Towards a Circular ICU

How to implement reusable video laryngoscopes at the Intensive Care

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Executive Summary

The healthcare sector uses a lot of on single use medical products, causing large amounts of CO_2 emissions and excessive amounts of waste. This project contributes to a circular Intensive Care Unit (ICU) by investigating the barriers and possible solutions for a transition from single use video laryngoscopes (VL) to (partly) reusable ones, in order to develop guidelines and best practice for the transition of other single use medical products to reusables.

To produce single-use products, raw materials are extracted, products are manufactured, used, and disposed of after using the product just one time. This is known as the linear economy or the 'take-make-waste' system, having a devastating effect on the environment. However, reusing medical products comes with organisational challenges. Concerns with patient safety, liability, the costs, and complexity of developing and maintaining in-house reprocessing infrastructure and logistics have left hospitals with a complex organisational challenge.

The research question for this project is: **How can the ICU become more sustainable through overcoming organisational challenges hindering the implementation of reusable video laryngoscopes?** With the sub-questions: 1. What are the barriers and enablers for implementing the reuse of video laryngoscopes in the ICU? 2. How can the reuse of video laryngoscopes be implemented at the Erasmus MC? 3. What could be the next step in transitioning similar products (to the video laryngoscope) from single use to reusable?

This design project was structured through three phases: Exploration, Analysis and Conceptualisation phase. Three product journeys were analysed: a single use VL, semi-reusable VL and a completely reusable VL. This project concludes, contrary to the original hypothesis, that barriers to for the implementation of reusable VL's are minimal. The semi-reusable VL seems to require the least change from the organisation, but the fully reusable VL contributes better to the end goal of a fully circular ICU in 2030, notwithstanding its higher up-front cost.

For the implementation of the reusable VL it is essential to spark the actual implementation of the reusable VL and communicate with and facilitate stakeholders. The implementation processes need to be kickstarted through the set-up of a tender, followed by a pilot, pilot evaluation and expansion of the pilot in order to ensure proper implementation. After implementing the VL three other medical devices were identified to follow in the footsteps of the reusable VL: Laryngoscope blades, bronchoscopes, and scissors. Laryngoscope blades and bronchoscopes can be collected in the same place since the use-case of them is very similar to the VL. Scissors will require further research but follow a similar journey to and from the CSD.

This report brings value to the ICU of the Erasmus MC through identifying that the Erasmus MC has the resources and capabilities to implement the reusable VL's, as well as presenting recommendations for the implementation process.

Acknowledgments

This project marks the end of my Industrial Design education at the TU Delft. I would like to thank some of the people who were involved in the completion of my master thesis.

I would like to thank Nicole for giving me the opportunity to graduate at the Erasmus MC on such an important topic as sustainability. I greatly enjoyed getting 'a look behind the curtain' of the processes at the Intensive Care Unit, Procurement Department and Central Sterilisation Department. The passion you bring to advocating for more sustainable healthcare is truly inspiring. Thanks for the opportunity to star in the EY video and present my findings to members of the Convergence Square. Besides Nicole, I would like to thank all the people I interviewed at the Erasmus MC. Thank you for making the time and proving me with valuable insights.

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Furthermore, I would like to thank my friends and family. Thanks to (other) Maaike, Elke and Amber for accompanying me to endless sessions in the TU library. I hope the Coffee Star can stay in business when we are all graduated. Thanks to Jan, for eagerly discussing my project and supporting me when times were difficult. Even as a software developer, you have proven yourself to be a worthy designer. Finally, I would like to thank my parents for supporting me throughout my studies.

I hope you enjoy my thesis,
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Glossary

Definitions

Medical devices
Any device intended to be used for medical purposes is a medical device. This includes products such as hearing aids, infusion pumps, ventilators, gloves and even software.

Single-use medical device
A medical device intended to be used only once. The product is disposed of after use.

Hybrid medical products
Medical products which are part reusable, part disposable.

Reprocessing
Reprocessing is the process of preparing a medical product for safe reuse through cleaning, disinfection, sterilisation, and related procedures

Life Cycle Assessment
A methodology for assessing the environmental impact of all the stage of the life cycle of a product, process, or service.

