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Redesigning single use to reuse: identifying opportunities for surgical instrument sets

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Abstract: Hospitals have a significant impact on the environment due to their size, energy-intensive processes, consumption of resources and waste generation. A trend of increased reusable products usage and so re-sterilized products is becoming visible. Nevertheless, reusable products have to compete with the added values of single use regarding convenience, effort and costs. Although the concept of reusable sterile surgical instrument sets seems valuable to reduce resource consumption compared to single-use instruments, their use is threatened by multiple inefficiencies. This case study aims to understand why the sterile sets usage is not optimal, what the consequences are for the various departments, what journey they take within the hospital, and how communication occurs regarding these sets. Observations and in-depth interviews were conducted in operation rooms, central sterilization department and the healthcare logistics department of a large sized university hospital. This led to a roadmap of the sterile surgical instrument sets within the hospital through each department involved. Using the roadmap, several critical points are discussed to design optimal reuse contexts in hospitals. In sum, we found that sets are often incomplete due to (i) a lack of turnover time for checking completeness, (ii) difficulty of recognizing specific instruments based on their name, (iii) lack of a good communication system to communicate incompleteness. Additional unwanted waste is created due to (iv) extra sets that are opened as a precaution for missing instruments, (v) unused instruments are thrown away or re-sterilized, (vi) broken sterility due to storage problems, which requires repackaging and re-sterilization.

Introduction

Hospitals have a significant impact on the environment due to their size, energy-intensive processes, consumption of resources and waste generation (Hunfeld et al., 2023; Pencheon, 2009). The increasing amount of medical waste, most of it coming from the operating rooms, is a growing concern. This escalation is linked to the aging population requiring more care, the extensive use of disposable products and sterilized products and their packaging used in surgical procedures (Conrardy et al., 2010; Ertz & Patrick, 2020; Harding et al., 2021; World Health Organisation, 2024). Despite a trend towards increased use of reusable products due to rising awareness and willingness among healthcare workers to reduce waste, reusable products must compete with single-use items in terms of convenience, effort, and cost.

In this research, we focus on reusable surgical instrument sets, which combine medical devices (MD) into one sterile package per specific surgical procedure shown in (Figure 1 (a). The sets are organized based on specific rules related to operation sequence and user requirements and are organized per medical procedure. The MD are packed together in net baskets made of stainless steel and another packaging layer, as shown in Figure 1 (b), to ensure sterility up to the moment of use and should allow for an aseptic presentation (FPS Public Health, 2017) Based on previous research , (Ahmadi et al., 2019; Nast & Swords, 2019; Van De Klundert et al., 2008) the following problems are indicated that hinder efficient usage of reusable surgical instrument sets and could limit further usage and extension: (i) Surgical instrument sets are often incomplete (Thomasson et al., 2016). As a result, additional sets must be opened regularly. (ii) Even when only one instrument is used from the set, the entire set is unsterile and must go through the sterilization process again in its entirety. (iii) Re-sterilization requires a lot of water, energy, and packaging materials. Moreover, (iv) it is costly. In addition to the cost of sterilization itself, the cost of transportation, storage, and instrument use also increases. Furthermore, an investigation of intraoperative equipment failure reports that (v) issues with surgical instruments occur unacceptably high (Efthymiou & Cale, 2022).

Figure 1 (a) Surgical instrument set with MD and (b) packaging layer.

In the University Hospital Antwerp (UZA), Belgium, the tertiary referral hospital for this study, an average of 250 sets are re-used and sterilized daily. This means that about 90,000 sets must be packed every year. Each set requires a polypropylene cloth, protective liners and indicator tape. These packaging materials are not reusable, creating 2.6 tons of waste per year for only UZA. Knowing that Belgium has 103 hospitals (of varying size), an impression can be created on the total amount of waste. We argue that a significant part of this could be avoided if the reuse system of these surgical instrument sets were optimized.

The objective of this case study is to examine the practical challenges that impede the effective use and management of reusable sterile surgical instrument sets, further referred to as 'sets'. This study aims to pinpoint opportunities for enhancing and optimizing the usage cycles of these sets. By combining sustainability and convenience, this research seeks to propose solutions to mitigate current issues with reusable surgical sets and to increase their adoption.

Materials and Method

This study utilized a qualitative approach to examine the reuse cycles of surgical instrument sets at the University Hospital of Antwerp (UZA). Three stakeholder groups were included: (i) operating room (OR) staff, (ii) Central Sterilization Department (CSD) staff, and (iii) logistics personnel. These groups provided insight into the processes, challenges, and opportunities associated with set management.
The research was conducted sequentially across departments, beginning with the OR, followed by the CSD, and concluding with logistics. This order allowed findings from each department to inform subsequent observations and interviews. A convenience sampling technique was used to select surgeries and staff based on their availability and relevance to set management issues. Surgeries involving urology and gynecology were chosen because these specialties frequently encounter problems with surgical sets, and their personnel were motivated to participate in improvement efforts.

