is service shops, with examples including hotels and rental service, which incorporate medium level of customization and customer contact. However, the volume-variation plotting in product process is not perfectly applicable to some services. As the transaction volume of a service increases, the service provider will not necessarily change the process of a service, since for some services, the same business practices can be replicated to fit the increasing demands. Therefore, as pointed out by Collier and Meyer (1998), the structure of the service system affects the service encounters. For example, the replicability of a service is dependent on the availability of the unique components, which suggests that a better understanding of service architecture could provide better implications.

Combining the service management and service modularity literature, the research by Hsuan et al. (2012) portrayed the service systems in a continuum between standard and specialized systems. Standard services are related to generic and mass services, and specialized services resemble service shops and professional services. The characteristics of the standard and specialized service systems are as follows.

### 2.2.6 Characteristics of standard and specialized services

#### *2.2.6.1 Use of standard and unique components*

A service can be viewed as a system that is composed of various distinct service elements or modules (Pekkarinen and Ulkuniemi, 2008). Similar to a product module, a service module incorporates a group of independent elements that are capable of performing the service function collectively.

A service module can be categorized either standard or unique (Voss and Hsuan, 2009). Standard service modules are routinized and has been adopted as general practices to develop shared services in the industry. Through standardizing, streamlining and consolidating common functions, using standard service elements aim to improve efficiency and effectiveness in the service provision processes (Voss and Hsuan, 2009). Standard service modules are abundant in multi-site services, such as transportation and warehousing services in third-party-logistics services (Hsuan and Prockl, 2013). By contrast, unique service modules are exclusive within a company and cannot be easily imitated or copied by competitors in the short run. For a specialized service that delivers special and professional service offerings, the number of unique components is high. Therefore, standardized service tends to use a high number of standard modules than specialized service.

#### *2.2.6.2 Replicability and volume*

Replicability denotes how easily a service can be reproduced (Voss and Hsuan, 2009). A similar concept service repeatability is proposed by Collier and Meyer (1998), which focuses on duplicating specific service encounter sequences among different customers. Viewing from a service family perspective, replicability highlights the potential to leverage service innovation across different sits and service offerings (Voss and Hsuan, 2009). A high degree of replicability indicates that the service process is standardized, whereas a low degree of replicability suggests flexibility, which allows for customization and innovation.

For example, the regular maintenance of a car is a standard service, which can be replicated across aftersales service providers. Whereas tuning a car for customized and elevated performance is a specialized service, which is only available in specialized providers, such as Brabus, a renowned tuning company for high-performance Mercedes-Benz cars. Unique service modules and processes are required for services such as engine and suspension tuning, which consequently increase the difficulties to carry out the same service in multiple sites. The ability to replicate and leverage unique services significantly contributes to innovation and competitive advantage of an organization, especially for multisite and multiservice organizations (Voss and Hsuan, 2009).

The extent to which a service can be replicated is closely related to the volume of a service. Silvestro et al. (1992, p. 66) suggest that service volume can be measured as "the number of customers processed by an individual service unit per day". When considering the replicability of service, the measurement by Silvestro et al. can be generalized into the total number of customers received the same service from a service provider per day, which is the criterion of service volume used in this thesis. A standard service that is highly replicable can be offered to a larger number of customers simultaneously than that of a specialized service. In addition, with routinized and streamlined processes in a standard service, a service unit is can handle with customers in an efficient manner, resulting in a large number of customers processed per unit per day. By contrast, the flexibility and customization options in a specialized service retain the customers in the service system for a longer period of time. Therefore, a standard service can be offered at a high volume owing to its high replicability nature and streamlined procedure, whereas in a specialized service, more efforts are required to replicate the unique modules and customer contact is usually high, resulting in low service replicability and volume.

#### *2.2.6.3 Degree of customization and personalization*

Through customization can organizations provide individually tailored solutions to customers. The marketing and management literature has provided two perspectives of customization with regard to employee adaptive behavior: 1) the modification of interpersonal behavior of the service delivering employees; and 2) the modification of service delivered (Gwinner et al., 2005). Voss and Hsuan (2009) further highlight the influence of customer needs during the process of a service delivery system and distinguish between personalization and customization.

The concept of personalization considers the adaptation of the interpersonal behavior of the employees in the way that the service is delivered (Gwinner et al., 2005). In personalization, the needs of customers could only influence the delivery process of the service, where the interactions between the customers and employees are modified. Whereas in customization, the customers' needs influence the configuration process of a service and the interaction of service personnel transmit the customer needs to the service provider. Despite the differences, the integration of two practices are recognized as crucial in situations where highly individual treatments are desirable, such as health care (De Blok et al., 2013). Collectively, when considering the process of producing and delivering a service as a whole, personalization can be regarded as a special type of customization that customer involvement occurs in the delivery process. The point of customer involvement in the service process can be regarded as the criterion for measuring degree of customization (Bask et al., 2011; Duray et al., 2000). Therefore, personalization can be regarded as the equivalent to standardized customization. In a specialized service, the degree of customization is generally high. Customer needs are influential during the whole process of service production and delivery, which incorporates personalization. On the other hand, a standard service encompasses a low degree of customization, as customers are only involved in the delivery stage.

#### *2.2.6.4 Summary*

The characteristics of specialized and standard services have been summarized in Table 3, with the two types of services portrayed at the two ends of each features. Specialized services encompass a relatively large number of unique components that are exclusive to the company. The possession of such unique components may contribute to the competiveness of the company. Due to a low number of standard components, specialized services are generally difficult to be replicated. Customers remain in the service system for a long period of time, which limits the volume of customers that a service unit can handle in a given period of time. The high customer contact also results in early customer involvement in the customization process, leading to pure customization and personalization, featuring a high degree of customization.  On the other hand, standard services incorporate a high number of standard components that are streamlined and consolidated. Customers stay in the service system for a relatively low period of time, and as a result, the volume of customer serviced is high. The standard components can be easily replicated across service sites. As for customization, customer involvement occurs in the delivery process through personalization. The service package delivered has a low degree of customization, with only the interactions between customers and service employees are adapted for specific circumstances.

*Table 3 Characteristics of service systems.*
*Adapted from Hsuan et al. (2012).*

| **Characteristics of service systems** | Specialized services | Standard services |
|---|---|---|
| No. of standard components | Low ⟷ | High |
| Volume | Low ⟷ | High |
| Replicability | Low ⟷ | High |
| Degree of customization | High ⟷ | Low |

Thus far, this thesis has demonstrated the characteristics of modular and integral products, as well as distinguished between specialized and standard services. The predominant advantage of modularity in product and service designs is flexibility which enables mass customization. The next chapter will describe the framework, the servitization matrix, which combines products and services and explores the related servitization strategies.

# 3 Theoretical framework - The servitization matrix

By combining the two types of product architectures (i.e. modular and integral) with the two types of services (i.e. standard and specialized), a 2×2 matrix can be created which illustrates four quadrants that a firm can consider in servitization. The servitization matrix, as shown in Figure 5 is proposed by Hsuan et al. (2012).  In their categorization, the concept of PSS is used and the PSS strategies are demonstrated with examples from the maritime industry. Since the purpose of this research is to enrich this framework in the context of operations research, this thesis would use the concept of 'servitization' instead of 'PSS' as has been discussed in the literature review section.