Hygienic obsolesce
Product which are discarded because they are no longer sanitary and safe to use on another patient.

Abbreviations

ICU	Intensive Care Unit
SUD	single-use device
Erasmus MC	Erasmus Medical Centre
OR	Operating Room
ER	Emergency Room
CSD	Central Sterilisation Department
VL	Video Laryngoscope
LCA	Life Cycle Assessment

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Project Introduction

The healthcare sector uses a lot of single use medical products, causing large amounts of CO_2 emissions and excessive amounts of waste. This, however, puts a lot of pressure on the environment, both in the CO_2 emissions and excessive amounts of waste. The Intensive Care at the Erasmus Medical Centre in Rotterdam wants to change this and is aiming for a fully circular Intensive Care (ICU) by 2030. This project contributes to a circular ICU by investigating the barriers and possible solutions for a transition from single use video laryngoscopes (VL) to reusable ones, hoping to inspire the transition of other medical products to reusables.

This chapter contains an introduction to the project, the problem this project is trying to solve, the projects aim and research questions. As well as an explanation of the design approach and project structure.

01.

1.1 Introduction

1.1 Project stakeholders

This project was executed in collaboration with the Green Team of the ICU at the Erasmus MC, a multidisciplinary team that explores the possibilities for a circular and sustainable ICU. Additionally, the topic of the sustainable ICU falls within 'Convergence', a collaboration between the Erasmus MC, the Erasmus University Rotterdam (EUR) and the TU Delft. In this initiative different disciplines are brought together to encourage scientific discovery and technological innovation in the field of health and healthcare (Health & Technology, 2022).

1.1.2 The impact of the healthcare sector on climate change

Of the global greenhouse emissions, 4.6% comes from the healthcare sector (Watts, et al, 2019). The impact of Dutch healthcare is above this global average, being responsible for 6-7% of its national greenhouse gas emissions (Zijp et al., 2021). Generally, the more high-income countries have higher greenhouse emissions since there is some correlation between a country's healthcare sector climate footprint and a country's health spending (Healthcare without harm & Arup, 2019).

One of the contributors to the negative environmental impact of the healthcare sector is the use of single-use medical devices. To produce single-use products, raw materials are extracted, products are manufactured, used, and disposed of after only using the product just one time. This way of dealing with products is known as the linear economy or the 'take-make-waste' system. The linear economy depletes natural resources, generates excessive amounts of waste, greenhouse gases and contributes to climate change (MacNeill et al., 2020). The effect of this system jeopardises human health through the devastating effects of climate change, such as severe weather, air pollution and water quality impacts. Figure 1 shows an overview of the detrimental effects of climate change on human health. Paradoxically, the large number of single-use products which are used to improve people's health contributes negatively to public health.

A department within hospitals which is particularly reliant on single-use products is the Intensive Care Unit (ICU). At the ICU, patients in life-threatening conditions are treated. This requires a lot of care and subsequently a large variety of single-use medical equipment and protective clothing.