Operating Room (OR):
In the OR, four surgeries (totaling 10 hours of observation) in the urology and gynecology department were observed. Observations were structured to record detailed information on instrument use, waste disposal, and the management of incomplete or missing instruments. The researcher mapped the OR layout, documented workflows, and recorded each action in a standardized template. During surgeries, two main aspects were observed: (i) instrument and product usage, including instances of incorrect disposal, and (ii) unused instruments. In later observations, specific questions were posed to OR staff to clarify their handling of set-related issues and communication methods.
Between surgeries, brief, focused discussions were conducted with three OR nurses to gather their perspectives on set usage challenges. Key questions addressed (i) common issues with sets, (ii) primary difficulties encountered, (iii) current problem-solving methods, and (iv) inter-departmental communication practices.

Central Sterilization Department (CSD): Here, data collection began with an in-depth interview and facility tour led by the head nurse, who provided background on CSD tasks, challenges, training, and inter-departmental communication. The observation day (totaling 8 hours of observation) was divided into sessions within each of the CSD's three zones, where staff were shadowed and asked to explain each task's purpose, key challenges, and details regarding the handling and processing of sterile sets. Special attention was given to differences in set contents and technical specifications. Observations were documented using a template, and photographs were taken to capture specific processes.

Healthcare Logistics Department:
The logistics study consisted of a structured interview and tour with the head coordinator. Questions focused on logistical processes, communication with the OR and CSD, and inventory management challenges. A step-by-step tour provided insight into the storage systems, transport, and workflow.

All observations and interview notes were transcribed and coded to identify recurring themes, patterns, and discrepancies between departments. Data were analyzed to pinpoint specific procedural inefficiencies, communication gaps, and opportunities for improvement in set reuse. Findings were organized by stakeholder group to facilitate comparisons and identify overarching issues affecting the instrument management cycle across departments.

Results

The results describe the workflow analysis and critical issues that were identified for each researched department. These formulated critical issues directly or indirectly affect the optimal usage and consequently the ecological impact of the sets.

Results of the Operating Room

During the observation in the operating room, the following workflow analysis was conducted, as shown in Figure 2:
Before patient entry:
1. all necessary sets (both reusable and disposable) are taken from the storage cabinets and put on a transportation cart.
2. Sets are scanned at the computer.
3. Set is opened and placed ready on a wheeled cart.

During surgery:
4. The instrumenting nurse hands the instruments to the surgeon
5. The PP cloth is either discarded in the green trash or used as a table cover for the wheeled cart.

After surgery:
6. Set is taken to a secondary room of the OR, and the instrumenting nurse checks that the set is complete.
7. Set is taken to a CSD transport cart in the hallway.

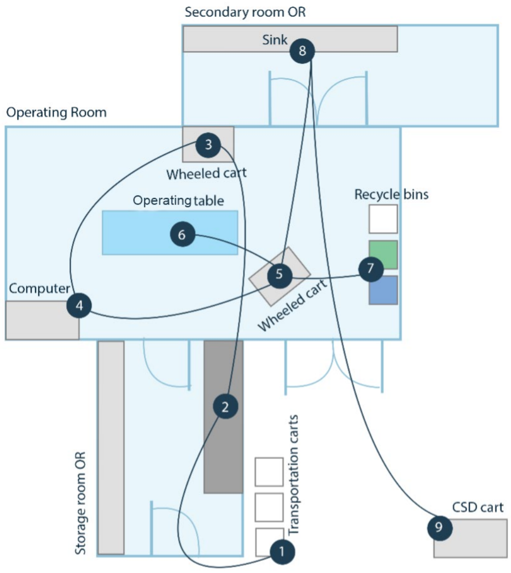

Figure 2. Workflow analysis of the OR.

The observations and group discussion with the OR nurses and surgeon resulted in critical points being identified in the OR contributing to the inefficient use of sets: (i) A primary issue was identified in OR storage, where sets can be misplaced or out of stock. When this occurs, nurses may use sets from different specializations or procedures, which are then by default not consisting of the right instruments, requiring them to open additional sets or individually packaged instruments to complete the necessary items. (ii) Missing instruments within sets are also common. Both surgeons and nurses repeatedly noted this in interviews, and during observations at least one instrument was found to be missing per surgery. Nurses often notice this before surgery begins and proactively bring a backup set or additional instruments as a precaution. This often leads again to requiring them to open additional sets or individually packaged instruments to complete the necessary items. (iii) Communication between departments regarding missing or incomplete sets is inadequate. The current system relies on scanning comments in the computer, which is rarely performed due to system complexity and time constraints. Instead, nurses write missing items on a card placed within the set, hoping it reaches the CSD, though no feedback is provided. This approach is unreliable, especially in the busy OR environment, where limited turnover times between surgeries often prevents thorough instrument checks. (iv) Frequent shift rotations among nurses can result in lapses in communication regarding missing instruments, as outgoing staff may forget to update incoming colleagues. (v) Another recurrent is the preference for Custom Procedure Trays (CPT) containing single-use instruments (e.g., scissors, knives, clamps), even though reusable versions are available. This preference dates back to a shift toward disposables, largely driven by infection control, convenience, cost considerations, and efficiency.

