Towards Circular ICUs: Circular Intubations as a Catalyser for Systemic Change

Alicia Ville, Nicole Hunfeld, Conny Bakker, Baptiste Sene, and Jan Carel Diehl

Abstract This project aims to reduce the environmental impact of the Intensive Care Unit (ICU) of the Erasmus Medical Center (EMC). Systemic design research was executed to map the current waste flow created by the ICU. Literature review, interviews and observations were performed to gather information about the healthcare protocols, hospital procurement process, intubation practices and used devices and consumables. This resulted in a set of challenges which were used to ideate from different perspectives to improve the sustainability of the ICU. A set of opportunities to introduce circularity within the ICU were defined. These opportunities ranged from waste separation to the reduction of the disposal of unused products. The selected circular opportunity was intubation, needed when patients cannot breathe by themselves. For this, a video laryngoscope, which is composed of various plastics, a video camera, and a led light, is used for only a few minutes and disposed of (and incinerated) directly afterwards. The aim of the second part of this research project was: Can we design a circular intubation procedure as a catalyzer for systemic change towards circular ICUs? One of the proposed circular strategies for the video laryngoscope is the reprocessing of intubation devices used at the ICU itself. A transition model toward reprocessing using UV-C radiation technique was further developed. Compared to current reprocessing procedures, UV-C disinfection consumes no water and less electricity and offers the possibility of decentralized reprocessing within the ICU department itself. This project aims to provoke conversations between the hospital, manufacturers and other stakeholders about how the healthcare sector could start reprocessing valuable medical devices towards a circular ICU.

Keywords Circular healthcare · Systemic design · Intensive Care Unit · Intubation

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1 Background

The healthcare sector presents the paradox of being responsible for saving lives while simultaneously contributing to climate change. Healthcare itself has been referred to as the greatest health threat of the 21st century (Karliner et al. 2020), contributing in the Netherlands to 5.9% of the national ecological footprint (Browne-Wilkinson et al. 2021). 71% of the emissions generated by the healthcare sector in the Netherlands are related to the production, use, transport, and disposal of medical products used in the hospital (Browne-Wilkinson et al., 2021).

An ICU is a special facility within a hospital that provides intensive supervision, monitoring and life support to critically ill patients. Due to its intense nature, it is one of the areas of the hospitals where a relatively high amount of waste per patient is produced. The EMC ICU produces 50.000 kg of waste annually (Browne-Wilkinson et al., 2021). A wide range of products is being used at the ICU like electronic devices, sophisticated invasive devices, and single-use devices, which currently are all disposed of by incineration.

Despite the intensive use of single-use and disposable products enhanced by regulation to reduce (cross-) infections (Kane et al. 2018), alternative sustainable health practices are increasingly considered across the sector. In fact, transitioning from a linear to circular economy is crucial to prevent depletion of finite natural resources and the associated negative environmental and social impacts. The circular economy is regenerative and restorative by design and would enable hospitals to capture and retain value for longer, thus being less harmful to the environment.

To explore how the ICU of EMC could start envisioning a more circular future, we will focus on one of the more frequent ICU procedures: intubation. Patients get intubated if they cannot maintain their airway or breathe independently without assistance. As it entails a critical condition with constant observation and care, intubated patients are usually placed in the ICU. The purpose of this project was to redesign the intubation process through the use of circular strategies to reduce its environmental impact. A set of different objectives were set: (1) understanding what are the main challenges that the current system of intubation to detubation presents from a sustainability perspective and (2) designing a pilot system which initiates the ICU transition towards fully circular intubation system.

2 Methodology

This project was approached from a systemic design perspective since not only the product itself but also the system within which a product is manufactured, used and disposed of (Browne-Wilkinson et al. 2021) needs to be taken into account to create impactful change.

First, a context research was done to better understand the current waste created by the ICU and answer the question: What are the main challenges that the current

intubation to detubation system present from a sustainability perspective? A literature review, a waste audit, interviews and observations (further described in Table 1) were performed to gather information about the healthcare context, intubation procedures and devices procurement.