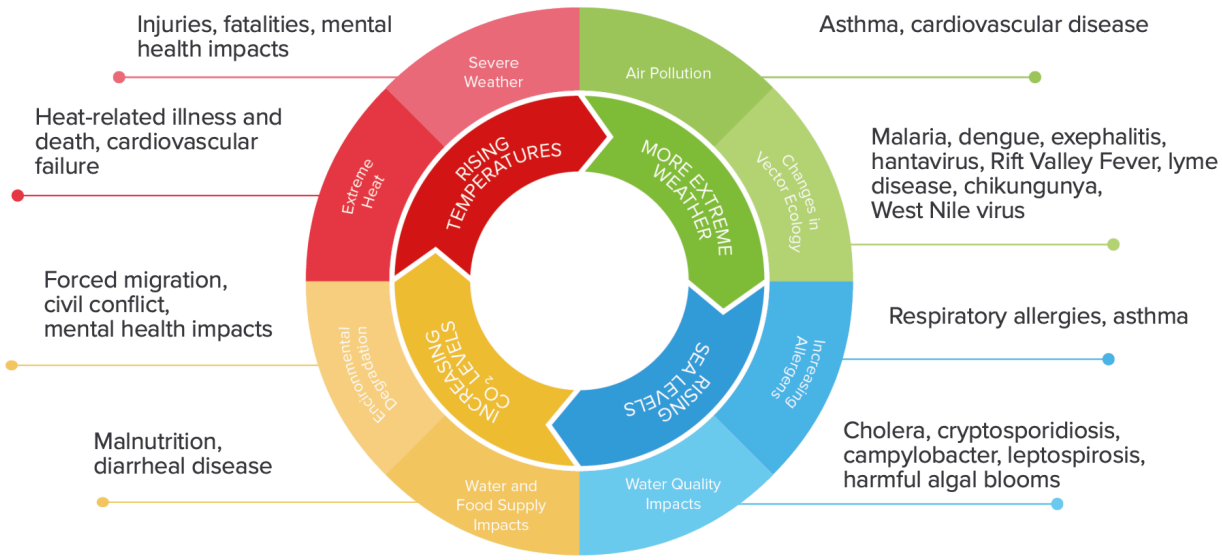


Figure 1: Impact of climate change on human health (Healthcare without harm & Arup, 2019)

1.3 Project aim

The aim of this project is to contribute to a more sustainable ICU. A possible solution to reducing the environmental impact of the ICU is by reusing more medical products. However, reusing medical products comes with organisational challenges. Concerns with patient safety, liability, the costs, and the complexity of developing and maintaining in-house reprocessing infrastructure and logistics have left hospitals with a complex organisational challenge (MacNeill et al., 2020). In order to identify organisational barriers (and enablers), this project investigates the possible transition of one medical device in the context of the ICU at the Erasmus MC, from single use to reusable alternatives. By identifying these organisational barriers, solutions can be found to overcome them.

1.4 Case product: video laryngoscope

Figure 2: Image of a video laryngoscope

The video laryngoscope (VL) (Figure 2) is used as a case product to investigate the barriers and enablers of reuse in the ICU. This device is used in the ICU find the patient's airway and guide the endotracheal tube during the intubation procedure (Figure 3). It is used for a maximum of 2 minutes during the intubation of a patient and discarded afterwards. The implementation of reusable alternatives will be investigated, while considering both the environmental impact and the impact on the organisation.

Figure 3: Image of intubation with a VL

1.5 Research questions

The main research question and the sub research questions for this project are as follows:

How can the ICU become more sustainable through overcoming organisational challenges hindering the implementation of reusable products?

1. What are the barriers and enablers for implementing reuse of video laryngoscopes in the ICU, in literature and in practice?
2. How can the reuse of video laryngoscopes be implemented at the Erasmus MC?
3. What could be the next steps in transitioning similar products (to the video laryngoscope) from single use to reusable?

1.6 Design approach

This project was executed through a strategic design perspective. To improve the sustainability at the ICU, the Erasmus MC's vision and context are translated into a feasible, viable and desirable service. The concept of feasibility, viability, and desirability, also known as 'the three lenses of innovation', was originally developed by design consultancy IDEO (IDEO Design Thinking, n.d.-b).

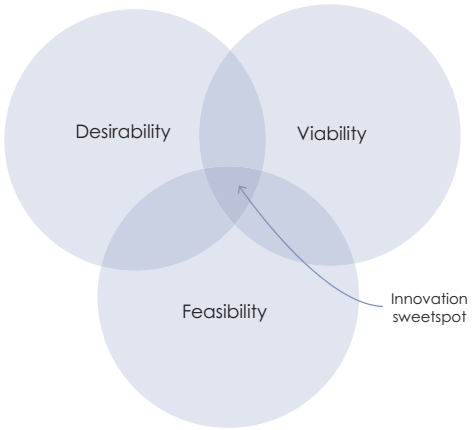


Figure 4: Three lenses of innovation (IDEO)

The model provides the designer with three questions that need to be answered:

- Is the design what people desire?
- Is the design technically and organisationally feasible?
- Is the design financially viable?

