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Matching reuse models to hospitals: Reframing value-chains for reusable medical products

Charlotte Harding[(a)], Regan Watts[(a)], Paola Travella[(a)], Gunter De Win[(b,c)], Ingrid Moons[(a)], Els Du Bois[(a)]
a) Department of Product Development, Faculty of Design Sciences, University of Antwerp, Antwerp, Belgium
b) Antwerp Surgical Training, Anatomy and Research Center (ASTARC), Faculty of Medicine and Health Sciences, University of Antwerp, Antwerp, Belgium
c) Department of Urology, University Hospital Antwerp, Edegem, Belgium

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Abstract: In the transition towards a circular economy, also critical sectors such as the healthcare sector need to be reviewed. A large portion of hospital waste consists of low-value, disposable consumables. Currently, the circular design strategies of reuse, maintenance, and repair in healthcare are predominantly applied to high-value products. This study proposes four reuse value-chain models specifically for small, low-cost medical consumables. Reuse models are distinguished on reprocessing location (internal or external) and product usage (shared or personal). Business model evaluation and value propositioning are used to gain understanding of the models and a co-creation session with a MedTech company verified these understandings. Our research sought to support manufacturers of reusable medical products by addressing the importance of the fit between the reuse model and the hospital's context (location, infrastructure, staffing, organisational structure, product volume and type). These context features, as well as the hospital's interest in reusable products should be documented in the tendering documents of the purchasing process. Internal reprocessing makes the hospital more self-sufficient but requires additional staffing for reprocessing and quality control. External reprocessing decreases the hospital's workload, but requires the involvement of additional service partners. For all reuse models, continuous communication and collaboration (feedback, training and guidance) between the hospital and value-chain partners are vital.

Introduction

Disposable products used in healthcare are causing excessive waste production and risk the further depletion of natural resources and energy (Janik-Karpinska et al., 2023). Most healthcare professionals have an aversion to the negative impact created as a by-product of their professional activities (López-Medina et al., 2022; Yap et al., 2023). One of the solutions include a transition to product circularity, where a used product is collected, cleaned, inspected, maintained and brought back for a next use-cycle (Keil et al., 2023; Macneill et al., 2020; Ramos et al., 2023). This was historically a common practice, but innovations of new materials, more complex medical devices and safety considerations have pushed the development of new value-chains and product logistics since the introduction of disposable products (European Commission, 2010). In recent years, environmental awareness has grown and some manufacturers and suppliers start to offer reusable products (Chauvet et al., 2024; Drew et al., 2022; Vozzola et al., 2018). However, many companies still face challenges in effectively supporting hospitals and providing more optimised products and services.

Objective

In this study, we focus on reuse of medical products to reduce waste generation. Our analysis will concentrate on small medical consumables including medical textiles, using these to compare different reuse value-chain models for Class I devices according to the Medical Device Regulation (European Union, 2017).

Background

Previous research has highlighted design strategies aimed at increasing circularity in medical design (Hoveling et al., 2024). Kane et al. (2018) identified three key factors influencing circular medical design: hygienic

device criticality in terms of sterilisation requirements, financial product value, and organisational support structure surrounding the device. Based in these factors, design strategies were defined. The principles of the Circular Economy, aim to keep products at their highest utility and value, prioritising repair, maintenance and reuse over refurbishing, repurposing and recycling (Ellen MacArthur Foundation, 2015). Consequently, our interest goes out to **design optimisation for hygienic recovery**, such as reuse through sterilisation, to ensure safety and effectiveness. Building on this, Guzzo et al. (2020) proposed nine circular business models (CBMs) for the medical device industry based on existing cases. Two CBMs stand out from a reuse perspective, but are applied to medium to high-value product categories. In the CBM '*Hospital-based reprocessing support'*, materials and services are provided to facilitate the reprocessing of medical equipment within the hospital (**internal reprocessing**). The service can be provided for various levels of disinfection, ranging from surface cleaning to full sterilisation. In the CBM '*full provision for reprocessed devices'* medical products are collected in the appropriate container at the hospital. Thereafter, a service provider or external sterilisation facility collects the products, verifies, sorts, reprocesses, inspects and repackages the medical products so that they can be put back into circulation at the hospital (**external reprocessing**). Based on our previous research into the reuse of medical (textile) products, some items can be shared and others are preferred or required to be personal. **Shared products** such as surgical gowns, drapes or positioning pillows can be collected together and do not necessarily have to be reused by the same person . For products such as a radiotherapy mask, **personal use** is necessary. Face masks and incontinence briefs are other examples of products where personal use can be selected.