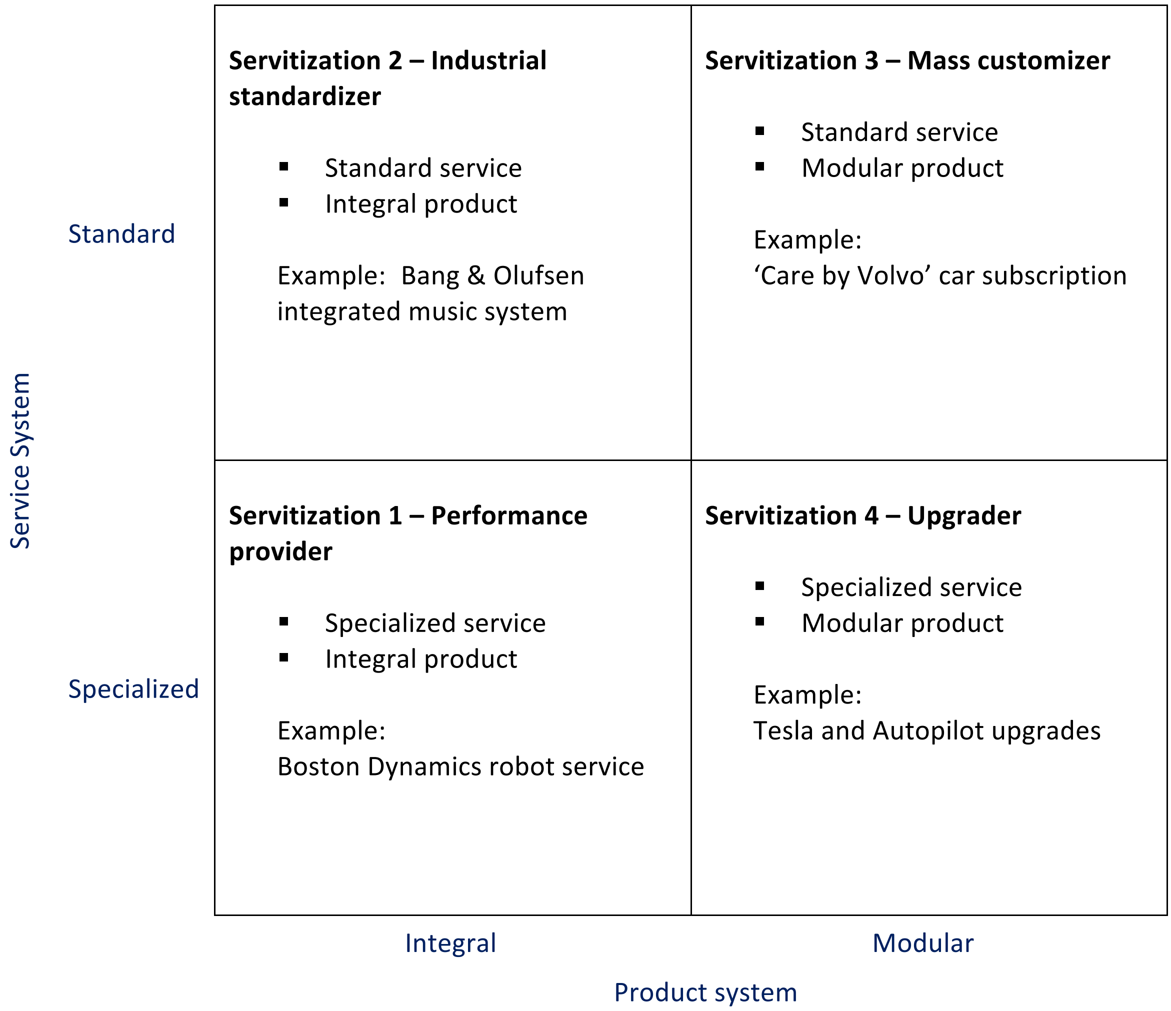


*Figure 5 The servitization matrix.*
*Source: Adapted from Hsuan et al. (2012)*

The following sections will describe the characteristics of the four quadrants of the matrix, distinguishing between integral and modular product architectures, and standard and specialized services. According to Hsuan et al. (2012), the matrix could help organizations position themselves and find the balance between product- and service-related activities in deciding their product offerings. It is necessary to point out that, with the characteristic dimensions of products and services described as continuums, the framework is not dichotomous. Yet through the discussions of extreme cases can assist the visualization and formulation of the strategies.

## 3.1 Servitization 1 – Specialized service on integral product

This type of servitization describes companies offering specialized service on an integral product. When a product has an integral architecture, it is difficult to decompose the architecture into distinctive and independent subsystems. There tends to be a high level of embedded complexity in the product architecture and considerable amount proprietary technology is involved (Hsuan et al., 2012). The interfaces tend to be tightly coupled, and there appears to be limited use of standard components, leaving little possibility for mass customization. Unique components are extensively deployed, and the degree of customization is limited.

For the specialized services added, it requires unique service components in the service offerings. The linkages between the unique services are complex with a high degree of coupling. Such services are difficult to be replicated across service unites. With a high level of customer integration and early customer involvement, customers remain in the service system for a relatively long period of time per transaction. Resulting from low replicability and long processing time, the service volume is expected to be low. The degree of customization of the service is usually high, and personalization is quite abundant, for the goal of catering to customers' special requirements, with both the design and deliver processes being subject to customers' influence.

By providing specialized services to integral products, a company resembles the role of a "performance provider" in servitization literature. The integral product is usually not made available for customization. The product and service offering is result-oriented, and the transaction between the two parties are relationship-based. For such integrated product, the specialized services might be required during the product lifecycle, for continuously improving and upgrading the product. For example, Boston Dynamics is a robotics design and engineering company that primarily serves military use. The company was first known for its product line "Big Dog", which is a quadrupedal robot developed to serve in the US military as artificial pack animal (Gibbs, 2013). Observing from the appearance the robots, the architecture embeds a high degree of complexity, with most of the parts integrated and difficult to be decomposed. It is likely that there is a high amount of proprietary technology, which controls and coordinates the precise movement and automated navigation of the robots. Therefore, it can be speculated that the related services are specialized. Sophisticated technologies and programming are developed exclusively for the robots to fulfil clients' requirements, such as high mobility and auto-navigation in rough terrain. Based on customers' feedback, the software and hardware might need continuous improvement and adjustment. Therefore, customers' inputs and feedback is highly integrated in the service process, which incorporates various service packages that incorporates a number of nods and linkages, and leads to highly customized outcomes.

## 3.2 Servitization 2 – Standard service on integral product

Companies with integral products and offers standard services are captured in Servitization 2 type. Standard service features routinized and streamlined components with low degree of customization and personalization. The time that customer remains in the system is relatively low, leading to limited customer integration. The core element in delivering the service is generally an equipment or designed service system that follows standardized routine. Such services can be easily replicated to different service sites, and a large number of customers can be handled in a relatively short period of time. The products tend to be an integral product meets the homogeneous customer needs for a specific functionality and no customization is provided. Hsuan et al. (2012) suggest that such product appears to be vertically integrated and has been developed entirely by a firm, therefore, only generic services are needed.

Companies with such product service offerings can be regarded as integrator. Their products adopt the dominant design or features a high amount of technology proprietary, and usually features an integrated product system. The production strategy seems to be MTS and not affected by the customer order decoupling points. The services can be product-oriented that gives advice on the purchase of the product, as well as providing use-oriented suggestions on how to use the products effectively.

The wireless sound system by Bang & Olufsen (B&O) can be a good illustration of integrator. BeoSound Moment is a wireless music system console that organizes users' digital sound contents and integrates them into a single system. The speakers in multi-rooms can be wirelessly connected and controlled, and users can choose or search music using the built-in online streaming service from Deezer ("BeoSound Moment - Premium online wireless system", n.d.). The music system is vertically integrated with B&O's multi-types of speakers and software that enables system connection. The product system is integral, non-customizable, and only standard services such as assisting customers' purchase experiences and music online streaming services are provided.

## 3.3 Servitization 3 – Standard service on modular product

This type of servitization combines standard services with modular products. The modular product features loosely coupled components, standardized interfaces and components sharing across families. The product is highly modular that comprise of a large amount of mass-produced standard modules. A high product variant can be configured by effortlessly combining different modules. Customer heterogeneous needs can be recognized by mass customization through mixing-and-matching, resulting in a variety of customized configurations. CODP usually appears at the assembly stage in production, and the production strategy can be make-to-assemble (MTA), which provides opportunity for efficient production as well as a high degree of customization. The related services are carried out in standardized procedures, and can be easily replicated to multi-sites, serving a large volume of customers in a relatively short period. The services use a clear defined interface between service modules, such as through designed apps or working system, which contributes to efficiency in service delivery.

This type of servitization strategy can be categorized as mass customizer. Both the product and service feature a high degree of standardization, yet through the benefits of modularity, customer needs can be easily recognized using mass customization. Services can be product-oriented, such as provision of spare parts, and use-oriented, such as product rental and leasing services. For example, automobile manufactures have begun to explore servitization through car leasing. Instead of selling a car, customers are offered subscriptions to a car for a designated time period with certain mileage allowed. Companies such as Volvo, Cadillac and Porsche are providing customers with monthly subscriptions to the cars (O'Kane, 2017). Other than the ownership of a car, customers receive a service package covering driving mileage, insurance, regular maintenances, and accessibility to many car models. Such subscriptions of cars benefit the manufactures with the possibility to further standardize and streamline the service processes. The leasing model also enables the manufacturers to continuous monitor the condition of cars, which increases the predictability of the occurrence of maintenance and reduces the variations in service provision. The insurance, maintenances and swapping service modules in the service package are modularized and loosely coupled, which can be mixed for customers' needs. It is possible to outsource certain modules, for example, the insurance service in Care by Volvo package is provided by Liberty Mutual, a third-party insurance provider (Volvo Cars, n.d.).

## 3.4 Servitization 4 – Specialized service on modular product

This type of servitization describes a modular product that is served with specialized services. The product architecture is modular, and according to Hsuan et al. (2012), the product feature short product life cycles with specialized services for continuous upgrades and incremental innovations.

This type of servitization can be called as upgrader. The individual composition components of the products tend to be updated periodically while the related technology continues evolving. For example, as discussed already, cars feature a high degree of modularity, and the electric cars are no exception. As the technology of autonomous driving evolves, car manufactures are projecting future mobility with self-driving cars. Tesla has offered Autopilot to their cars. The vehicles have already equipped with hardware for self-driving, and by upgrading the autonomous driving system software, the cars are equipped with more safety and convenience features, and eventually might achieve the company's vision of being full self-driving (Hawkins, 2017). Although the upgrading services is less focused on customization than functional improvements for all users, the software can coordinate and integrate all the pre-installed hardware as a whole, which cannot be achieved by other service providers. Therefore, Tesla takes the role of an upgrader by offering specialized service to a modular product.