When it comes to desirability this does not only include explicit needs and wishes, but also 'latent' needs (needs unknown to the user) and needs for society as a whole. It should enhance people's lives and create a better society. Since 'desirability' is broader than just their needs. Although not explicitly mentioned in the model, it could be argued that sustainability falls within the 'desirability'. Since reducing the negative effects of climate change contribute to a healthier society. According to the book 'Strategic Design' by Calabretta et al. desirability, feasibility and viability are co-influenced and co-decided by the designer (2018). This is an iterative process which can shift over the course of the design project. Throughout this project the three lenses will be considered and will be evaluated in the discussion.

Other design characteristics within this project are the contextualisation of literature, focus on implementation and the use of design methods such as journey mapping. The contextualisation of literature is done through literature research and stakeholder interviews and observations at the Erasmus MC. By comparing the findings from literature to the finding from stakeholders specific to the Erasmus MC, we can more specifically identify opportunities, and are able to better implement solutions.

Project structure

This design project was structured through three phases: Discovery, Analysis and Conceptualisation. Figure 5 shows the approach in an overview. Discovery was done through desk research, literature research and immersion in the healthcare environment. In the Analysis phase stakeholder research was done in order to map proposed product-journeys of reusable VL's in order to identify barriers. With the use of these journeys the different scenarios could be evaluated. In the Conceptualisation phase the knowledge from the Discovery and Analysis phase was used to create recommendations for the hospital on how to implement the reusable VL's as well as expanding the impact of the VL to other devices in the ICU.

Discovery

Understanding the context

Circular healthcare

The case product: video laryngoscope

Analysis

Stakeholder research

Product journey's and procurement process

Evaluating the scenarios

Conceptualisation

Implementation guide reusable VL

Expanding the impact of the reusable VL

Figure 5: Project structure

Discovery

In the Discovery phase the focus is on understanding the sustainable healthcare context, circular healthcare principles, and the case product. The research question that will be answered in this section is “what the barriers and enablers for are implementing the reuse of VL’s in the ICU, according to literature. This is done through desk research, literature research and immersion in the context.

02.

2.1 The context

Unsustainable healthcare is an issue that cannot be solved in the ICU at the Erasmus MC alone. There are many parties involved outside of the ICU and the hospital, such as the government, manufacturers of medical devices and medical waste processing companies. In this chapter context is given to the goals and ambitions of the healthcare sector, through the Green Deal. As well as the goals from the Erasmus MC and the ICU and the experienced barriers by healthcare organisations.

2.1.1 Stakeholders in sustainable healthcare

Figure 6 shows an overview of stakeholders in sustainable healthcare. The inner ring contains stakeholders within the IC, the middle ring contains stakeholders within the Erasmus MC and the outer ring consists of stakeholders outside of the hospital. This report will mainly focus on the inner and middle ring, since those are the stakeholders within the direct span of control the Erasmus MC. It is however important to realise that the parties do influence each other. For example, the Erasmus MC can advocate for different regulations for reusing medical devices. The government could subsidise sustainable healthcare initiatives, the Rotterdam municipality could build infrastructure to provide the hospital with green energy, waste companies could innovate their recycling facilities and the hospital could demand more sustainable medical products. Understanding these stakeholders and coming up with jointly supported solutions can be beneficial for the transition to sustainable healthcare.