Results of the Central Sterilization Department (CSD)

Based on the observation, the following workflow analysis, as shown in Figure 3, could be detailed:

Unclean area:

1. CSD staff will pick up the cart with dirty sets and instruments from the OR hallways and bring them to the CSD.
2. Sets are scanned at the computer. In each zone, staff members not only scan the sets they handle but also scan every action performed, listed below.
3. Instruments are unloaded, opened and divided into two or more net baskets (depending on the size of the set).
4. The loaded net baskets are put into the ultrasonic machine for pretreatment.
5. The loaded net baskets are prepared on a loading cart.
6. When this cart is full, the net baskets are loaded into the washing machine.

Clean area:

7. The net baskets are taken from the washing machine and scanned again.
8. Instruments are unloaded, checked, and put back together based on a list of the original set. Missing instruments are supplemented here. Sets are packed using PP cloths and sealed with indicator tape.
9. The packed sets are prepared on the loading cart.
10. When the cart is full, the sets are loaded into the autoclave.

Sterile area

11. The sets are taken out of the autoclave.
12. Staff checks the indicator tape to ensure validity of the sterilization process.
13. The sets are placed in cluster bins in the transport cart and are ready to be picked up by the internal transport and taken to the sterile or OR storage area.

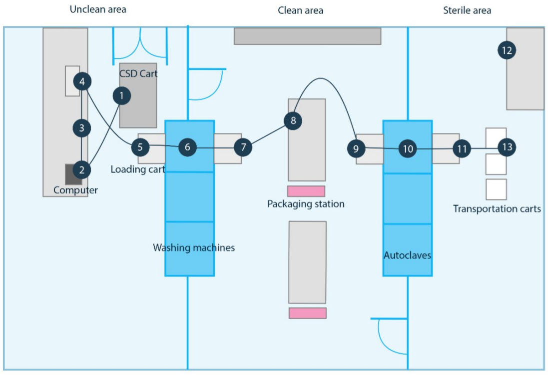

Figure 3. Workflow analysis of the CSD showing unclean, clean and sterile areas.

Based on the observation and in-depth interview, the following critical points could be identified in the CSD:

Related to the design of sets itself: (i) ergonomic challenges; several staff members reported back problems due to lifting heavy sets (up to 12 kg) in awkward positions. Additionally, (ii) the handles on the surgical instrument sets lack ergonomic design, being thin with poor grip and can only be used when the set is unwrapped, despite most handling occurring while wrapped. A third point (iii) involves material degradation, as aging stainless steel trays damage instruments and packaging, compromising sterility and necessitating re-sterilization.

Furthermore, (iv) knowledge support is missing during the set assembly process in the clean area. Staff rely on lists that only name instruments without visuals, making identification difficult for both new employees (with only three months training) and for experienced staff's routine-based inattention. (v) Storage and restocking challenges arise when specific instruments are missing. No effective communication with the OR alerts them to shortages, creating operational delays. An in-depth interview with the CSD head nurse highlighted further issues: (vi) Missing instruments are attributed to accidental disposal in the OR. (vii) Although a traceability system exists, it is underused in the OR, where sets are often unchecked. (viii) Effective communication between OR and CSD is hindered by procedural misunderstandings and long communication chains, with the interviewee suggesting any initiative for improvement should come from the OR staff.

Results of the logistics department

Based on the tour given by the head of logistics the following workflow could be analyzed, as shown in Figure 4:

1. Before surgery, all necessary reusable instruments and sets are sterilized in the CSD and placed in the correct storage area by the logistics department.
2. On the day of surgery, the pick list (detailed by the surgeon while planning the surgery) is prepared in the sterile storage room. A logistics worker takes all supplies (surgical sets (reusable and disposable), separate sterile-packed instruments and other necessary tools). These are placed in a cluster box. All cluster boxes are put into a cluster cart in the hallway. Per operating theater, there is one cart per day that contains all necessary materials for that day's operations.
3. The cluster cart is taken to appropriate OR storage area and cluster boxes are unloaded there.
4. During surgical preparation, if instruments or sets are missing in the storage area, the OR nurses can contact logistics personnel to request missing instruments be delivered.