## 3.5 Summary

This matrix distinguishes between modular and integral product architecture, and standard and specialized service. The four quadrants with tentative typologies describe four types of possible servitization strategies that a company may adopt. Performance provider offers integral products with result- and performance-oriented services. Industrial standardizer offers large volume standardized service to the integral products. Mass customizer exploits the benefits of modularity, offering a large volume and variety of customized products and services. Upgrader continuously offers improvements and innovations to the modular products.

As proposed by Hsuan et al. (2012), the matrix can be used in identifying the current position of the PS offerings and the primary factors that exert effect on that position. Using the matrix, companies can map out their current position and planning for achieving the desired position. The next chapter will present two cases, with product and service architectures being discussed and mapped using the servitization matrix.

# 4 Case study – modular and integral smartphones

Consumers are becoming increasingly aware of their role in influencing the design or production of products and services for customized outcomes (Sigala, 2006). Such a trend has been recognized by companies using mass customization. The mobile phone industry is characterized by high production volume, growing product complexity, shortened product life cycles, and customers demanding for larger product variation and customization (Comstock et al., 2004). Modular architecture remains the core of mass customization, allowing for combining interchangeable parts and customized configurations.

In consumer electronics, the trends are moving towards seamless and slim designs and the objects are becoming increasingly integrated. While the performances of the devices are increasing, customers are left with limited choices with regard to the functionalities and appearances. Previous research on mass customization in mobile phone industries are focused on customization of the software codes that determines users' interactions with the phone, for example, personalized ring tones and screen savers (e.g. Comstock et al., 2004; Sigala, 2006). Such aspect appears to be obsolete when considering the current smartphones, which are permitting virtually endless varieties of customized outcomes by the choices such as installing varied apps for functionalities. Since the 2007 launch of Apple iPhone, smartphones have gradually gained mainstream popularity with their touch screens and boosted processing capabilities, and in 2016 around 1.5 billion smartphones were sold worldwide, demonstrating a significant increase compared with 122 million in 2007 (Gartner, n.d.). Until the third quarter of 2017, the smartphone market leaders Samsung and Apple have reached a market share at 22.3% and 12.5%, respectively (IDC, n.d.). The expansions of other brands such as Huawei and Xiaomi have further intensified the competition, with a variety of products targeting varied market segments.

Despite the seemingly various choices of brands, the smartphone sector has appeared to be following a trend of "sea of sameness" (Fildes, 2017). With Android and Apple iOS being the duopolistic operating systems on the market, the handsets feature a uniformity of design, and new products are predictably coming with bigger screens, faster processors and camera pixels (Fildes, 2017). In addition to the lack of choices for functionalities and customization, the integrated product architectures made it a complicated process to handle common damages resulting from daily use, for example, the replacement of a smashed screen or a deteriorated battery.

A possible solution to limited opportunities for customization and decreased reparability of the electronic devices is modularity. The concept of modular smartphones was introduced as early as 2014. Different from a conventional smartphone, the modular smartphone is envisioned to comprise of modules that are flexible, mass-customizable, and easy to repair and upgrade with a longer lifespan. Until today there are limited modular phones that have been launched to the market. The following section will analyze two cases from the smartphone industry, including the product architectures and services added. To figure out the servitization strategies for modular and integral products, such as smartphones, this thesis uses a comparative case study design and analyzes both modular and integral phones based on secondary data. Two cases are selected according to the modularity continuum of Schilling (2000), which illustrates modular and integral product at the two ends. The secondary data are collected from webpages, new articles, videos and developer conferences. As pointed out by Hsuan et al. (2012), the servitization matrix can be used for both single and collective product service systems. In this thesis, the analysis is primarily based on different types of services offered to a single product, namely the smartphone. The modular smartphone concepts that have been proposed to the market will be briefly mentioned, with Project Ara and Phonebloks being the focus of the analysis. Afterwards the modular phones will be compared with integral phones, with the focus case of integral product case being Apple iPhone.

## 4.1 Project Ara and modular smartphones

In September 2013, an open-source modular smartphone concept called "Phonebloks" was proposed by Dave Hakkens in a video on YouTube (Hakkens, 2013a). The primary goal of the modular concept was to reduce electronic waste by extending the lifespan of a phone. When phones break down or become outdated, users usually have little choice but to repair or replace the entire phone. The unsatisfying performance of a phone is normally due to specific defective or performance-limiting components, while other components remain intact. With the integrated design of smartphones, it is difficult for users to replace a malfunctioning component or upgrade obsolete components. Phonebloks is built up by attaching modular components, the “bloks”, to a main board, which connects the bloks and enables easy replacement (Hakkens, 2013a). The modular architecture allows for component decomposition, with each module being responsible for a specific function of the phone. As a result, instead of changing to a completely new phone, the users could simply replace the defective module or upgrade the obsolete module while keeping the functioning ones. Product variety and mass customization are also made possible with Phonebloks. With a variety of bloks offered by different companies and individual developers, users can choose the modules according to their preference and customize the phone to suit their needs.

The campaign of Phonebloks raised substantial attention and support on social media. The vision of modular smartphone was also embraced by Motorola[1], who was working on building a modular phone in Project Ara. Phonebloks teamed up with Project Ara as collaborator in building the open-source online community for conceptualizing and developing modules for the phone (Hakkens, 2013b). The project was then joined by 20 partners in different industries, such as Sennheiser and Toshiba making audio and camera modules (Google Developers, 2014). Despite the efforts and nearly three years of development, in September 2016 Project Ara was suspended by Google, and the modular smartphone with swappable parts and the hardware ecosystem never made commercial launch to the market (Love, 2016).

After Project Ara, other phone companies, including both incumbents and start-ups, quickly grasped the idea of modular smartphones. This thesis highlights four other concepts, including ZTE Eco-Mobius, Xiaomi Magic Cube, PuzzlePhone, and Fairphone. While some

[1] The modular phone project was initially led by the Advanced Technology and Projects group in Motorola. In 2014, Google sold Motorola to Lenovo but retained Project Ara and the patents developed by the group (Patel, 2014).

of the models remain in concept studies, Fairphone has been successfully launched and is available for purchase.

ZTE, a Chinese smartphone company, revealed its modular phone concept "Eco-Mobius" in 2013. The concept model is composed of four modules: LCD (including screen and lens), core (consisting of customizable CPU, GPU, ROM and RAM), camera, and battery (Yu, 2013). The concept was designed for the goal of "easy upgrade with low cost", with modules fitting in a standardized framework across the product series and an efficient exchange platform for module parts (Yu, 2013). Xiaomi, a Chinese smartphone vendor, posted a picture of a modular smartphone concept named "Magic Cube" on Weibo shortly after awareness of the modular phone concept was raised. No detailed information regarding Magic Cube was announced from Xiaomi. From the picture attached to the post, it can be speculated that there are three rear modules, including a camera, battery and main processor. The front screen might also be a changeable module. Although both ZTE and Xiaomi have proposed their versions of modular smartphones, the two companies seem to have no further development to the concepts. It seems that the concept of modularity is more of a fad to firms with established position on the smartphone market.

Fairphone develops smartphones with social ethical supply chains and Fairphone 2 reconfigured the design of the phone, and decomposed and aggregated the components into six main modules, which is shown in Figure 6. The phone could be separated and reassembled, offering possibilities of easy repair and potential upgrade. Spare parts for six modules – display, camera, battery, core, top and bottom – are available from the web shop and instruction videos are also provided to users ("Fairphone spare parts", n.d.). As for the other modular phone start-up, PuzzlePhone adopted a design with three exchangeable modules: brain (containing the main electronics), spine (an LCD display), and heart (consisting of battery and secondary electronics) ("PuzzlePhone", n.d.). The modular architectures of the two phones facilitate an easy change of modules for both repair and meet users' upgrading requirements. Fairphone has already launched to the market as the first modular phone available, whereas PuzzlePhone are/is currently going through a development and fund-raising process.