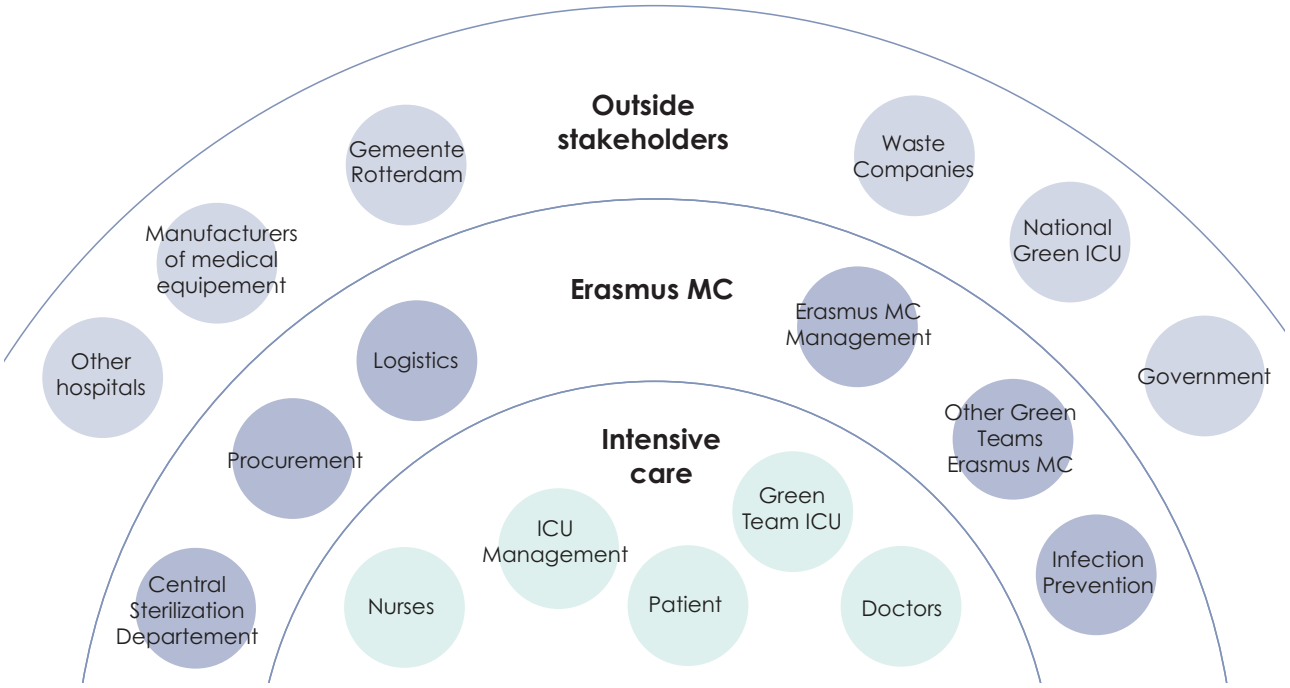


Figure 6: Stakeholders in sustainable healthcare

2.1.2 The Green Deal

In 2015 healthcare organisations launched the first Green Deal for sustainable healthcare to make their business operations systematically more sustainable (Milieu Platform Zorgsector, n.d.). In this 'Green Deal Sustainable Healthcare' healthcare institutions, companies and (local) governments commit to making changes to minimise environmental pollution (Ministerie van Algemene Zaken, 2021).

Ambitions of the Green Deal Sustainable Healthcare 2.0 are:

- 49% CO CO_2 reduction in 2030.
- Circular business operations.
- Removing medicine residues from wastewater.
- Providing a healthy living environment.

2.1.3 The Erasmus MC and sustainability

The Erasmus signed the Green Deal 2.0 endorsing all of the above goals. Their goal is to achieve a CO_2 emission reduction of at least 49% in 2030 compared to the emissions in 2019.

They intend do this by:

- Using 100% green electricity by 2030 at the latest.
- Reducing employees' daily commute by 10%.
- Reducing patient mobility by 10%.
- Letting 50% of all departments in 2021 participate in the Train Zone Map challenge, which means that business trips within Europe will largely be by train.
- A 15% reduction in waste and production of materials.
- **Working circularly**, which is promoted through:
  - circularly demolishing the old hospital buildings for at least 75% in 2020 and 2021.
  - introducing reusable catheters by 2022. restoring more than 80% of surgical instruments to new condition by 2023.
  - making sustainability a guiding principle in the integrated construction programme.

Specifically, the goals for 15% reduction in waste and production of materials, promoting circular working and restoring more than 80% of surgical instruments to new condition by 2023 are relevant for this project, since they are about reducing medical waste and reusing medical products.

Besides endorsing the Green Deal 2.0, the United Nations Sustainable Development Goals (SDGs) have a leading role in their mission to reduce their environmental impact (Erasmus MC, 2020). The Erasmus MC has chosen five SDGs (Figure 7) to focus on:

Figure 7: Sustainable Development goals Erasmus MC

Particularly SDG 12, responsible consumption and production, is relevant for this project since the goal is to reduce the environmental impact of single-use medical products through circular design strategies. In the Erasmus MC's sustainability report, SDG12 responsible consumption and production is clarified as focussing on people's well-being and preserving nature. The Erasmus MC is committed to maximising the reusability of products and raw materials and minimising value destruction.