Study objective

Reusable products in hospitals require correct sorting and streamlined reverse logistics. Different stakeholders have to work together to succeed (Sattari et al., 2020). The involvement and coordination of stakeholders shape the reuse value-chain of a product. We hypothesize

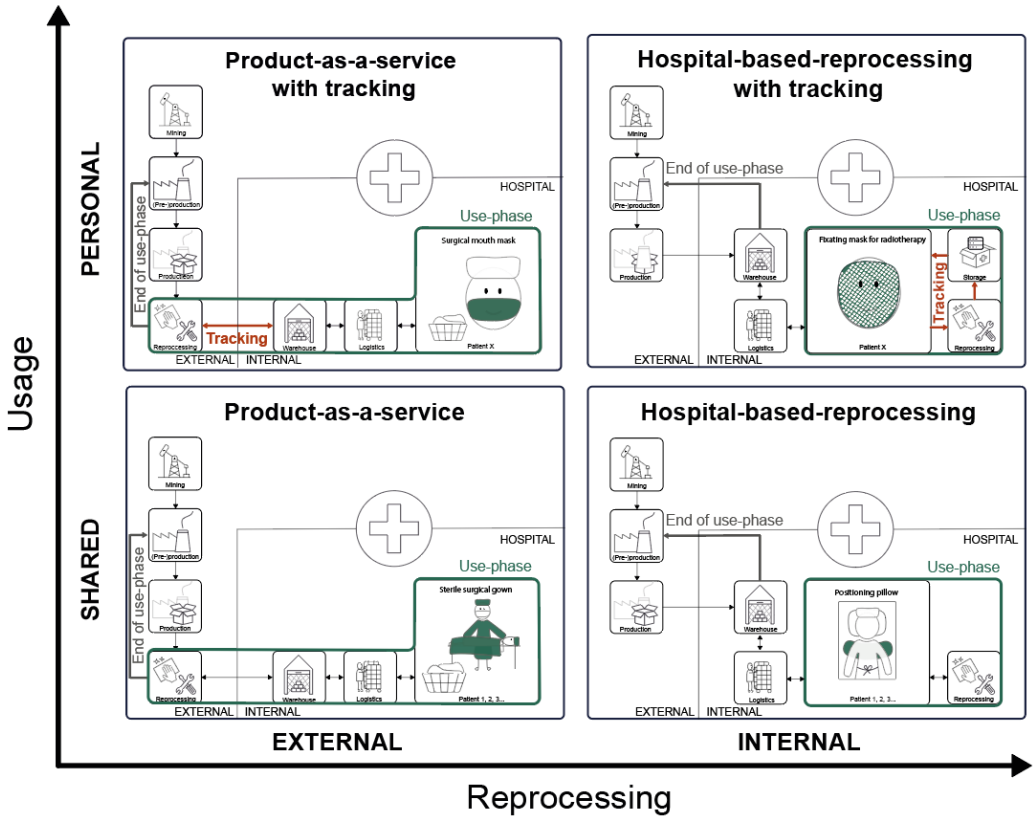

Figure 1. Four reuse value-chain models in hospitals, which cluster around whether the use is shared or personal and whether the reprocessing of the medical product occurs on-site or externally.

that four reuse models are distinguished based on location of reprocessing and the use of the product (Figure 1). Some hospitals have the infrastructure to support reprocessing of products in-house. Others, need to rely on external service partners that can do reprocessing for them. Whether the reprocessing takes place in the hospital itself or not has an impact on which (additional) partner should be involved. Furthermore, some products need to be tracked in order to ensure that a personal product can be returned to the patient it belongs to. The type of use, either shared or personal, also affects the logistical and infrastructural organisation of reuse. To return products to their personal user, the product must be traceable by e.g. a barcode or chip depending on the appropriate situation. This study aims to analyse and compare the four reuse value-chain models by identifying their similarities and differences. We seek to explore whether different reuse models necessitate distinct business models or if they can be integrated. Additionally, we will examine the value propositions of these models and extend the analysis to include the supplier perspective.