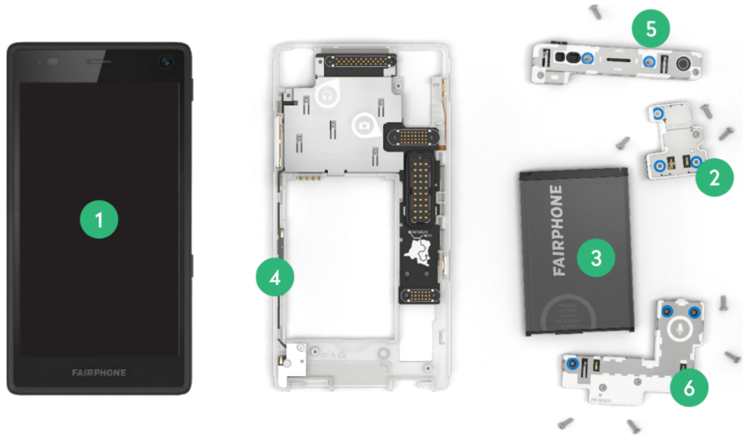


*Figure 6 Fairphone and constitutive modules*
*Source: https://shop.fairphone.com/en/spare-parts/*

The abovementioned modular smartphone models are summarized in Table 4. Some manufactures (i.e. Google and Fairphone) use the distinct parts directly, while the others have aggregated some of the modules together and reduced the visible number of composition modules. All the modular phones recognize the benefits of extended product life through updating and substituting modules. With a larger number of swappable modules, Ara phone and Fairphone 2 have a higher degree of modularity, which result in higher flexibility in product configuration and customization. Google envisioned leveraging the modular phone architecture as a platform to engage third-party developers in designing and manufacturing modules. The advantage of outsourced design and production is fast development cycles. A large variety of modules can be available to meet customers' customization requirements. On the other hand, being start-ups doing in-house design and production, currently Fairphone 2 and PuzzlePhone only offer (or had planned to offer) spare parts for repairing and upgrading. It is possible that in the future the companies can leverage on the modular architecture and offer a variety of parts for customization. In terms of service added, the provision of spare parts is the prevalent type.

*Table 4 Summary of the modular smartphones*

| Model | Ara | ZTE ECO-MOBIUS | Xiaomi Magic Cube | Fairphone 2 | PuzzlePhone |
|---|---|---|---|---|---|
| Company | Google | ZTE | Xiaomi Inc. | Fairphone | Circular Devices |
| Modules | 11 (medium size)<br><br>Each module accounts for a function | 4<br>- LCD (screen & lens)<br>- Core (CPU, GPU, ROM, RAM)<br>- Camera<br>- Battery | 4<br>- Screen<br>- Camera<br>- Battery<br>- Processor | 7<br>- Display<br>- Camera<br>- Battery<br>- Core<br>- Top<br>- Bottom<br>- External case | 3<br>- Brain (CPU, GPU, RAM, memory, camera)<br>- Spine (screen)<br>- Heart (battery) |
| Design and production | Outsourced | N/A | N/A | In-house | In-house |
| Design protocols | Open-sourced | N/A | N/A | Close-sourced | Close-sourced |
| Degree of customization | High | Medium | Medium | Current: low<br>Future: high | Medium |
| Benefits of modularity | Customization, upgradability, reparability | Upgradability, reparability | N/A | Reparability, upgradability | Upgradability, reparability |
| Added service | Configuration app;<br>Developer kit | Trading platform for modules | N/A | Spare parts;<br>Recycling<br>Software and hardware upgrades | Spare parts |
| Current states | Suspended | Concept | Concept | Available | Under development |

Despite the suspension of Ara phone, the concept of modular smartphones remains promising in terms of breaking the sea of smartphone sameness, introducing the possibility of customization as well as extending product lifespan. The modular smartphone provides the opportunity to investigate and speculate the types of services that could be offered to a modular product. The following section will demonstrate the product architecture of the Ara phones in details.

### 4.1.1 Product architecture of Project Ara

Project Ara was a project aiming at developing a modular smartphone architecture, hardware and an open platform. This thesis will focus on the physical architecture of the phone and the services offered to customers. The software development for Ara phone will be left out since it is out of the scope of this thesis.

The hardware development consists of: 1) common parts for the basic functions, such as processors and displays; 2) specialized parts for more functionalities, such as enhanced speakers and heartrate sensors; 3) the skeletons, known as "endo", which connect the front and rear parts and allow swapping of the modules according to the specific needs of the users (McCracken, 2014). Figure 7 demonstrates the architecture of Project Ara phone that has eleven modules: two front modules, eight rear modules and one endo. The rear modules have three types: 1×1, 1×2 and 2×2.

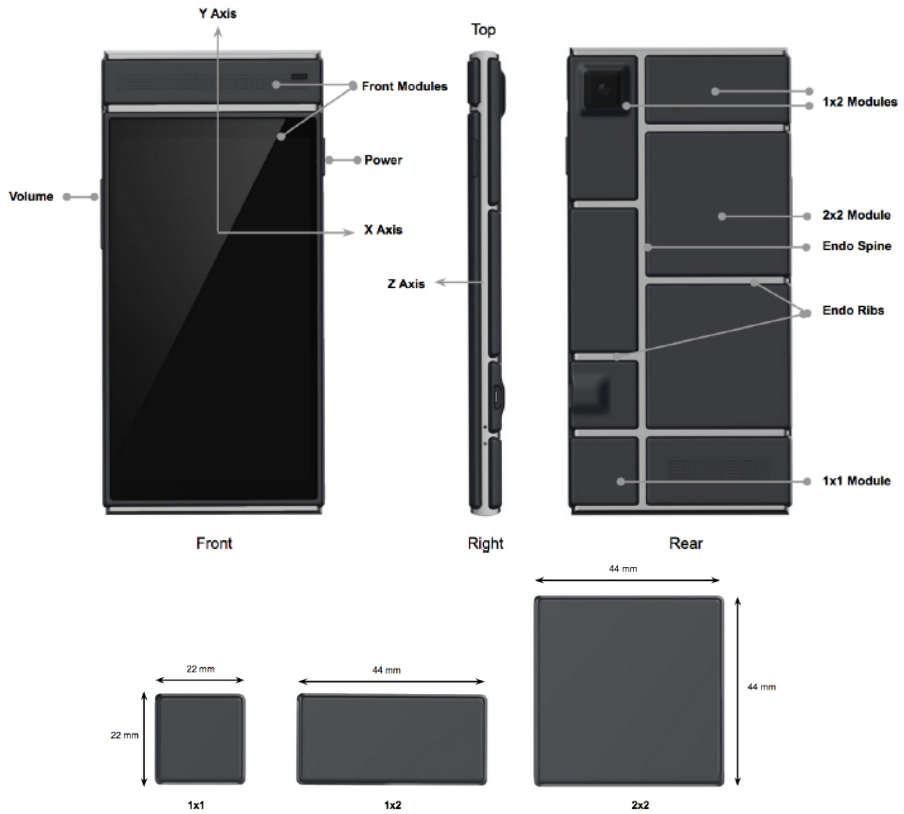


*Figure 7 Architecture of a medium size Project Ara phone, and the three types of rear modules*
*Source: http://www.modularphonesforum.com/developers/faq/how-project-ara-modular-phone-works/*

With three sizes of skeletons, the phone has three configurations that can be regarded as three product families: Mini (2×5), Medium (3×6), and Jumbo (4×7). The initial design was to make all the modules of the phone changeable, yet in the later development processes Google decided to integrate the common modules into the frame, reducing the number of changeable modules and choices for customization (Phonebloks, 2016). Despite the changes, this thesis will focus on the version of phones that comes with interchangeable modules.

The architecture of a product considers the arrangement of functional elements into building blocks and specification of the interfaces (Ulrich, 1995). The Ara phone is comprised of an aluminum frame (i.e. the endoskeleton), to which the modules are attached via electropermanent magnets (EPM). Figure 8 demonstrates the endoskeleton for a medium size Ara phone, with illustrated EPM for connecting the modules and data pads for the interface block. The functionalities are allocated to distinctive modules, with front modules being display and speaker, and rare modules that include modules such as processor and battery, indicating that the functional and physical elements are one-to-one mapped. The modules are hot-swappable, which means that the modules can be taken off and changed without switching off the phone. It implies that the interfaces between the modules and the rest of the device are loosely coupled, and the changes to one module can be made without the changing of other components. With a modular architecture, as demonstrated in the Ara phone, to achieve a functional change of the product only requires minimized physical changes of the other components.

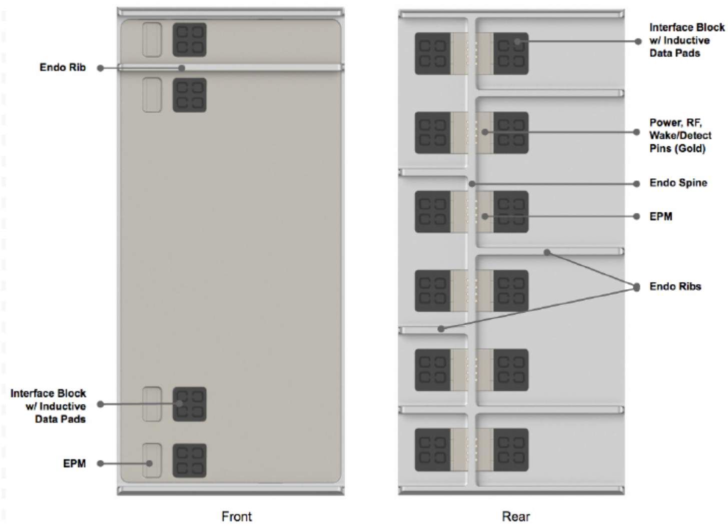


*Figure 8 The endoskeleton for a medium size Ara phone.*
*Source: http://www.modularphonesforum.com/developers/faq/how-project-ara-modular-phone-works/*

Each rear modules of the Ara phone consist of three sub-assemblies: the module base, printed circuit board (PCB) and the shield, which are covered under the module shell ("About architecture of Project Ara modules", n.d.). As shown in Figure 8, the PCB serves as the Interface Block, which is shared among the modules and specifies the protocols for the interactions across the endoskeleton. "Module Developers Kit" is provided to third-party developers and specifies the requirements and protocols for module development, which ensures the standardization and specification to achieve module compatibility.