Some examples of sustainable projects within the hospital are the circular demolition of the old hospital building whereby the old materials of the building are offered to a marketplace to be reused, the lease mattress project which reimages ownership of the hospital mattresses and the pharma filter which prevents the toxins of medicine waste to enter the groundwater.

These sustainability projects can entail large changes to the organisation, since it can require technical and logistical changes, an added workload to some stakeholders, collaborations with external parties and different procurement procedures. For instance, the lease mattresses require a new contract with a supplier, a different take-back system and since this was done hospital-wide a lot of collaboration and consensus between internal stakeholders as well.
In conclusion, the Erasmus MC and the ICU have ambitious goals to improve circularity within the hospital and the ICU. Sustainability projects tend to be complex and involve many different stakeholders. Therefore, it is important to investigate and engage the stakeholders who are or could be involved in the transition to reusable VL's.

2.1.4 Challenges of the Green Deal

After the first Green Deal the Ministry of Healthcare commissioned an evaluation report in order to reflect on the Green Deal. A survey was done among 60 healthcare organisations. One of the topics was the barriers experienced when working on making healthcare more sustainable. The participating organizations answered that they experienced the following barriers: other themes (besides sustainability) receiving more priority, a lack of financial means, a lack of time and manpower, hard to change working habits, the Covid-19 pandemic, being too dependent on other parties, lack of urgency from management, lack of urgency from staff, difficulty changing current processes, lack of internal knowledge and a difficulty making ideas actionable.

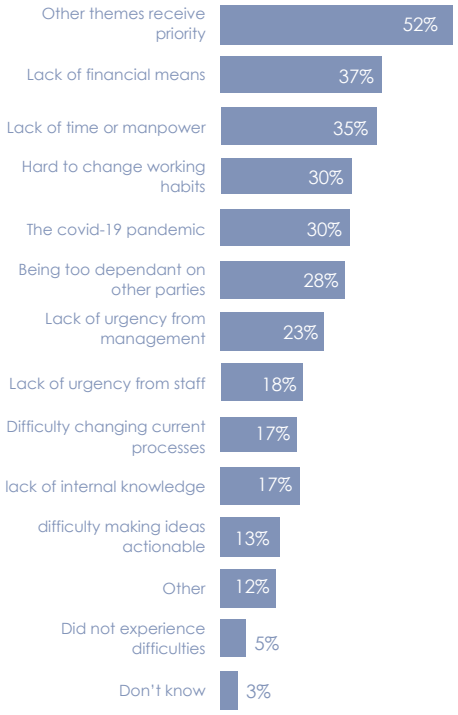


Figure 8: Experienced barriers while working on sustainable initiatives in healthcare, according to green deal participants (n=60)

Next to explaining the barriers in transitioning to more sustainable healthcare, the organisations elaborated on what they need in order to become more sustainable. The recipients replied that they needed more financial support, more attention from the government, a culture change within the whole chain and better examples. This project could help fulfil the need for better examples, since it investigates one specific product which could be used as an example to spark the transition to other reusable products.

2.1.5 Sustainability at the ICU

The Erasmus MC is aiming to be a frontrunner in sustainability at the ICU and aims for full circularity by 2030. "Green Teams" have been set up in different departments (ICU, Operating Room (OR), Radiology) to help implement this vision on sustainability. These Green Teams are multidisciplinary teams consisting of nurses, doctors, pharmacists, buyers, and other employees who are determined to contribute to making their departments more sustainable. These multidisciplinary are necessary to provide varying stakeholder perspectives and facilitate easy collaboration. Often multiple stakeholders are required to implement a sustainable initiative.

The Green Team of the ICU has bi-weekly meetings where they bring up ideas to make the ICU more sustainable and discuss how these sustainable initiatives can be implemented. An example of such an initiative is that the ICU Green Team is currently working on transitioning the single use medical protective coats towards reusable ones. This requires an investigation in the total footprint of the reusable alternatives, close contact with manufacturers and determining the right process. Can the hospital wash the coats themselves or does the washing need to be outsourced? Are the coats comfortable for healthcare personnel? Are they just as safe as disposable ones?