Methods

Defining reuse value-chain models

Using the Circular Design Map from Switchrs (2019) a framework of four reuse value-chain models (Figure 1) was hypothesized to position different approaches of reprocessing in healthcare. For each reuse model, a (simplified) value-chain from mining to the use-phase and to the end of use-phase is mapped out and illustrated with an example product.

From concept to value: business model canvas and value proposition

To gain a deeper understanding of how the reuse models differ or align, a workshop (March 2023) with nine design researchers was carried out. First, an adapted business model canvas (Guzzo et al., 2020; Osterwalder & Pigneur, 2010) for each reuse value-chain model was filled out. The canvas consists of 3x3 frames (Table 1 and 2). The value creation is composed of stakeholders, activities and resources. Value capture can be described for: organisational profit, benefits for people and planet. Then, value delivery is achieved by a combination of customer relationships, channels and segments. The business models (BM) were completed from the view of the hospitals. Secondly, a Systems Value Proposition (Jones & Van Ael, 2022, pp. 124–127) was construed for the reuse model for shared products with internal reprocessing and the model for personal products with external reprocessing. The Systems Value Proposition is a tool that can be utilised to present the value proposition for larger systems where multiple parties benefit. Value can be created at three levels: individual (staff and patient), organisational (for the hospital), and societal (society and the value-chain partners). Additionally, there are four dimensions that describe the economic, ecological, psychological, and social value for the system. At the end, a discussion on the differences and similarities of the four reuse models was held. We employed purposive sampling to select participants with relevant expertise in research related to value-chains, product reuse and stakeholder management, ensuring they could provide meaningful input.

Broadening and verifying the reuse value-chain model: supplier perspectives

Additionally, to expand and verify our understanding of the reuse value-chain models a co-creation session with a MedTech company was performed. Currently, the company offers a disposable product (Class I – non-invasive according to MDR) for hygiene reasons, which is unfortunate as high quality materials are used. Additionally, reuse could lead to cost savings by distributing the purchase cost across multiple (re)use cycles. The goal of the co-creation session was to gain a deeper understanding of the value-chain of the specific medical product. Together with the CEO and product engineer of the company, the current value-chain of the single-use product was mapped out. Stakeholders and steps were added to refine the value-chain along the procurement of materials, production, distribution, regulatory requirements, potential for reprocessing during the use-phase (internal/external), options for the end of use-phase, and after-sales services. The involved partners and usage steps were also discussed. By reviewing these stages, the product's value-chain was further detailed. An alternative reuse cycle was then proposed, using a different colour to indicate the partners, materials, energy requirements, and costs. Attention was given to different methods of reprocessing and end-of-use options.

Results

A framework for reuse: value-chain models by reprocessing location and product usage

As shown in Figure 1, four types of reuse models could be identified: **Hospital-based reprocessing:** The hospital manages the medical product reprocessing. Some items require only surface disinfection, such as wipes in treatment rooms, while others need thorough cleaning or sterilisation by central hospital services like the laundry or sterilisation department. Reusable items, like positioning pillows or support blocks for arms and legs in the operating room, can serve multiple patients if properly cleaned between uses. **Hospital-based reprocessing with tracking:** In this reuse model, the hospital manages product reprocessing and assigns each product to a specific patient or user. For example, a radiotherapy mask, custom-fitted to ensure precise targeting during radiation treatment, must be stored for the patient's subsequent therapy sessions. This system requires tracking the product through barcodes or RFID chips, allowing them to be linked to a specific patient or surgeon. This model also applies to surgical instrument sets and loaned products, such as crutches, which require cleaning and maintenance. **Product-as-a-service:** Most reusable textile products, such as staff uniforms, bed linen, reusable nappies, or absorbent pads (also known as incontinence pads), follow the product-as-a-service model. After use, these items are laundered. The following day, a fresh uniform or bed linen is taken from the hospital's stock for use. This model works best when products stay in circulation and are not left unused in storage, ensuring optimal use of available products. Due to the high consumption of these items, hospitals often partner with external services. In the case of textile products, this partner is often a laundry service, which may take over some of the hospital's responsibilities, ranging from core tasks, like laundering, to managing textile logistics and inventory control. **Product-as-a-service with tracking:** This model involves an external partner and requires each textile item to be traceable to an individual user. Personal use demands a higher number of items per user in circulation compared to products are shared among users. However, for certain products, there is often discomfort or distrust in sharing them with others. This usually applies to items in contact with intimate hygiene, such as face masks or incontinence briefs. Despite cleaning processes that ensure rigorously monitoring and thorough removal of contamination, some users may feel more at ease with personal use of such products.