The flexibility resulted from the modular architecture also unlocks the potential of leveraging the phone as a platform. With standardized interfaces defined by the Interface Blocks, a variety of derivative modules can be configured in an efficient manner. The common architecture, the endoskeleton, integrates the modules and interfaces and allows for different configurations of the phone, creating three product families (small, medium, jumbo) while meeting different customer requirements in both display size and functionality. Component sharing can be achieved across the three families, since all the rear modules are standard components. It is possible to create economies of substitution through mass production and reusing modules to configure different functions of the phone.

According to Pine (1993), mass customization synthesizes the mass production of goods and services that have been individually customized. With the standardized modules and specified interfaces, it is feasible for Google to offer a variety of phones through mass customization, both on the functionality and the appearance. With a variety of modules offered by Google and developers, the customers can configure the phone that serves specifically to their everyday needs by selecting and switching on the corresponding modules. The production strategy of the modules can be assemble-to-order, using modules from inventories and assembling according to customers' orders. In addition, the customization can be easily and conveniently achieved by the users themselves during the product lifespan. Besides the everyday-customizable functions, the appearance of the phone can also be changed by switching the shell of every rear modules.

In summary, the architecture of the Ara phone encompasses a high degree of modularity, which features a large number of loosely coupled standard components (the front and rear modules) and standardized interfaces (the Endo). The modules are highly substitutable across the product family. An abundance of product variants can be configured through the mixing-and-matching of standard components, and component sharing across the product families, resulting in the practice of effective mass customization.

## 4.2 Services of modular smartphones

Due to suspension of Project Ara, the services in this section are devised from an online developer forum and project archives. This thesis further speculates about other services by referring to the services that have been offered by Fairphone, which is currently selling modular smartphones to customers. It is assumed that both featuring modular product architectures, Ara phone and Fairphone could be serviced in a similar manner. In addition, this thesis proposes other possible services that might be applicable to Ara phones.

### 4.2.1 Configuration service

With a modular product architecture, the service system of Project Ara appears to be standard and modular. The service that has been proposed by Project Ara is an app for configuring and purchasing the phones. With the highly customizable smartphone comes the "Ara Configurator" app, which allows customer to customize each layer of the phone and build their own (Ray, 2015). This thesis identifies three types of configuration service bundles that Ara offered to customers. The possible service decomposition is shown in Figure 9.

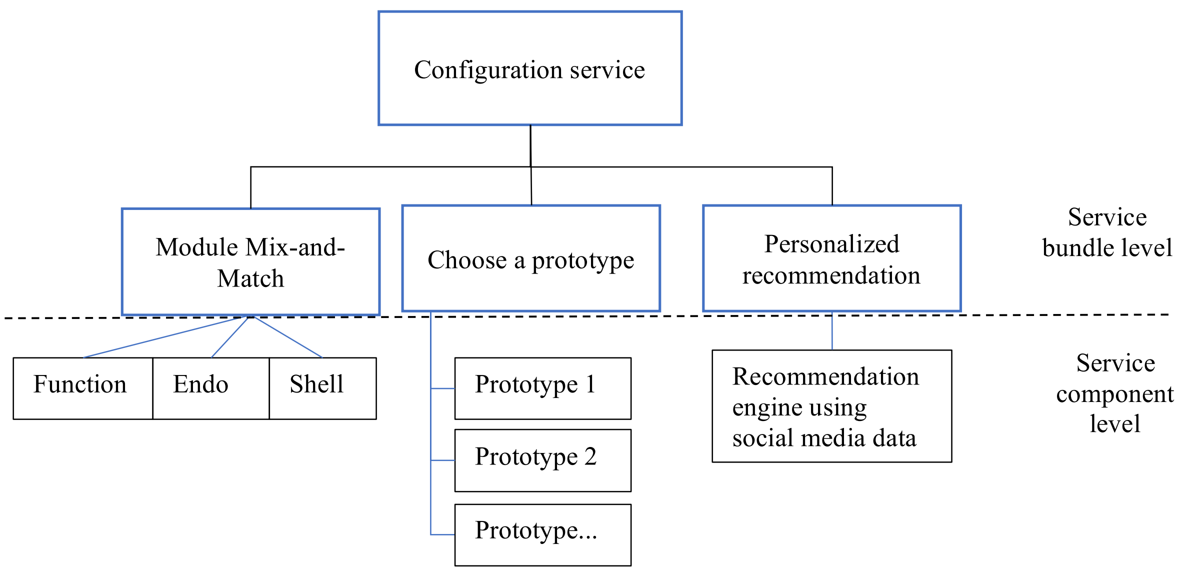


*Figure 9 Customization service architecture of modular phones*

The methods of customization include both "combinatorial" and 'menu-driven' (Voss and Hsuan, 2009). In the app, the embedded "Marketplace" offers a wide selection of standard modules from developers with a variety of functionalities. In the first type of "Module Mix-and-Match" service, customers can select freely from the modules and compose their own phone based on the three sizes of endoskeleton in the 'Endos' section. In the "Shell Makers" section, users can choose the shells for each rear module, which collectively serves as the appearance of the phone. For a unique appearance, users can upload photos or use designs from collaborating artists. The second type, "Choose a prototype", offers predesigned prototypes with different highlighted features that customers can directly use and finish the configuration. In the third type, "Personalized recommendation", the app analyzes social network data and figures out the lifestyles of the user, offering recommendations for phone configurations accordingly (Ray, 2015). For example, a travel enthusiast might be suggested to have a 360-degree camera module, whereas a gamer might appreciate a phone with excellent processor capacity and additional battery modules. Such prototype-based customization and personalized analysis could be effective in helping indecisive customers selecting the right phone quickly, as well as make it more relatable for customers who place limited emphasis on the opportunity and benefits of customization.

### 4.2.2 Repair and upgrade services

Due to limited information available and the suspension of Project Ara, this thesis speculates the following services that Ara phone could offer to customers based on its modular product architecture. The services are speculated based on Fairphone 2, a modular phone that has been launched to the market and services that have been offered to customers since 2015.

Fairphone is a Dutch company that develops smartphones with social ethical supply chains. Fairphone 2 features a modular architecture with a design focusing on extending the life expectancy through easy repairing. Unlike the concept of full customization in Project Ara, where users can literally build up a phone utilizing the modular architecture, Fairphone 2 exploits product modularity by providing spare parts and tutorials for replacing broken parts. With a modular design of six modules (display, camera, battery, core, top and bottom) and use of non-proprietary screws, Fairphone is the only receiver of a ten (out of ten) "Reparability Score" by iFixit ("Smartphone Repairability Scores", n.d.), implying that the phone is easy to disassemble with service manual provided, and major components can be easily replaced. The phone can be decomposed and reassembled with basic tools, making the phone easy to repair and reassemble. Using a modular design, the components use press-fit and standard screws for easy disassembly.

The service of Fairphone 2 is primarily related to reparability. The repair service added to a modular phone can be regarded as product-focused standard service. With a modular product architecture, the phone can be fixed or upgraded by changing the standardized modules. For the product-service provider, the process of offering repair service is product-focused and transaction-based.

Focusing on the reparability of the phone, Fairphone's online shop has listed selections of spare parts for repairing and some modules for upgrading, such as an enhanced camera module for upgrading the camera modules ("Fairphone spare parts", n.d.). Users are encouraged to self-repair the phone and detailed instructions are provided for every spare part. For the repair service, the role of Fairphone is to help customers self-repair and upgrade the phone by making the parts and necessary knowledge available. As a result of the modular architecture of the phone, the repair service can be carried out in a modular and standardized fashion. Since the modules are attached to a standardized interface, it is relative easy to detect the defects and switch the modules. Based on the repair service by Fairphone, this thesis speculates on the process of repair service that can be generalized to a modular phone. Following the three-step service decomposition logic proposed by Eissens-Van Der Laan et al. (2016), namely defining the boundary, identifying functional parts, and categorizing module interdependencies, the speculated repair service process is decomposed into four steps. Figure 10 demonstrates the decomposition of the repair service, with the first type of service "self-repair instructions" being a modular service.