In order to get better insights on the impact of the different product categories at the ICU, Metabolic, a sustainability consultancy, did a material flow analysis of based upon all products procured in 2019. As Figure 9 shows, the biggest impact is made with syringes, protective clothing, and nitrile gloves, which Metabolic identified as hotspots. The VL is not necessary a product with the highest total impact, but a product with a large impact per product. Unlike many of the 'hotspot' products it is also suitable for reuse, which will be explained further in section 2.3. This means it could be a valuable product to investigate the reuse of medical products at the ICU, in order to incite the reuse of other products. By investigating barriers for the VL we could also learn what needs to be considered when implementing other reusable medical devices.

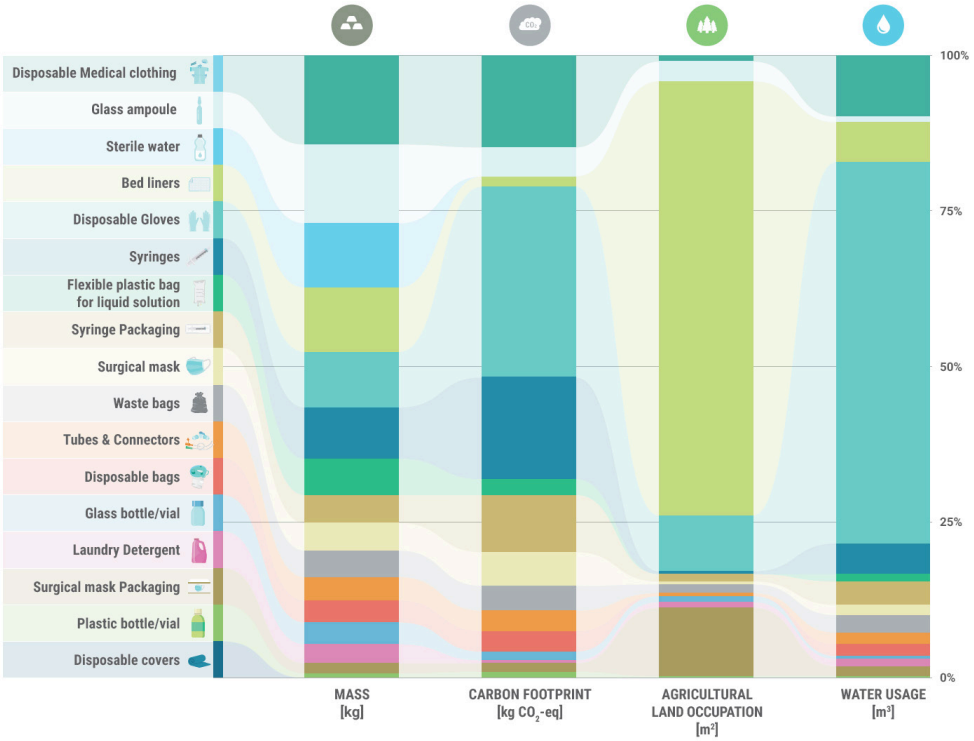


Figure 9: Impact analysis per product in the ICU by Metabolic

2.2 Circular healthcare

The previous chapter shows that the ICU at the Erasmus MC is aiming to be fully circular by 2030. But what does circular healthcare mean? In this chapter some core principals of the circular economy and circular healthcare are presented in order to provide a better understanding.

2.2.1 An introduction to the Circular Economy

In this chapter key concepts of circular healthcare are explained. The circular economy is a more sustainable alternative for the take-make-waste system or linear economy, defined by the European Parliament (2022) as "a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible". It is essentially based upon three principles:

- Eliminating waste and pollution
- Circulating products and materials at their highest value for as long as possible
- Regenerating nature (Ellen MacArthur Foundation, n.d.).

Circulating products and materials at their highest value can be illustrated by the Value hill model created by researchers from the Circle Economy and Sustainable Finance Lab, Nuovalente and TU Delft (2016). The concept of the Value Hill (Figure 10) is that value is added during the pre-use phase by extracting raw materials, manufacturing the product, assembly, and retail and that this value is destroyed once we dispose of the product. The goal of the Value Hill is to keep products for as long as possible at their highest value.

