Digital servitization and modularity: responding to requirements in use

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1 Introduction

A major challenge faced by manufacturers when moving into advanced services is providing bespoke service offerings at scale. Traditionally manufacturers have operated in a closed system in which products are designed for a fixed use. The traditional firm perspective on value is 'exchange': value is created at the point of exchange e.g. goods exchanged for money (Ng, G Parry, et al. 2012). Advanced services however, operate in an open system where value is phenomenological (Ng and Smith 2012), which is to say that value is emergent and co-created with customers who use service offerings in a variety of contexts (Smith, Maull, and Ng, 2014). To meet the different customer's requirements that arise from use in multiple contexts, service providers have relied on human resources to meet customer requirements, absorbing the variety of their emergent demands (Green, Davies & Ng, 2017). This chapter demonstrates how modularity and digitisation of a product can allow the product to be flexible, helping to absorb variety in use.

The chapter begins by discussing in greater detail the challenge to manufacturers in serving customer's varied requirements in use. It then synthesises the literature on digitisation and the modular systems theory, specifically focusing on the perception of modularity as a closed system, and the change to an open systems approach, underpinned by digital technologies (Davies et al. 2020). An example is then used to explore how modularity and digitisation can create a product that can be flexible to heterogeneous requirements in use.

2 Theoretical Background

2.1 Servitization as an Open System

Servitization describes an observed strategy where firms seek additional value by adding services to their core offerings (Vandermerwe & Rada, 1988). When servitization occurs in professional service firms, such as lawyers or consultants, the business model and approach to value creation remains the same. However, product centric firms such as manufacturers must develop new capabilities in order to create service-centric business models (Kowalkowski et al. 2016). In advanced services (Ziaee Bigdeli et al. 2018) firms move beyond the delivery of traditional services to offer customised, dynamic and complex services that adapt to customer's changing needs. The provider firms responsibilities are extended (Baines & Lightfoot, 2014) as an intimate understanding of the customers' operations is required if the provider is to support a customer’s core activities. Service providers must build a relationship with the customer that extends across the life-cycle of the service offering (Story et al. 2017).

Traditionally, manufacturers have designed goods in a closed system whereby a boundary is drawn between the producer and customer at the point of exchange (Kimbell 2011). Whilst this is in part reflective of the payment mechanism used to transfer ownership between the two parties, the boundary also allows organisations to separate design and context (i.e., where the product is used) such that product purpose and hence design is fixed(Garud, Jain, and Tuertscher 2008; Simon 1996) and customer requirements frozen in the form of stable specification of required functionality and performance attributes (Henfridsson, Mathiassen, & Svahn, 2014). As a result of the separation of design and context, many of the theoretical and practical insights developed within manufacturing new product development (NPD) adopt a stable process that requires structural and functional requirements to be specified during the design cycle and frozen prior to their transfer to the production department (Baldwin & Clark, 2000). When manufacturers draw their boundary they create a closed system where the customer and their context is treated as exogenous to the manufacturing organisation. Products are designed for fixed and predictable use, with value realised ‘in exchange’ across the boundary (Smith et al. 2014), e.g. a TV for money.

In services, the provider operates in an open system in which the boundary between the provider and customer, and between design and context, is blurred (Ng 2014; Ng and Smith 2012) The provider is involved at the point of use, so the focus of value is when the customer utilises the service providers resources to gain a benefit, co-creating value in use (Prahalad and Ramaswamy 2004). In advanced services providers shift their focus to enabling customers to realise desired outcomes of value within their specific use context (Smith et al. 2014); use-value is measured as the benefits customers gain in context (Akaka and Parry 2019). Value in use requires providers to understand contextual variety, which may stem from differences between individual customer preference, industries, and/or the physical environment in which an service is accessed (Palmatier 2008). Servicing heterogeneous customer requirements introduces complexity into the system; product manufacturers are no longer able to separate customer induced variety from their design and manufacturing processes (Ng, Maull, & Yip, 2009).

To address the service challenge, advanced services often utilise new technology (Green, Davies & Ng, 2017; Cenamor, Sjödin & Parida, 2017). Digital sensors embedded in products, (the internet of things [IoT]), can provide data to support digitally enabled advanced services [DEAS] (Vendrell-Herrero & Wilson, 2016; Kowalkowski & Brehmer, 2008). Provider firms can also benefit from advances in 3D printing, which when combined with a modular systems approach allows firms to tailor products to customers' requirements (Davies, Parry, Alves & Ng., 2020).