The boundary of the repair service covers both self-guide instructions and help lines. The process of assisting self-repair service can be decomposed into the following steps:

1) Problem identification: help users identify the defective parts and ordering the parts needed from the online store;
2) Parts positioning: assist users to locate the parts that need to be changed on the phone;
3) Parts changing: demonstrate users how to detach the failing parts and assemble the new parts;
4) Further support: service team is available for help if customers have further questions.

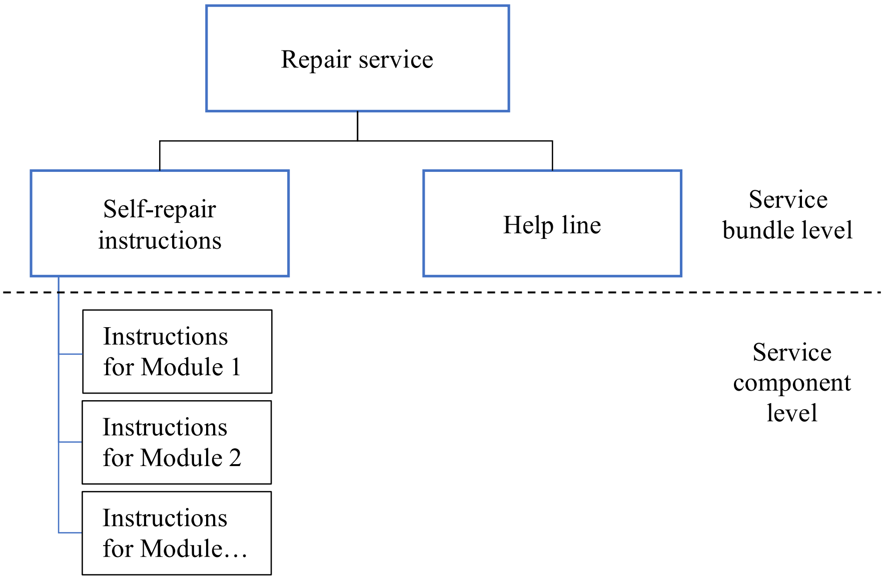


*Figure 10 Repair service architecture of modular phones*

As service modules are regarded as small groups of independent elements, five functional parts (or service modules) can be speculated as follows:

1) Assessment and plan: assess the module and project the possible sources of defects, proposing solutions;
2) Instructions production: demonstrating the repairing process by written or video instructions that are readily accessible to non-professional readers;
3) Materials organizing and online publishing: categorizing the solutions and organizing into a flow that guides the users through the whole process;
4) New parts development and software update: continuously develop new modules and providing upgrading services;
5) Help team: specializing in handling customer requests that cannot be solved by the existing guides.

The five service modules feature a high degree of standardization. The production of the repair manual can be a standardized routine that can be used across the product modules and product families.

Consisting of five modules, the repair service can be regarded as a standard product-oriented service. With a modular product architecture, it is relatively easy to standardize and streamline the repair services accordingly. The repair service is highly replicable. For each new module developed, the repair guide can be produced by replicating the existing processes.

The degree of coupling of the repair service can be relatively low. As a standard service, it could be inferred that the repair service has specified rules and procedures for information sharing between the service modules on standard interfaces. Although the service is standardized, using self-service, customers can choose the related instructions and customize the service by themselves. Direct customer contact is only established when the customers call the helpline or message the service team, which is possible for personalization in the way that the service is delivered. With the instructions, the repair and change of modules require relatively low level of efforts and easy to be followed by ordinary phone users using simple tools.

### 4.2.3 Rental and recycle services

In addition to product-focused repair service, it is likely that users would like some modules with special functionalities on certain occasions. Therefore, use-oriented services, such as module renting, can be added to the modular phones. For example, a module that turns the phone into a projector would be relatable for users who make occasional presentations. Currently Motorola is offering an expandable module, 'moto insta-share projector', for its product line Moto Z, yet the module has been commented as expensive ($299) with acceptable performance (Velazco, 2016). For some expensive or infrequently used modules, it might be feasible to offer customers a choice to rent the parts. With the ownership of the modules remaining with the provider, the users have the flexibility to choose and use the modules without concerning the risks that are related to ownership. When certain modules become obsolete, a recycle service can encourage customers to send back the used modules for recycling. Fairphone offers two types of recycling: recycling for the whole phone and recycling for modules, that can be sent to the company and third-party partners ("Recycling Program - Fairphone", n.d.).

Both the speculated rental service and recycle service are standard services. A large number of standard service components can be used in renting out different modules, such as order taking, and module packing and shipping. For the recycling service, the process of decomposing and recovering the components and modules can be carried out using the same process, which allows for outsourcing. Using standardized and highly replicable service process modules, both services can be offered to a large volume of customers.

### 4.2.4 Summary

Google Ara phone and Fairphone 2 have been used as illustrations of modular smartphones. With standardized components and specified interfaces, the modular phones can be mass-customized to meet various customer requirements by assembling pre-made components. Components can also be shared across product families, allowing for efficient configuration of multi-product lines. As for the services, both the configuration and repair services are standardized and modularized, and customers can choose the distinct service modules and compose the service experience exclusive to their needs. The speculated rental and recycling services are also standard services. The process of delivering the service is mainly driven by customers, using the Configurator app or company website as the service platform. As a result, the services can be easily replicated and offered in at large volume.

It appears that the servitization strategy for modular smartphone manufacturers fits in the mass customizer, i.e. standard service on modular product, type in the servitization matrix. The following section will present iPhone as the contrasting case, i.e. integral product architecture, to the modular smartphones. Although the exact architectures differ from the two phones, for the purpose of a theoretical demonstration and analysis, from this section onwards, this thesis will subjectively disregard the differences and views them both as modular products. The services will be combined as though they have been offered by a modular phone manufacturer, in this case, Project Ara. Having discussed the architectures and services of the modular phones, the next section will introduce the Apple iPhone as an integral product for comparison.

## 4.3 Apple iPhone – the integral smartphone

Since the launch of the first iPhone in 2007, Apple iPhone has disrupted the mobile phone industry and shed light on the arrival of smartphones with the power of a pocket computer (Pressman, 2017). From the first-generation iPhone to iPhone X, in ten years iPhone has become an icon with outstanding user experience by sophisticated designs and the seamless iOS system. With 216 million units iPhone sold and $141 billion net sales in 2017 (Apple, 2017a), Apple maintained the position as the second largest smartphone vendor with a market share of 12.5% (IDC, n.d.). Unlike Samsung and other phone makers' large variety of models, Apple offers a small number of phone models that exclusively targets the high-end market.

The architecture of an iPhone can be regarded as an example of an integral architecture. Based on the available information online, the analysis in the following section will be focused on the architecture of iPhone 8, which was launched in 2017.

### 4.3.1 Product architecture of iPhone, with iPhone 8 as example

Compared with the modular Ara phone, the product architecture of iPhone is highly integral. Although Apple does not provide detailed information about the parts and architecture, it can be speculated from the teardown process by iFixit, which decomposes the iPhone 8 into individual parts. The general complex systems theory suggests that nearly all complex system can be decomposed into a set of subsystems (Simon, 1962). Therefore, to compare with the modular phones, the focus of analysis will be directed to the components that carry the basic functions, including battery, screen, camera and processor, which all have been designed easily swappable in modular smartphones.

Having been known for the iconic seamless product design, the body of an iPhone 8 is tightly sealed with adhesives, for water resistant considerations and securing the parts intact. The architecture of the iPhone features a large number of intricate connections of parts ("iPhone 8 Teardown", 2017). Battery, screen and camera are the three parts that can be relatively easily identified and detached, with every part having one connecting cable attached. However, the other modules of the phone are tightly coupled, connected with delicately folded cables and secured with brackets, which tremendously adds to the difficult of decomposing and identifying distinct modules ("iPhone 8 Teardown", 2017). The teardown process indicates that it is almost impossible to change any parts of the phone without affecting other components, indicating a high degree of coupling.

The architecture of the iPhone 8 incorporates a large number of unique and new-to-the-firm components. Comparing with the previous model iPhone 7, almost all the components in iPhone 8 are modified or newly-developed, including the basic components. The battery is slightly smaller in capacity than iPhone 7, the screen is improved in color tones and brightness and the camera is equipped with bigger sensor ("iPhone 8 Teardown", 2017). With each generation of iPhone, Apple continuously improves the parts for better performance. Therefore, with new parts developed and manufactured for every generation, it could be inferred that the sharing of standard components across the iPhone product family is relatively low. iPhone 8 has a limited number of product variations. Customers choose from three colors and two memory capacities, and there is no choice for customization. In summary, the components of the iPhone 8 are tightly coupled, the interfaces are numerous, and the degree of components sharing across product families and customization are low.

### 4.3.2 The Services – Apple Care, repair and recycling, and retail store

Being a provider of both hardware and software, Apple is known for providing a seamless user experience to customers by a tightly integrated product and service system (Euromonitor International, 2017). The service related to iPhones can be categorized into two types: repair and recycle service, and use-oriented customer support services.