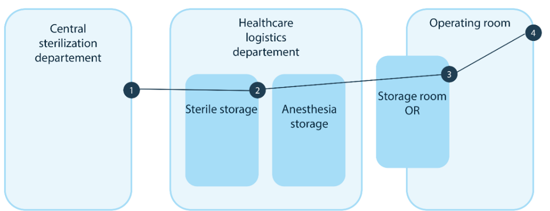

Figure 4. Workflow analysis of the logistics department.

Healthcare logistics is essential for maintaining an uninterrupted supply of materials between the OR and the CSD, ensuring 24-hour support for surgical operations. Three storerooms; sterile, OR, and anesthesia must remain stocked. In the logistics department, key challenges include (i) insufficient storage capacity, with growing demand outpacing infrastructure, leading to storage overflow into corridors and misplacement of sets. This spatial limitation frequently disrupts the "first-in, first-out" (FIFO) inventory method and increases retrieval time. Additionally, (ii) the computerized inventory system lacks logical organization, causing frequent errors in supply preparation and contributing to operational delays and workflow tensions. (iii) The current tracking software, Steriline, does not provide real-time updates, allowing only retrospective tracking of instruments' locations.

Discussion

Reorganizing the critical findings revealed three main problem clusters, which form the foundation for new design opportunities:

1. Communication-related issues: limitations of the electronic health record system, limited time for checking instrument completeness, the lack of visual identifiers on instrument lists, and reliance on an unreliable physical card system to track missing instruments. Additionally, the need to search for sets stored in different locations and the precautionary use of extra sets exacerbate these issues. Inter-departmental tensions originate due to a lack of understanding of each department's procedures.
2. Set-related problems: excess waste from unused single-use and sterile packaging, non-ergonomic set handles and heavy weights of sets, and the presence of both unused and missing instruments. Prior research also highlights that sets frequently contain surplus instruments for precautionary use, adding to waste.
3. Organizational challenges: misplaced sets, inadequate storage space, and stockouts of sets or spare instruments.

Based on these identified problem clusters, we propose the following high-level design drivers to guide innovation and enhance the efficient use of reusable surgical instrument sets:

1. Ensuring set completeness and accuracy

2. Facilitating interactive communication on set status, location, and sterility
3. Improving ease of use and reducing workload for stakeholders
4. Promoting sustainability by achieving full reusability and minimizing unnecessary waste
5. Enhancing cost-effectiveness by reducing losses

After conducting a brainstorming session with the observed personnel to generate potential solutions for the identified problems, five concepts were developed. These concepts were then evaluated by operating room and central sterilization department personnel, who scored them based on the design drivers to facilitate a trade-off analysis. As a result, the following potential design opportunities were identified:

1. Communication tool: A physical or digital tool could standardize inter-departmental communication, reducing confusion about tool completeness, location, and identification. Technologies such as AI, machine learning, and intelligent systems could assist staff in identifying and detecting missing instruments. Communication between the tool and staff should allow the set composition to stay up to date.
2. Surgical instrument set redesign: Redesigning the reusable surgical instrument basket and packaging could eliminate disposable packaging, enhance ergonomics, and ensure set completeness.
3. Storage system optimization: Improving the storage system to maximize limited space and introducing automation could reduce staff workload.

Research Limitations

This case study was conducted in one university hospital, limiting generalizability. To verify these conclusions, further studies should include various hospital settings, including public and private hospitals. The study focused on urology and gynecology, which use smaller instruments; further research should examine whether similar issues arise in other specialties with larger or robotic instruments.

Conclusions

This paper presents a case study examining the challenges associated with reusable sterile instrument sets for surgeries. Inefficiencies in the current system have contributed to a trend toward reintroducing single-use sets, which undermines efforts to promote circularity in healthcare systems. Consequently, merely developing reusable medical products does not guarantee effective usage or replacement of single-use alternatives. To identify critical issues, we observed and interviewed key stakeholders involved in managing reusable surgical instrument sets: (i) operating room staff and surgeon, (ii) central sterilization department personnel, and (iii) logistics staff.

Key obstacles for efficient use of reusable surgical instruments identified include communication-related issues, set-related issues, and organizational issues. To address these, three design oportunities are proposed based on high-level design drivers: redesigning reusable surgical sets and their packaging, optimizing storage systems, and implementing a structured communication tool.

Further innovation should focus on understanding and optimizing the broader context of reuse. Future research should examine how hospital contexts, including the entire value chain, and including production, can be holistically adapted to support reuse. By following research through design principles, we should focus on developing intelligent systems for detecting missing instruments, efficient communication frameworks, and sustainable, waste-free packaging solutions to minimize medical waste.

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