Designing for value: comparing and aligning business models and value propositions

For each reuse model, a BM was created. BM's for shared and personal products showed clear similarities, so they were combined into one canvas for external and another canvas for internal reprocessing. The canvasses are shown respectively in Table 1 and Table 2, with additional notes in same frames distinguishing shared from personal use. Differences between external and internal reprocessing across the three value levels are:

VALUE CREATION: The external reprocessing model requires **additional key partners,** such as laundry and logistics service partners. These external services can be complemented by a Work Integration and Social Enterprise (WISE), that specialises in customised (manual) labour. Internal reprocessing, adds the hospital's responsibility for cleaning and **quality control** of the products (key activities), increasing its workload. This requires additional resources like energy, water, laundry facilities, packaging solutions, storage space, and certifications. Personal products need **tracking** and tracking infrastructure for external and internal reprocessing. When external reprocessing is chosen, the cost for the IT-infrastructure could be divided over multiple hospitals.

VALUE CAPTURE: External reprocessing makes hospitals reliant on the supply chain, while internal reprocessing ensures **self-sufficiency**. With external reprocessing, staff can be sure that the **service partner maintains product quality**, safety and reliability. Additionally, shared products in external systems offer **volume advantages**, as they can be used by different users across multiple hospitals, maximising product use. Lastly, depending on the country, personal products with internal reprocessing may be eligible for (partial) reimbursement of a personal treatment by the patient's health insurance.

Interestingly, the frames for value capture for the planet, and VALUE DELIVERY (channels and customers segments) are similar for internal and external reprocessing, as they align with the overarching goal and remain unaffected by the chosen approach.

Closer analysis of the BM's in Table 1 and 2 reveal that the value propositions are similar. The Systems Value Proposition tool highlights that the most prominent value is created at the organisational level, such as reduced CO2 emissions, resilience to shortages, decreased raw material use, and mindset change. Societal value creation is also significant, including staff flexibility, visibility among colleagues, and shared efforts. At the individual level, value creation is most evident with personal or intimate products, enabling tailored care, improved treatment, and enhanced trust and safety.

Verification study: linking hospital and supplier's perspectives

The co-creation session contributed to a better understanding of the value-chain for a medical product. During the development of an alternative reuse cycle, external and internal reprocessing options were explored.

EXTERNAL REPROCESSING for personal and shared products

Product-as-a-service (with tracking for personal products)

Value creation	Value capture	Value delivery
Key stakeholders *Who are the key partners in the system?* Producer, Social Work Integration Ent., Legislators, Medical personnel, Patient, Logistics partner, Laundry service, Purchaser (tender procedures), Hospital (departments: hygiene, management, logistics)	**Profit** *Potential value captured by organisations* Builds hospital's environmental image, Decreasing waste costs, Decrease purchase cost, Job creation through social work integration **ONLY FOR SHARED PROD.:** Volume advantage	**Customer relationships** *Which relationships need to be maintained to offer the business model?* Delivery of clean products, Reprocessing service, Customer loyalty
Key activities *What is performed to deliver the value proposition?* Stock control and ordering, Collection and transport, Data management, Training (correct use and collection) **ONLY FOR PERS. PROD.:** Tracking	**People** *Potential value captured by individuals, ecosystem and society* Ecosystem society dependence, Qualitative products (comfort), Activation of target groups through job creation, Reliable product, Safety assurance	**Channels** *How do you reach your customer segments?* Experience other hospitals, Raising awareness, Internal consultation, Green deal sustainable care, Exhibitions, Website or (social) media, Sales person, Internal information session
Key resources and capabilities *What resources do you need to deliver the value proposition? (technological, natural resources, energy sources)* Collection recipient, Data infrastructure, Staff (hospital logistics) **ONLY FOR PERS. PROD.:** Tracking infrastructure	**Planet** *Potential value captured by the environment* Decrease in resources/material consumption, Decrease waste and incineration	**Customer segments** *Who are your customers?* Patient, Medical personnel

Table 1. Overview of the business model canvas evaluation for external reprocessing from a hospital's perspective.