2.2 Modularity and digitisation

Digital components embedded in a product offer opportunities for value creation and capture through monitoring, control, optimization and autonomy (Porter and Heppleman 2014). Digital components operate to sense and capture information on the use and condition of products; to connect digitalised products through a wireless network; and to generate data to be analysed and transformed into useful insights and actionable directives (Lenka, Parida, and Wincent 2017). Digitisation also offers manufacturers the potential to engage in complex and dynamic interactions with customers e.g., using embedded sensors to analyse real time and historical user data to tailor maintenance and deliver increased operational efficiency (Parida et al. 2015). With such data, manufactures can identify and react to customers changing and emergent needs and customise offerings to meet heterogeneous demands (Lenka et al. 2017). Cenamor, Sjödin and Parida's (Cenamor, Rönnberg Sjödin, and Parida 2017) discussion on modular platform architecture highlighted the importance of the information module to understanding context and enabling the re-configuration of product and service modules.

Modularity is a general systems concept that allows organisations to offer both flexibility and efficiency in their offerings (Baldwin and Clark 2000). Modularity can be described as *'the degree to which a system's components can be separated and re-*

combined, and it refers both to the tightness of coupling between components and the degree to which the "rules" of the system architecture enable (or prohibit) the mixing and matching of components' (Schilling, 2000: 312). A modular system decomposes products and process into separate components or process stages, named 'modules' (Langlois and Robertson 1992). Modules are connected together by standardised interfaces, enabling modular systems to be readily adapted as components can be interchanged (Sanchez 1995). Baldwin and Clark (Baldwin and Clark 1997) highlight the importance of modular design rules for modular offerings, as these rules define the architecture that specifies which modules are created and their function within the system; the interfaces that loosely connect modules to one another; and the standards that ensure compatibility and conformity of modules across the system.

Modularity literature tends to favour a closed systems perspective, creating a boundary between design and use context (Ng, 2014). This follows Simon's (1962) scientific approach to design, where design and context are separated allowing firms to benefit from the ability to change aspects of the design during the development process (MacCormack, Verganti, & Iansiti, 2001; Ulrich, 1995), economies of scale in production (Salvador 2007), and the ability to leverage supply chain capabilities to incorporate modules designed and manufactured externally (Fixson 2005). Early specification supports module decoupling (i.e., one module can be changed without requiring changes in another module) and allows modules to be upgraded through life (Pil and Cohen 2006). The careful planning of the structural and functional elements, the decoupling of modules and definition of how they interface with one another, allows organisations to augment modules (add or change them) through a product life cycle (Wouters, Workum, and Hissel 2011). Gil (Gil 2007) refers to this as *planned flexibility*, which is useful when there is uncertainty in future demand. However, the freezing of the structural and functional elements pre-production effectively minimises the opportunity for re-design once the offering has been produced (Henfridsson, Mathiassen, & Svahn, 2014).

One of the key managerial decisions for modularity is the degree of flexibility planned into the architecture during design (Engel, Browning, and Reich 2017). Organisations embedding flexibility that permits future module augmentation (Baldwin & Clark, 2000) only provide limited flexibility in the form of differences in degree (Yoo, Henfridsson, and Lyytinen 2010). In closed systems, design decisions are made on the assumption that no rework of the architecture will be needed at a later date (Verganti 1997). Implicit in this approach is that all requirements can be captured in advance of use and that the scope of requirements remains stable once the offering has been designed, produced and exchanged with the customer for use. Following the closed system approach means accommodating change beyond the architectural specification defined during design is difficult and costly, particularly when change is made to the physical product (Davies et al. 2020).

Products with known long life cycles have flexibility designed in at the beginning. Unexpected advances in technology, development of new modules and emergence of new customer requirements, will likely render the architecture obsolete. This ultimately requires the product to be re-modularised (Lundqvist, Sundgren, and Trygg 1996), which can be done at high cost (Gil, 2007; Wouters et al, 2010). In advanced services, where requirements emerge in use and the organisation are required to match that variety in order to maintain a contracted level of performance (Ng, Parry, Smith, Maull, & Briscoe, 2012; Smith et al., 2014), closed systems are problematic when emergent changes are required that are not part of the designed ‘planned flexibility’. Davies, Parry, Alves and Ng (2020) find that organisations who incorporate emerging requirements post-production do so by diminishing the degree of modularity present in their architecture, losing efficiency gains and potentially increasing coordination costs through life; effectively impacting upon their long term viability.

Traditional approaches to product design limits flexibility post production, and so people are employed within systems to absorb variety in service. Ng & Briscoe (2012) encouraged the servitization community to consider how products can be made more flexible, stimulating innovation in design of delivery systems so products could absorb variety in use.