The takeaways of this research were summarized in three system maps used to hotspot the challenges the ICU faces from a sustainable perspective. Based on the identified challenges, we first ideated on a set of proposals that could improve the ICU sustainability, next one specific proposal was selected and further detailed. A specific product used throughout intubation was selected, around which the detailing of the selected proposal could be articulated into a tangible pilot.

Table 1 Research methods

Literature review	Base literature concerning the current wastefulness stage of ICUs. A set of four research questions were identified before conducting literature review: What are the laws, regulations and policies guiding procurement and waste management in EU hospitals? – Which current practices make ICUs a non-circular environment and their consequent impact? – Are there already some pilot projects showing potential areas where circular strategies could be applied in ICUs and hospitals? – What are the effects of climate change and COVID on healthcare systems?
Interviews and observations at Erasmus MC	A set of observations were performed at the ICU of: – A nurse setting up a room for intubation – An intensivist performing his daily assessment of intubated patients – Nurses' general workflow by observing corridor workflows – Two nurses cleaning a room after an intubated patient stay Finally, several interviews were made. Nurses, a medical device designer, an IC physician, a device procurement advisor, a strategic buyer and a physician were interviewed
Waste audit	General hospital waste from the pediatric ICU of Erasmus MC was collected for four consecutive days. The waste generated during 24 h by each of the units of the pediatric ICU were analyzed consecutively: Bags were weighted, opened and the items within the bags were then sorted and counted. Items were then classified as 'used' or 'unused' and sorted depending on their product category. Product categories were eventually weighted and photographed once all bags from the unit were analyzed

3 Results

Based on the observations and interviews, a set of three maps were developed: An overview of the intubation steps is provided in Fig. 1, indicating stakeholders involved, tasks and times they are performed. The wastefulness of each stage is illustrated as well at the bottom of the visual. Figure 2 maps non exhaustively the devices used in regular intubation. It visualizes how these devices are used (and disposed of) and in which quantity. Finally, Fig. 3 shows the general journey from raw material extraction until their end of life of intubation devices.

All three maps highlight in red the different challenges that were detected throughout the research, and that will be listed and discussed next.

3.1 Single Use Predilection

The large majority of devices used throughout an intubation are disposable. Even devices of relatively high value (Kane et al. 2018) such as bronchoscopes or video laryngoscopes, are disposed of and incinerated. We observed through interviews that some of the high-value devices were previously reused. Reusable devices must undergo reprocessing, to clean and then disinfect or sterilize them to eliminate microorganisms from previous patients (Food and drugs administration 2019). The