INTERNAL REPROCESSING for personal and shared products

Hospital-based-reprocessing (with tracking for personal products)

Value creation	Value capture	Value delivery
Key stakeholders *Who are the key partners in the system?* Producer, Legislators, Medical personnel, Patient, Purchaser (tender procedures), Hospital (departments: hygiene, management, logistics), Waste management company	**Profit** *Potential value captured by organisations* Builds hospital's environmental image, Decreasing waste costs, Decrease purchase cost	**Customer relationships** *Which relationships need to be maintained to offer the business model?* Efficient hospital logistics, Cleaning in minimum time with maximum ease of use, Communication between hospital departments
Key activities *What is performed to deliver the value proposition?* Collection and transport (in and out of storage), Cleaning, Quality control, Data management, Storage, Training (correct use, cleaning and storage conditions) **ONLY FOR PERS. PROD.:** Tracking	**People** *Potential value captured by individuals, ecosystem and society* Ecosystem society independence **ONLY FOR SHARED PROD.:** Access to care for patient due to lower cost **ONLY FOR PERS. PROD.:** A personal health insurance company can be involved for (partial) reimbursement of a personal treatment	**Channels** *How do you reach your customer segments?* Experience other hospitals, Raising awareness, Internal consultation, Green Deal sustainable care, Exhibitions, Website or (social) media, Sales person, Internal information session
Key resources and capabilities *What resources do you need to deliver the value proposition? (technological, natural resources, energy sources)* Energy and water, (Expansion of) laundry dept., Packaging solution, Storage room, Certificates, Data infrastructure, Staff (cleaning, logistics and storage) **ONLY FOR PERS. PROD.:** Tracking infrastructure, A designated storage space is needed for personal items	**Planet** *Potential value captured by the environment* Decrease in resources/material consumption, Decrease waste and incineration	**Customer segments** *Who are your customers?* Patient, Medical personnel

Table 2. Overview of the business model canvas evaluation for internal reprocessing from a hospital's perspective.

The reuse value-chain for *hospital-based-reprocessing* was completed based on input from the co-creation (Figure 2). Notably, the session provided a comprehensive insight into the supplier and producer side. However, it did not enhance our understanding of in-house processes and logistics within hospital departments. This is because the company uses a distributor to supply its product and does not have direct contact with hospitals. Technical, organisational and practical aspects for transitioning to reusable products were identified:

1. VALUE CREATION/DELIVERY: It is generally **easier for distributors to sell** a disposable product because its use is already known to the hospitals. Disposable products provide more margin/sales and an assured purchase flow. At the same time, there is increasing demand from hospitals for durable products. By offering these, the distributor can differentiate themselves positively. However, knowledge on hospital needs are essential to optimise offers.
2. VALUE CAPTURE/CREATION: Reuse in this case can only be achieved by introducing a low-cost auxiliary tool to **ensure hygiene**. Further studies should assess whether this extra activity is acceptable to staff. Technical feasibility should also be **monitored** to ensure patient safety (e.g. counting the reuse cycles).
3. VALUE CAPTURE: Hospitals are currently deterred by the higher price for a reusable product. It is a complex process to correctly estimate price for a reusable product where the price is spread out over multiple uses.

Discussion

This study aimed to identify a fit between hospitals and reuse models, while uncovering valuable insights from the value-chain to facilitate the adoption process of reusable products in healthcare. Each hospital has its own distinct features, such as location, organisational structure, and available infrastructure. Consequently, the hospital must choose the reuse model that suits its context. The purchasing department of the hospital can communicate these context features in a tendering document. To increase the chances that reusable products can be implemented, the hospital should also **include reusability in the tendering process**. Another aspect interesting in the implementation process is the **ownership** of reusable products, as detailed by