2.3 Optimising Me Manufacturing Systems: An Illustrative Case Study

Advances in manufacturing technology extend the scope of modularity to an open systems environment. This case study, drawn from an innovation in healthcare, illustrates how modularity and digital technology can be used to create a flexible responsive product and enable organisations to accommodate a degree of variety in use. The Optimising Me Manufacturing System [OMMS] is an innovation in the manufacture and delivery of immunotherapy treatment for certain forms of cancer. Traditional healthcare systems involve centralised, laboratory-based manufacture of therapeutics (medicine), which are treated as products. Drug delivery occurs in a separate hospital setting, perceived as the service. OMMS breaks from this, servitizing treatment by creating a micro-factory device that is worn on the body. The device monitors the patient, manufactures a bespoke therapeutic treatment and delivers it to them, all via an on-body system. Developments in material technology enable an automated modular system contained within the device, to responsively manufacture bespoke therapeutic treatments and deliver them to changing patient needs. The personalised medicines that OMMS will deliver are manufactured from an individual's own blood cells (Iyer, Bowles, Kim, & Dulgar-Tulloch, 2018 ; Piscopo et al., 2018).

One such example, CAR T cell therapy, removes, modifies and re-infuses a patient's own immune cells to attack cancer in their body.

The current process of manufacture and delivery of CAR T cell therapy is expensive, lengthy and contains potential risks. Blood cells are taken from a patient in hospital and transported to a centralised laboratory, where the cells are used as starting material for the manufacture of the therapeutic treatment. Manufacturing processes are labour intensive and undertaken by skilled operators, involve open handling and the use of many pieces of specialised equipment. Once manufactured, the therapy treatment is transported back to the hospital and administered to the patient. Transportation and other lab-based processes have potential risks in terms of contamination, operator error, and side effects to the patient (Iyer et al., 2018; Vormittag, Gunn, Ghorashian, & Veraitch, 2018; Wang & Rivière, 2016). The manufacture process is expensive, as is the patients' long stay in hospital under specialist care. Manufacturing and logistics processes may extend to 30 days, a long wait for patients with rapidly developing cancer (Olweus 2017).

Demand for the therapy is growing, but the potential benefits of the treatment can only be achieved if it is reliably delivered to patients at scale, with affordable costs, while meeting customers' heterogeneous requirements. To address these issues, a fully automated machine for closed, end-to-end processing was proposed by Kaiser et al., (2015), removing the need for transportation and preservation processes (Wang and Riviere, 2016) and allowing decentralised manufacture close to patient (Harrison, Ruck, Rafiq, & Medcalf, 2018; Kaiser et al., 2015). Automated manufacturing machines, an example of which is the CliniMACS Prodigy, are adaptable and can rapidly change between protocols using a different programme to manufacture specific therapies (Kaiser et al. 2015). However, the machines themselves are expensive, $155,000, must be used in clean rooms by specialised operators, use disposable items at $26,000 per patient, and can only manufacture for one patient at a time, which can take up to 24 days. Committing to this route locks the healthcare provider into a single source provider, their qualified related sundries, reagents and suppliers, and reduces flexibility of manufacture. The approach makes little difference to the patient experience, maintaining the product/service value in exchange ethos of centralised manufacture of the therapeutic product, with the service as the administering hospital.

The OMMS modular micro factory device offers an alternative solution that moves towards value in use. It is a wearable ‘sealed device’, located on the body, so risks associated with open handling and transportation are removed. Process stages are miniaturised and modularised to give portability, allowing mobility and potentially treatment in the patient’s home, lowering costs associated with long hospital stays, and transport and laboratory processing. The device will be 3D printed to fit the individual patient's body, enabling a secure fit, facilitating different use contexts. Internally, the device is formed of a set of distinct modules (Ulrich and Seering, 1988). Each module contains a processing unit, which performs a discrete function in the manufacturing stage. Modules are connected through standardised interfaces (Sanchez, 1995), which bind the modules together to form the process stages (Yoo, 2013). Blood is taken straight from the patient into the device where it is used as the starting material in the manufacturing process. The process is optimised for immediate delivery, which simplifies manufacturing (Ohno 1988; Womack and Jones 1996). Once manufactured, the therapeutic is infused directly to the patient, reducing time to treatment. The device is digitalizised (Vendrell-Herrero & Wilson, 2016), with biosensors embedded within each module connected to a data controller. Biosensors respond to an individual patient's starting material and make adjustments to physical elements within a processing unit (for example, modifying channel widths) to change manufacture pathways, creating a bespoke therapeutic product. Biosensors also test the product, constantly checking for cell viability and quality. Adjustments are dynamically, continually responding to patient's requirements in real time.