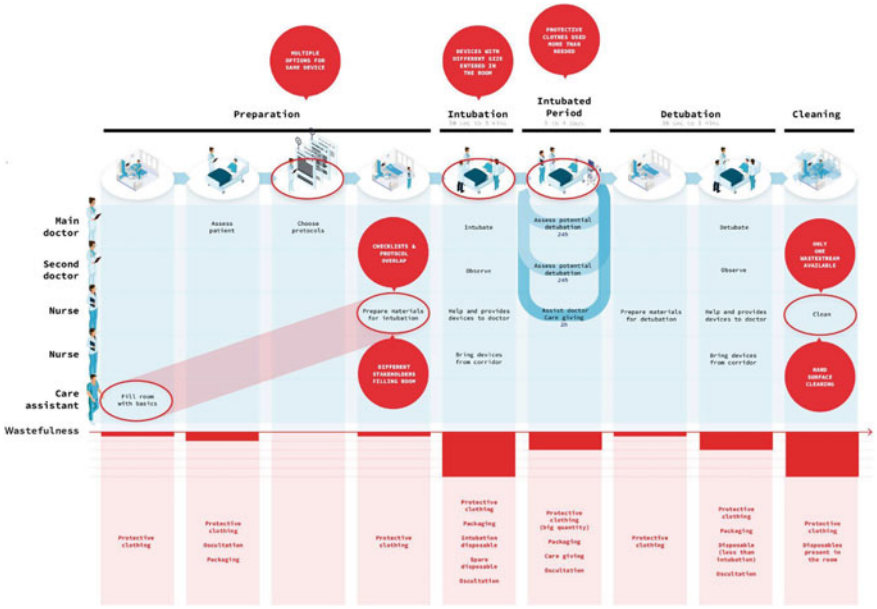

Fig. 1 Intubation steps and actions, and stakeholders required for each of them

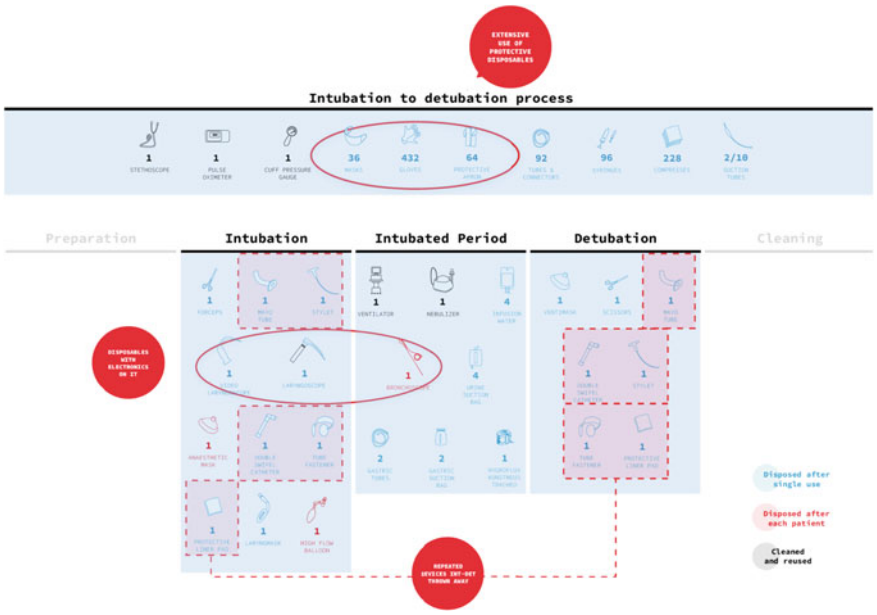

Fig. 2 Map of devices used throughout intubation

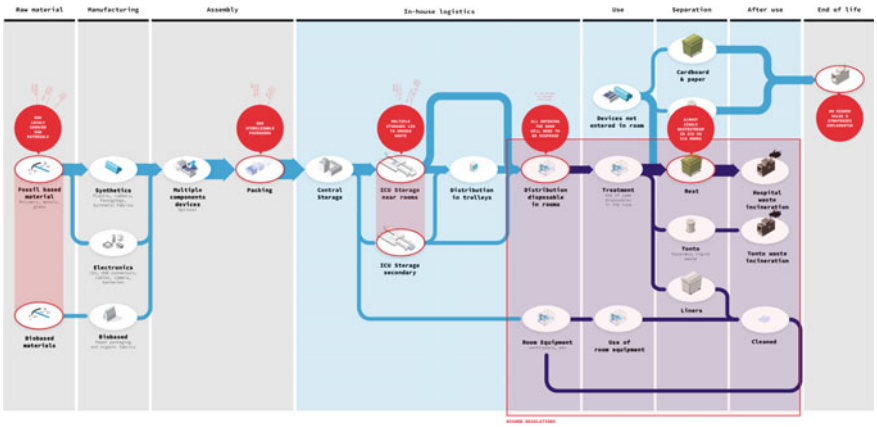

Fig. 3 Devices journey map

previous reprocessing model implemented at EMC ICU became obsolete due to the following non-exhaustive reasons:

1. **Technological innovation jeopardizes the reprocessing of devices**

Technological innovation is always sought in the healthcare environment as it provides higher quality, thus more safety. For instance, the inclusion of a camera in the

video laryngoscope, increases the rates of successful intubations (Baek et al. 2018). It also increases the devices' complexity (in shapes and components requirements), reducing the efficiency of the cleaning methods (Moses et al. 2021).

2. **An inefficient reprocessing system and technology**

The technique used to reprocess ICU devices at EMC was largely based on chemical and steam technology. Both these techniques have a relatively high environmental impact which makes the reuse of devices less attractive from an environmental standpoint. On top of this, the ICU experienced some in-house logistical hiccups. Receiving back the devices from the reprocessing department was taking in some cases too long, which caused a lack of availability of these devices at the ICU. Disposables were as such considered as a better alternative as their stock is not dependent on the performance of other departments.