The regular repair and recycle service can be categorized as a standard service. As indicated from the Apple support webpage, when the phone breaks, customers are recommended to either bring the phone to an Apple Authorized Service Provider or send it to Apple Repair Centre, and further help can be reached by calling or via an instant chat session (Apple, n.d.). In addition to regular repair service, Apple offers customers a subscription to an annual upgrading of iPhones, and a subscription to an aftersales services package. AppleCare offers one-stop technical support for customers, including hardware repair and software support. For iPhones, AppleCare comes with extended warranty for two years and two accidental damage coverage (Apple, n.d.). Customers are not offered the option to customize the service and the no personalization is included at the service delivery stage. The subscription service can be speculated as a standard service package that is composed of regular standardized modules, such as the repair of screen or battery change, which are assembled according to the needs of the customers. Such pre-designed service package could benefit Apple for better forecasted revenue stream and plan for service operations based on a worst-case scenario.

The repair networks of iPhones are tightly controlled by Apple. Instead of providing service manuals and spare parts, Apple have developed proprietary machines that specializes in changing the screen, which are projected to be distributed in designated authorized service provider stores by the end of 2017, which covers 4% of the worldwide service providers (Reuters, 2017). It appears that the repair service is comprised of certain unique components, which is regarded and protected as a core of competitiveness in the repairing business by Apple. According to Koebler (2017), the fingerprint sensor, a critical component associated with the repair of a cracked screen, will be integrated with cryptography, meaning that only the calibration machines by Apple can reconnect the newly-installed sensor for functioning. The result of such integration is that Apple becomes the "specialized" exclusive service provider, with the freedom of replicating a standard service while maintaining competitiveness by retaining the unique modules and blocking out the competitors. Therefore, the repair service of iPhones can be regarded as a standard service that has been made specialized with unique service components, i.e. the calibration machines. Similarly, the recycle process has been planned to use "Liam robot", a robot specializing in decomposing the phone and sorting out the components automatically. Using a decomposition robot also ensures the possession of unique service module in carrying out the recycling service.

Apple has devoted considerable effort in creating unique customers' experiences in the retailing stores. Apple tries to build the retailing stores as place where customers acquire experience with the Apple hardware and software, and find solutions to their problems. In 2017 Apple launched "Today at Apple", which offers workshops and sessions that introduce lifestyle-related topics such as coding, sketching and video producing with Apple products (Apple, 2017b). The "Genius Bar" in Apple Stores offers customers with personal support, and the service delivery process involves a high degree of personalization, with employees being trained to react to customers question in an empathic manner (Li, 2012). The services at Apple Store focus on helping customers achieve their goal by offering them solutions based on the Apple products. The process can be speculated as personalized standard service. Varied customer needs are met by employees' decision to mixing various modules of services into the service package, and the process of delivering the service is altered to best fit customer needs. However, the engineering or design process of the services is not altered by the customer order. The service process might be routinized, yet features a high degree of personalization, with the service employees adjusting the interactions and service delivered to the customer.

### 4.3.3 Summary

The product architecture of the iPhone is integral. A relatively large number of unique components is used, with tightly coupled and abundant interfaces that limit component sharing across the product family. The degree of customization is very low, and customers are offered limited choices on a small number of product variants. The repair service is standard service, however with the subscription model and control of the proprietary repair machines, Apple is establishing itself as the exclusive service provider to compete with third-party repair stores. Likewise, the recycling service is designed to unitize a unique component to protect Apple's exclusivity. The retail store service seems to involve a very high degree of personalization for service quality excellence. Putting together, Apple offers standard service on integral product, which fits into the industrial standardizer type in the servitization matrix.

## 4.4 Findings from the cases

Having analyzed the product architectures and service types of the illustrative cases, this section will first utilize the servitization matrix to plot the current product service offerings of the two companies. Next, the findings and implications from the two cases will be discussed. Finally, this thesis attempts to tentatively suggest possible configurations of PS offerings for companies to move to other quadrants.

The PS offerings of Ara and Apple have been exhibited in Figure 11 using the servitization matrix. The service offerings have been focused on the level of single products, i.e. the modular and integral smartphones. Currently, the modular Ara phone appears to take up the upper right quadrant position as mass customizer, which facilitates customers' choice of the best-fit combinations. As for the case of Apple iPhone, with integral product architecture and standard service, it can be regarded as type two servitization as industrial standardizer, which offers a few pre-determined alternative products and services to customers. With distinguishing product architectures, both companies are offering standard service, yet several different notable aspects will be mentioned below.

| Service offering | Integral | Modular |
| --- | --- | --- |
| Standard | **Servitization 2 – Industrial standardizer**<br>○ iPhone repair service<br>○ AppleCare<br>○ Apple retail store services | **Servitization 3 – Mass customizer**<br>▪ Ara phone configuration service<br>▪ Ara phone self-repair service<br>▪ Ara phone module rental and recycle service |
| Specialized | **Servitization 1 – Performance provider**<br>○ Assisting in enterprise use of Apple products | **Servitization 4 – Upgrader**<br>▪ Leveraging architectural knowledge for services |

Product architecture

*Figure 11 Mapping of services offered by Ara and Apple*

The effects of modularity on the product-service offerings have been manifested in terms of the degree of customization, approaches to reparability, and service design. The modular architecture of Ara and Fairphone enables mass customization of functionalities and appearances while increasing reparability. For iPhones, no customization choice is provided and the repair process has been restricted to designated repair stores owned by Apple. Both phones are providing standard services to customers, yet the platforms and level of customization and personalization differ. Leveraging the modular architecture of the phones, the Ara phone can be serviced in a standardized and modular manner. Using a mobile app and a website as platforms, the services are modular and made easily accessible and flexible for customers. The standardized and modular service structure enables mass customization at low cost. As for iPhone, the Apple retail store combined with the company website can be regarded as the platform for providing services. The service interface is regulated with protocols and requirements that specify the interactions between customers and employees, ensuring efficient service processes carried out in a highly personalized manner.

### 4.5 Possible movements on the matrix

Following the previous analysis of product architecture of the modular and integral phones, this thesis continues to propose the possible services that the two types of phone manufacturers can provide, in order to use the other two servitization strategies. For the Ara phone, it is feasible to leverage and exploit the existing knowledge on the modular architecture and offering service for special module development, or even developing modular tablets, for highly customized outcomes. Such service can be carried out based on the upgrading of existing phone modules, or expanding the endoskeletons for larger size of devices. With regard to offering specialized service, Apple could adopt a product system perspective to leverage its existing collections of iOS devices and configure specialized systems for enterprise use.

Thus far, this thesis has highlighted that the Ara phone has a modular architecture and the Apple iPhone has an integral architecture. The related services for the two phones seem to be standard service, and the two phones have taken the upper position in the matrix respectively. Possible services for moving to the other two positions have been mentioned.

## 5 Discussion

This thesis explores the potential role of modularity in product and service offerings of servitized organizations. The role is Having described and analyzed two cases, this section evaluates the findings from the cases, and proposes implications for the management world.

### 5.1 Variety, cost and customer value considerations for mass customizer

Manufacturers taking the role of mass customizer, as indicated by the Ara case, offer standard services on modular products. For the manufacturer, to exploit the benefits of modularity in both product and service architectures, the focal point of operations management could be maximizing the product variety through mass customization while maintaining low cost.

With the flexibility of modular architecture, product and service varieties are created by combining various standard modules and assembling the suitable final product and services for customers (Pine, 1993). Therefore, the number of module variety is decisive to the variety of the final product. To maintain a relatively large number of components variety while controlling investments in new components development, the mass customizer could consider engaging third-party developers or manufacturers for certain modules. Modularity in product architecture creates specified interfaces which allow for outsourcing and supplier involvement. Outsourcing leads to interfirm learning, access to resources from suppliers and boost innovation in the components (Mikkola, 2003a). It can be speculated that, for a modular product, it would be relatively easy to devise value-adding activities for a distinct product module, or a set of product modules, using standard and modular service processes. In the case of Ara phone, the repair service is specifically based on each product module. As suggested by the 3D of service modality, modularity in service production would require modality in process and organization design, which allows for flexible scale production through outsourcing to cope with external demand variability (Pekkarinen and Ulkuniemi, 2008). Leveraging the modular and standard service architecture, the mass customizer can maintain flexibility by outsourcing some of the service (Voss and Hsuan, 2009) to reduce the effect of variability in demand on the core business.