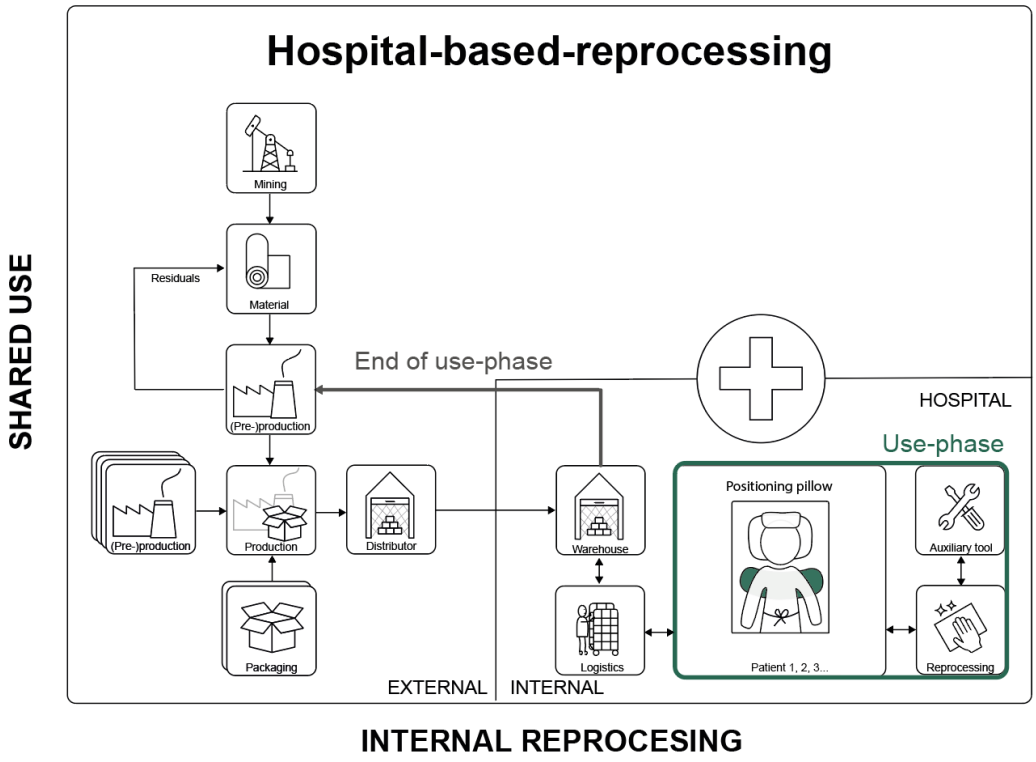

Figure 2. Hospital-based reprocessing model after co-creation. A distributor, different suppliers, recovery of residues, and an auxiliary tool in the use-phase are added to the value-chain.