3. **Safety**

Moreover, single-use devices eliminate infection risk management. This is welcomed both by the hospital administration and the staff that had to perform manually part of the reprocessing, thus having responsibility for its correct disinfection. It is also enhanced by manufacturers for their own economical benefits.

3.2 Limited Waste Separation

Most waste generated throughout intubation is disposed of together and incinerated as hospital waste. The current end-of-life solutions mostly rely on the incineration of goods and rarely on giving back the ownership of products to manufacturers.

3.3 Some Devices Get Disposed Unused

Based on a waste audit performed at EMC Pediatric ICU, the unused waste was estimated at 6%. Disposables are required to be disposed of, even unused, if entered into the ICU room due to infection prevention protocol. This means that the entire room inventory must be disposed of when a patient leaves after a stay that exceeds 24 h. The ICU has multiple storage spaces, most located outside of the patient room. Currently, more devices than required are placed in the ICU rooms during intubation procedures. This is due to doctors' decision-making and overlapping protocols. Many different stakeholders are involved in preparing the rooms, enhancing the entrance of the same device twice into the room. Also, some identical devices are available in multiple locations, jeopardizing their use before the expiration date of less regularly checked ones.

4 Discussion

4.1 Interpretation Results

A set of opportunities for EMC ICU to reduce its environmental impact were detected from the research and summarized in a booklet, as listed in Table 2.

We were able to conclude from the research that one of the main causes for unsustainability at the ICU was the systematic use of disposables. Consequently, a system that allows the reprocessing of intubation devices is explored.

Reprocessing involves a change in the ICU infrastructure, protocols and workflows. Each device requires a specific reprocessing procedure. These procedures are dependent on requirements stipulated by manufacturers, the technologies available for reprocessing, European and national regulations. Due to its inherent complexity, reusing devices requires a transitional design approach. As part of this approach, this paper proposes a pilot that could enable EMC ICU to explore a specific reuse scenario. This pilot is articulated around a specific product, the video laryngoscope. The latter is used to intubate patients. It is composed of various plastics and electronics, and has a relatively high procurement cost. Nevertheless, it is a single-use device, disposed of and incinerated after a few minutes of use.

Table 2 Opportunities deducted from the research

Packaging separation	It can be envisioned to separate device's packaging, mostly made from the same range of materials (paper, laminated PA, LDPE, HDPE, etc.), for recycling
Tools for conscious procurement	Taking into consideration the total cost of ownership of devices and their supply chain impact (CO2, land, water, toxicity, child labour, etc.) during procurement could increase hospital sustainability and the use of reusable devices
Educate doctors for conscious choices	Raising the awareness of ICU staff on these decisions could avoid nonessential use of resources and reduce waste
Enable external storages	Adding an external storage in front of the ICU room allows devices easily accessible, still out of the room. This saves unused devices from incineration
Cleanable packaging	Erasmus MC could explore collaboration with manufacturers to redesign cleanable packaging or alternative cleaning technologies. Cleaning of unused devices still packed could enable them to be saved from disposal
Reuse of high value devices	Allowing the reprocessing of high value devices
Avoid redundant devices	Reducing redundant versions of the same device avoids less known versions going unused until expiration
Redesign overlapping protocols	A redesign of protocols that allows nurses to know which devices can be potentially already in the room can be envisioned. Protocols could also distinguish better optional devices

Ideation on a system enabling a safe and hassle-free reuse of the video laryngoscope at the ICU with a lower environmental impact was done. We first explored which technologies could be used to reprocess video laryngoscopes and similar high-value devices at the lowest environmental impact possible. UV-C disinfection has environmental benefits compared to steam disinfection since less energy and no water is required (Leiden et al. 2020). UV-C radiation is a radiation of a specific wavelength. Lamps emitting this radiation can be used to disinfect surfaces. Indeed, UV-C radiation has been used for decades to reduce the spread of bacteria, and its use during the COVID-19 pandemic has allowed this technology to be recently certified for use in hospitals. UV-C radiation technology can be used to clean non-critical and semi-critical devices which require disinfection only on their external surfaces, such as video laryngoscopes. With UV-C technology, cleaning of non-critical medical devices can be fully automated, avoiding any additional device cleaning workload for ICU nurses. The disinfection of semi-critical devices could also be done through UV-C when previously cleaned with wipes. This reduces the workload for nurses compared to previous reuse scenarios.