Through its modular design, use of digital technology, and the dynamic functionality of physical elements contained within the modules, the OMMS micro-factory enables the hyper-local manufacture and delivery of a bespoke therapeutic product at scale (Salvador 2007). The flexibility of a modular system combined with 3D printing offers three further benefits: First, modules can be rapidly combined in response to patient needs: decisions about the form and function of the device can be postponed until requirements emerge in use (Davies, Parry, Alves & Ng, 2020); Second, in the development stages of the OMMS system, the device can be augmented for additional functionality (Wouters et al. 2011). Due to high standards of manufacture and the need for clinical trials, innovations in healthcare can take many years to come to market. Through the use of modular design, a proto micro-factory can be manufactured in the early stages of development, to perform one or two processes in treatment manufacture, with additional modules incorporated as they are approved for clinical use. This has the additional benefit of allowing time for more gradual socio-technical adjustments to the new healthcare device, increasing the chances of success of the innovation (Walrave et al. 2018); Third, modularity will allow for the replacement or upgrade of individual modules (Pil & Cohen, 2006).

Combined, these benefits enable the OMMS system to provide a bespoke treatment, delivered to the patient within their own context, maintaining contractual agreements with healthcare providers, while incorporating technological and medical advances into the service delivery system (Ng et al., 2012).

3 Discussion

3.1 Theoretical contribution

Using an example from health care innovation, modularity is shown to enable service providers to meet heterogeneous requirements in use, supporting the argument for an open systems approach in modularity theory, enabled by digital technology (Davies et al. 2020). In a closed system, designing for contextual variety entails segmenting customer groups and designing a targeted service provision based on generalised characteristics of the group (Palmatier 2008). Using the OMMS example, this would involve sizing one device to fit a child and another fit an adult, and having a set number of treatment pathways. In an open system, device size and shape are not predetermined, but are responsive to an individual patients' body shape. Equally, the OMMS system treatment pathways are dynamically responsive to requirements in use.

Servitization literature is commonly concerned with the ways in which firms create value through services that are additions to their products. The current CAR T treatment is a product (the therapeutic) delivered within hospitals as part of a health service system. The move to small scale product manufacturing via automation using the CliniMACS Prodigy manufacturing platform shifts therapeutic production from a centralised to decentralised locations. This impacts the logistics process, but it does not alter the service experience provided to the patient. The patient remains in the hospital and is the recipient of the therapeutic product delivered within the hospital setting. The OMMS device seeks to create an advanced service, delivering therapeutics within contexts beyond the hospital bed, responding in real time to patients' changing treatment need whilst contributing to the quality of their life.

The OMMS example highlights the potential of a product to adapt and absorb variety and thus improve a service offering. In the existing literature, products are perceived as fixed parts of the service. The product is an operand resource (Vargo and Lusch, 2004) as it is perceived as static. The people who form the surrounding support are the operant resources and are dynamic, helping to absorb variety through application of their skills to ensure the therapeutic is correctly manufactured and delivered safely to the patient. Through the application of modularity in combination with digital technologies, the physical product can become flexible and contributes towards the ability of the system to adapt to requirements in use, in a scalable manner.

Modularity and digitalization pose a new challenge to established service systems. Doctors will need to develop new knowledge competences as services move from skilled operators monitoring therapeutic manufacture, towards medical devices that undertake manufacture and analysis and output digital information (Harrison et al., 2018). The OMMS device enables treatment to be delivered in new service contexts; therapy delivery is potentially moved from a hospital setting to the patient's home. Further research is required to understand what changes in human resources may be needed in response to flexible, digitised products.

4 Conclusions and managerial implications

This chapter has challenged a number of assumptions surrounding the physical product within servitization. Building on existing research discussing modular solutions, this chapter has proposed an alternative pathway that integrates an open systems perspective that acknowledges complexity manifests from variety in use and that the product is able to help absorb some of this variety. Accepting an open systems perspective allows us to move beyond normative assumptions that the product is fixed and stable in use and start to understand how to design for open systems characterised by emergence and customer endogeneity.

This has a number of implications for practising managers. We highlight how variability introduced by the customer in their context has implications for the viability of the service system. By acknowledging the customer is endogenous, a challenge for practice is how to optimise the whole system, which includes the context of use and customer resources, as opposed to just the organisations delivery system that traditionally treated the customer as passive or exogenous to the system. This requires a shift away from a one-sided, product centric view of servitization toward a more holistic view of the service system as mandated by more advanced service contracts. Whilst a number of challenges still exist and the illustrative case we have used is novel, the core findings presented are useful at a general level for organisations to begin thinking about how an open systems perspective could create new sources of competitive advantage.

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