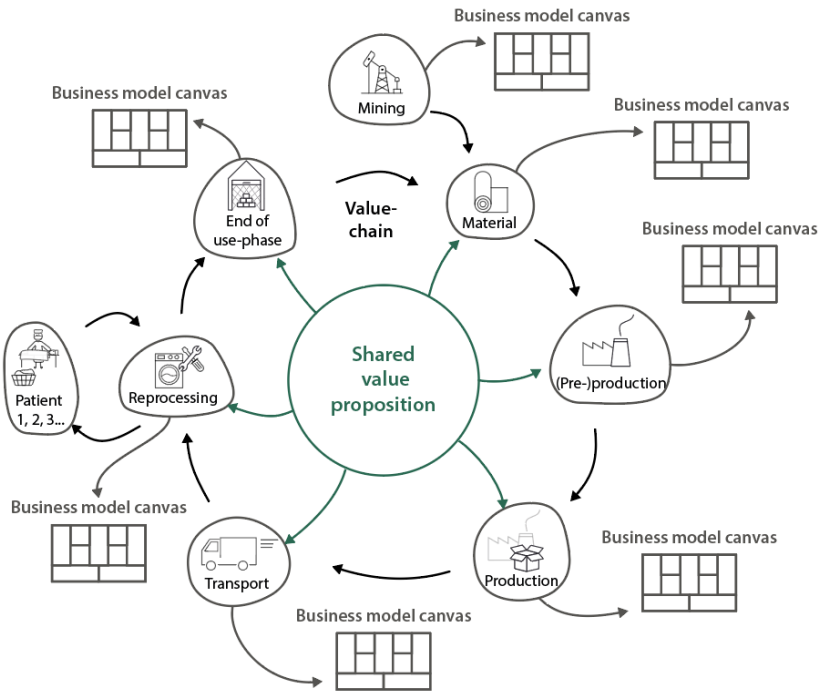

Figure 3 Stakeholders around a shared value proposition

Mahmoudi & Parviziomran (2020). In the case of external reprocessing, hospitals can either lease products owned by the service provider and pay per use, or they can purchase their own reusable products and have them reprocessed by the service partner. Furthermore, to ensure value creation of a reusable medical product, the value-chain is organised around a central, shared value proposition, e.g. the successful reuse of medical (textile) products (Figure 3). This can be a product, service or product-service system (Scholtysik et al., 2023; Tukker, 2015). Each player in the value-chain provides a specific value to another stakeholder, with each holding their own unique BM. To bring a reusable medical product to market, the **desired future value-chain can be mapped out**. This involves considering how the product will reach healthcare institutions and determining the relationships or value exchanges needed between the players within the value-chain. Bressanelli et al. (2019) identified supply chain management challenges for the Circular Economy, suggesting supply chain integration and development of partnerships and trust among partners as a requirement for information sharing. Consequently, knowledge (for every player) on what happens in each step of the value-chain is of critical importance for successful implementation. There are several learnings for the value-chain (manufacturers, reprocessors and potential support partners) that could enhance the introduction and implementation of reusable products. Effective hospital support depends on seamless **collaboration** across the value-chain. For internal reprocessing, collaboration between hospitals and producers is essential, as the producer supplies the reusable products and, where necessary, any supplementary cleaning tools. Ongoing interaction between these partners typically includes training and guidance on proper use and reprocessing methods. For external reprocessing, the primary objective is to reduce the hospital's workload by delivering ready-to-use products through a reprocessing service partner. Manufacturers and reprocessors must coordinate to establish an efficient and consistent cleaning process. Additional partners, such as WISE or automation companies, could further support reprocessing, depending on the nature of tasks involved. For flexible, small-batch cases, WISE partners provide adaptable labor solutions; for high-volume, repetitive cases, automation offers greater efficiency. Collaboration with a WISE enhances local job creation through activation of target groups (these groups typically include individuals with greater distance to the labour market) (Opstal & Borms, 2023). Collaboration across the value-chain could be enhanced

through platforms such as Green Deals at a governmental level (Departement Zorg, 2024), which align industry and government partners toward European Green Deal climate goals (European Commission, 2024). These platforms facilitate initial connections and opportunities for small-scale pilot tests, laying the groundwork for sustainable partnerships in healthcare. Lastly, **product tracking** can offer simplified return processes (Scholtysik et al., 2023), improve coordination among partners and monitor product state and usage. This helps mitigate operational risks and prevent careless behaviour in product usage (Bressanelli et al., 2019). For instance, the number of washing cycles performed or the energy consumed can be tracked and retrieved at any time, supporting effective maintenance though the use of IoT technologies.

Conclusions

In this paper, the goal was to determine whether reusable products in hospitals can be implemented using CBMs for product categories considered less valuable and therefore more challenging to execute as a sustainable business practice. We analysed possible reuse models, along with their respective BM and value proposition. While hospitals play a central role in shaping the reuse model, it is crucial that value-chain partners understand hospital processes and potential challenges. To enrich our insights from the supplier's perspective, we conducted a deep-dive session to address these aspects. The four **reuse models** each have their own advantages, and they can coexist effectively within a single company or hospital. The **choice of the most suitable model** typically depends on hospital-related context such as the location, staffing, the level of responsibility the organisation is willing or able to take on, the volume of product usage, the type of product, and the existing or required infrastructure. Developing reuse models in healthcare **requires close collaboration** between value-chain partners and hospitals, as they share a common value proposition but hold distinct responsibilities. **Hospitals can take a leading role by clearly outlining their specific needs and context**, guiding partners in fulfilling their unique roles. Future research should also consider whether involving a WISE or automation partner could improve value-chain efficiency. Finally, given the importance of collaboration and defined responsibilities among stakeholders, research that is mapping out the specific stakeholders involved in each reuse case could offer valuable insights for a comprehensive overview of the process.

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