In manufacturing process, a low system complexity and use of standard components can reduce the costs (Fixson, 2005). In a modular architecture, the system complexity has been decomposed and functions have been allocated into individual modules that are connected by standardized interfaces, as a result, the complexity is relatively low, which reduces manufacturing costs. Combining modularity with mass customization allows companies to use a two-stage production: make-to-stock of the predesigned components, and assemble-to-order for the final products. Such production strategy allows for standardizing production process before the customer order decoupling point for maximized efficiency (Mikkola, 2007; Rudberg and Wikner, 2004). However, it should also be noted that the process of mass customization features a high intensity of customer information that requires transmission in the organization efficiently (Piller et al., 2004). Therefore, the mass customizer should also consider the ways to make the assemble-to-order stage highly responsive, such as better systems for handling and integrating customer requests to the final products and services. With regard to product upgrade and new product development costs, when certain components become obsolete, the modular product can partially retain and reusing the current ones, which saves testing and production costs of the new modules and achieves economies of substitution (Garud and Kumaraswamy, 1995). The renewing of service can also be achieved by substituting certain modules on a service platform (Pekkarinen and Ulkuniemi, 2008), However, it should be noted that the modular product and standard service process have the risk of being imitated by competitors, due to the well-specified function mapping and reduced system complexity (Pil and Cohen, 2006). As demonstrated in smartphone industry, after the announcement of Phonebloks and Ara phone, it was not long before other companies, both incumbents and start-ups, adopted similar design and proposed their versions of modular phones.

The strategic goal of the mass customizer could be to provide customers with the exact configuration of products and services. The customers are encouraged to build phones that fulfil their requirements the best, as well as to decide the service contents they would like to receive. In other words, the company recognizes the heterogeneity of customer preferences, and assumes that to offer the product and service as precise to customer preference as possible is best valued by customers. Such type of customer preference has been referred as horizontal differentiation by Jiang et al. (2006). In contrast to vertical differentiation's assumption that customers value quality and price the most, by differentiating customers horizontally and delivering the best-preferred products and services, the manufacturer is likely to gain the "perfect-fit benefit", as a result of successfully fulfilling the precise customer needs (Jiang et al., 2006). Such benefits might be more intangible than economical, for example, increased customer relations and brand value recognition, which would contribute to market penetration and the reputation of the manufacturer. As the learning and knowledge about customer preference accumulate, manufacturers would gain better insights on the perfect-fits, from which sophisticated pricing scheme can be devised and inventory costs can be reduced, leading to better economical outcomes (Jiang et al., 2006). Furthermore, the mass customizer could achieve "economies of customer integration", which is related to the benefits from differentiation opponent in manufacturing, better access to customer information and increased customer loyalty (Piller et al., 2004).

From the perspective of customers, Merle et al. (2010) propose that customers place value on the extrinsic value on the product and intrinsic value on the co-design experience, with the latter having potential to influence the total value of the mass customization offerings. It is advisable for mass customizer to understand the aspects that customers might place value on. The Ara phone allows for customization on functionality and appearance, which is achieved both in the initial purchase process and on daily use basis. It is a unique utility that has not been offered by any smartphones before. Therefore, it can be speculated that customers will place a high value on the phone in assessing the value of mass customization. In devising the co-design process, it is essential for mass customizer to understand that overly complex processes and the unwillingness s of some customers to devote time might offset the value customers place on the co-design experience (Merle et al., 2010). Therefore, certain assistance should be considered when designing the customization process to make customization relatable to a large number customers, such as the three ways mentioned in the case section for customers to reach a configuration for the Ara phone. In addition, following the suggestion by Sigala (2006), to sustain the competitive advantage in the long run, the mass customizer needs to consider continuously developing new customizable services for achieving multiple customer values.

In summary, from the analysis of Ara phone, organizations taking the role of mass customizer should consider: 1) maintain an optimal number of components variety through outsourcing; 2) maximizing production efficiency before CODP, and incorporating customer specifications in an efficient manner; 3) leveraging the modular architecture for the premium of providing the perfect-fit products and services; 4) continuously upgrading components to maintain product value and designing varied approach to engage customers in the co-design process.

## 5.2 Unique service module and personalization considerations for industrial standardizer

Implications for industrial standardizer can be drawn from the case of Apple iPhone, which relates to standard service and integral product. The focus of the product-service offering could be differentiation. The advantages of modularity are manifested by strategically designing and controlling service components, as well as applying personalization in service delivering process.

As suggested by Voss and Hsuan (2009), unique components in a service is a source of sustained competitive advantage, and such components usually feature a relatively high level of knowledge and information, which are tightly coupled into the process. Such attributes made it difficult to be imitated by competitors in the short run, yet the organizations' ability to replicate the unique services to multisite is also undermined. As demonstrated by the case of Apple iPhone, the repair service is a standard service that can be carried out by third-party repair stores. However, to control the service and eliminate competitors, Apple has strategically developed a unique component in the standard service, i.e. use of special machines. By adding a unique module, the service process becomes less standardized. And by using a proprietary machine, the replicability of the process is elevated. For industrial standardizers, the strategic design of unique components and the replication of the service components should be careful planned. A standard service can be less imitable by adding a unique service component, and a unique service component with embedded complexity can be made more replicable by "tangibilizing" the intangible processes, such as substituting the process with a machine, robot or algorithm. As such, industrial standardizer can sustain the competitive advantage by replicating the tangible components across different service sites and offering the service in large volume. This can be related to the notion of "prodcutizaiton" by Spring and Araujo (2009), which suggest that using product components in service helps scale up the service. Moreover, with better insider knowledge of their own integral products, the industrializers have better control over the product components and are better capable of creating seamless services that cannot be easily imitated by third-party service providers. If expanding the point of analysis from a single product to the product system, it is feasible to integrate the existing products with certain type of standard services, such as the case of B&O integrated music system.

For an industrial standardizer, another method to differentiate from the competitors is the use of personalization during the service life-span. While customization in service is achieved by the employee configuring the service, personalization refers to the adaptation of the employee's interpersonal behavior (Voss and Hsuan, 2009). During the span of a service, personalization is applied through the whole process at every contact point between the customer and service employee (De Blok et al., 2013). Personalization assist the process of mix-and-match standard services for a customized package. By offering attentive personalization and recognize customer uniqueness, the length of time that a customer stays with the company can be extended (De Blok et al., 2013). In addition to effectuate customization, it is also likely that personalization makes the customer feel being serviced in a caring and attentive manner, which might increase customers' perception of the service value. Such value might be viewed as a compensate for the loss of degree of customization in the service content. Although the cost of applying personalization on a large scale might be high due to the extensive use of service employees and training, customers may associate the caring way of service with the brand value and image, which creates intangible value to the company.

To sum up, for organizations taking the role of industrial standardizer, it is advisable to consider: 1) adding unique service module and obtaining the benefits of large service volume by replication; 2) applying personalization as a point of differentiation.

## 5.3 Limitations and future research

This thesis has attempted to bridge modularity and servitization research area with the theoretical development of the servitization matrix. Two major limitations will be concluded. Firstly, due to lack of access to company data, some the analysis has been based on speculation and analogy. During the process of analysis, it is inevitable that the personal value and subjective judgements are incorporated into the interpretation of the data. Secondly, the choice of the cases does not perfectly into the context of servitization, which limits the applicability of servitization theories in the analysis.

Recognizing these limitations, several perspectives can be proposed for future research. First is to use in-depth case studies with both qualitative and quantitative data. Using quantitative models, such as the modularization function by Mikkola and Gassmann (2003) and service modularity function by Voss and Hsuan (2009), would lead to more objective comparisons of the architectures and characteristics between different cases. Second, the servitization matrix, as suggested by Hsuan et al. (2012), can be applicable to both single product as well as collective offerings. In this thesis, the focus was on multiple services on single product. It might be valuable to apply the matrix on perspectives such as PS offering, PS production process, and PS networks.

# 6 Conclusion

This thesis begun with the research objective in recognizing the role of modularity in servitization, and started with the research question of identifying the characteristics of product and service architectures, and proposing possible typologies for organizations to consider when combining product and services with different architectures into an integrated product-service offering. By comparing the models from servitization literature, this thesis found that although different typologies have been used in different literature, most of the type of product-service offerings can be categorized into product-, use- and result-oriented. Some literature has pointed out a servitized organization can flexibly offering a variety of services by selectively combining service modules. The review of modularity architecture implies that modular architecture generally utilizes a large number of standard components that can be shared across the product/service families, which leads to a large number of varied configurations. Mass customization can be achieved, allowing for customized outcomes to be produced and offered to customers on large scale.

Based on the characteristics of product and service architectures, this thesis has proposed four typologies. With a comparison analysis of two cases from the smartphone industry, the modular Ara phone and integral Apple iPhone, two of the typologies have been further discussed. Mass customizer offers standard service to modular product. With the aim of precisely fulfilling customer requirements, mass customizers should increase the variety of available modules and provide efficient method to involve customers in the process of co-design. Industrial standardizer provides standard service to integral product. By substituting a unique process module with a product that can carry out the service process, the industrial standardizer can increase the replicability of the service and offer the service at a large volume. Applying personalization in the service process might influence customers' feeling of uniqueness of the standard service.

This thesis has contributed to the theory building of the servitization matrix by proposing four typologies for the four quadrants.

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