A conceptual design of a system for reprocessing laryngoscopes at the ICU itself using different technology available in the market was developed. Two pilots, one using the current video laryngoscope used at the ICU and a second one using a hybrid one were generated. In Fig. 4, future scaleup of the reuse system to other devices is envisioned, as well as replicating it into other Erasmus MC departments.

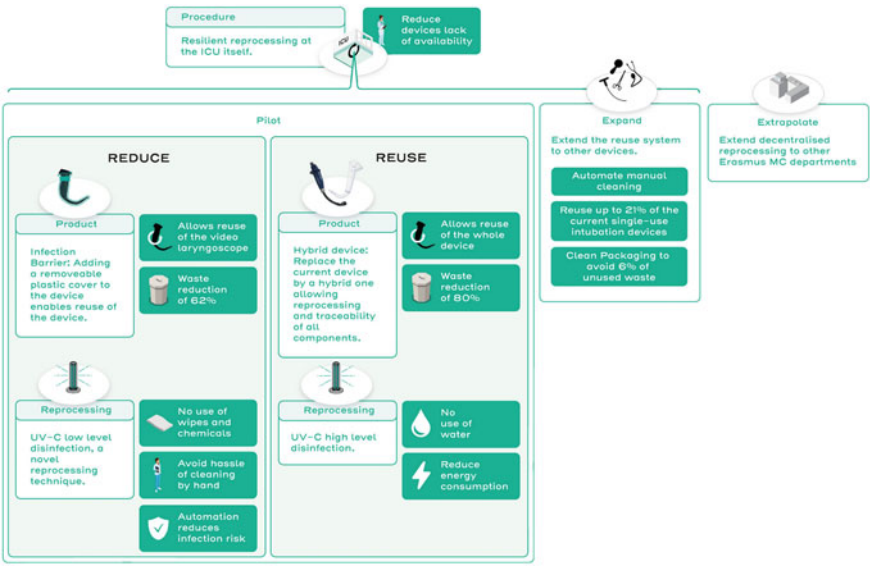

Fig. 4 Transition roadmap

4.2 Limitations

These pilots are conceptual, their feasibility must still be explored before implementation. For instance, testing of the UV-C resistance of the laryngoscope materials would be required. Also, these pilots consider video laryngoscopes as semi-critical devices, thus could not be applied to video laryngoscope entering in contact with blood.

4.3 Strengths and Next Steps

Individual patient safety-centered design limits the radical changes needed to make healthcare sustainable. Current hospital risk management focuses mostly on individual patient safety, leading to an excessive avoidance of specific risks, at the wider expense of unsustainable practices. As such, to catalyze systemic change in healthcare, a reframing of risk management is needed. Reuse practices would not make the EMC a less safe hospital but one that places more attention on their impact at an environmental and societal level instead of only searching for safety at a short-term and individual level.

These transition proposals as well as the pilot exploration aim to provoke conversations between the hospital, manufacturers and other stakeholders around how the healthcare sector could start reprocessing valuable medical devices towards a circular ICU.

5 Conclusion

This paper explores different directions in which EMC ICU could reduce its environmental impact of intubation through circular strategies. It explores the reuse of medical devices through the design of a pilot system on video laryngoscope reuse through an ICU based reprocessing and the use of UV-C radiation. This will result in decreased environmental impact. Even if the infection risk is low and compliant to regulation, tensions arise that can be leading us to the core of health wastefulness. A major takeaway from this project is that most unsustainable ICU practices are closely related with the reduction of safety risks to an absolute minimum. With sustainability acting on spatio-temporal scales that are not directly apparent, it becomes challenging to make decisions now that may have directly visible drawbacks (increased risk), while only offering invisible future benefits (mitigate climate change). Healthcare cannot be free of risks, and a better understanding of the value of sustainable health by organizations and society would allow for innovations toward a circular future.

The full story of this research can be found at: https://repository.tudelft.nl/islandora/object/uuid%3A0ff435ae-4f59-4196-b52c-92a528de3041?collection=education.

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