During this project future developments influencing the need for circularity were also explored, such as climate change, carbon taxations, supply chain issues and rising energy prices. These can be found in Appendix A.

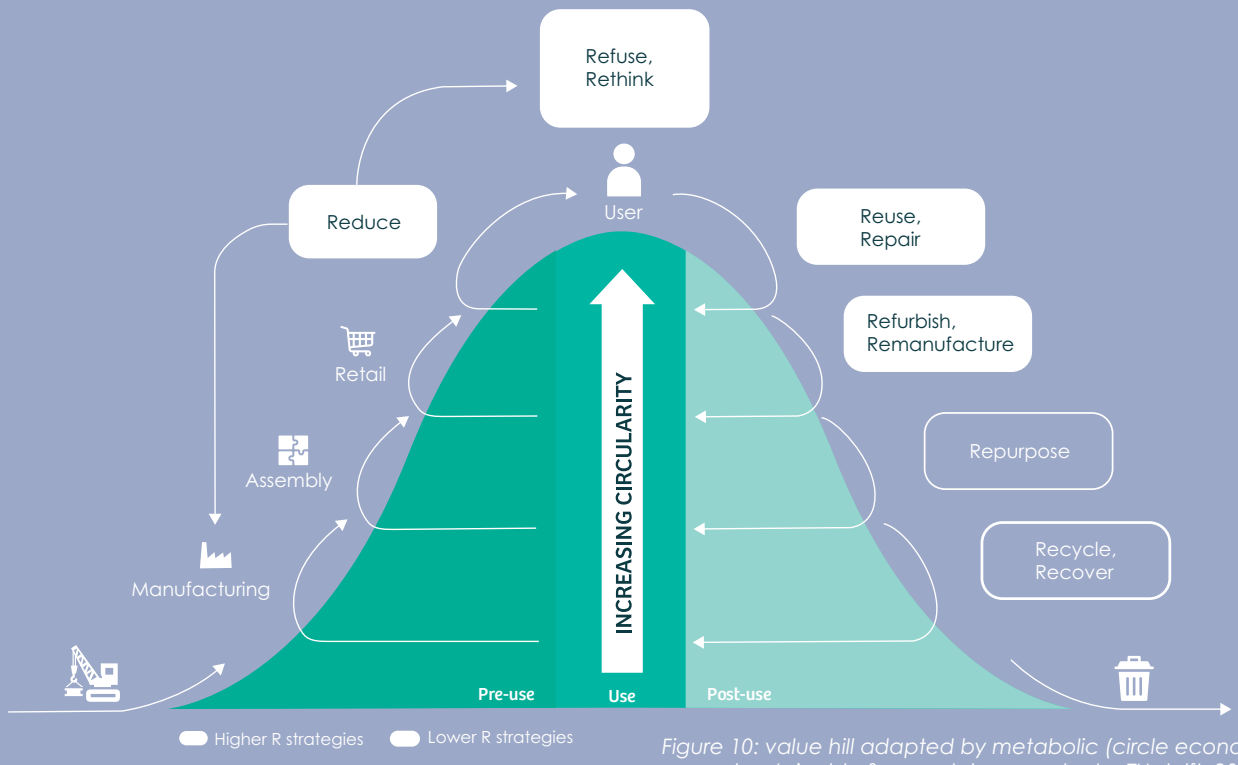


Figure 10: value hill adapted by metabolic (circle economy and sustainable finance lab, nuovalente, TU delft, 2016).

There is a hierarchy in circular strategies in terms of retaining as much of the initially added value as possible. Refuse, Rethink, Reduce, Reuse, Repair, Refurbish and Remanufacture are considered high R strategies, while Repurpose, Recycle and Recover are seen as low values. This can be seen in Figure 11. This hierarchy can be useful when re-designing or rethinking products and systems since aiming for higher strategies leads to a bigger impact.

The highest strategies such as Refuse, Rethink, and Reduce, are the most valuable, but have their limits. You can reduce or refuse the 'excess' of care, but you cannot reduce or refuse essential care. Some products and procedures are required in order to retain the current standard of healthcare, for this type of care reuse and recycle can be valuable as they can make essential care more sustainable. In this project it was decided to focus on reuse instead of recycling, since reuse is the higher R-strategy.

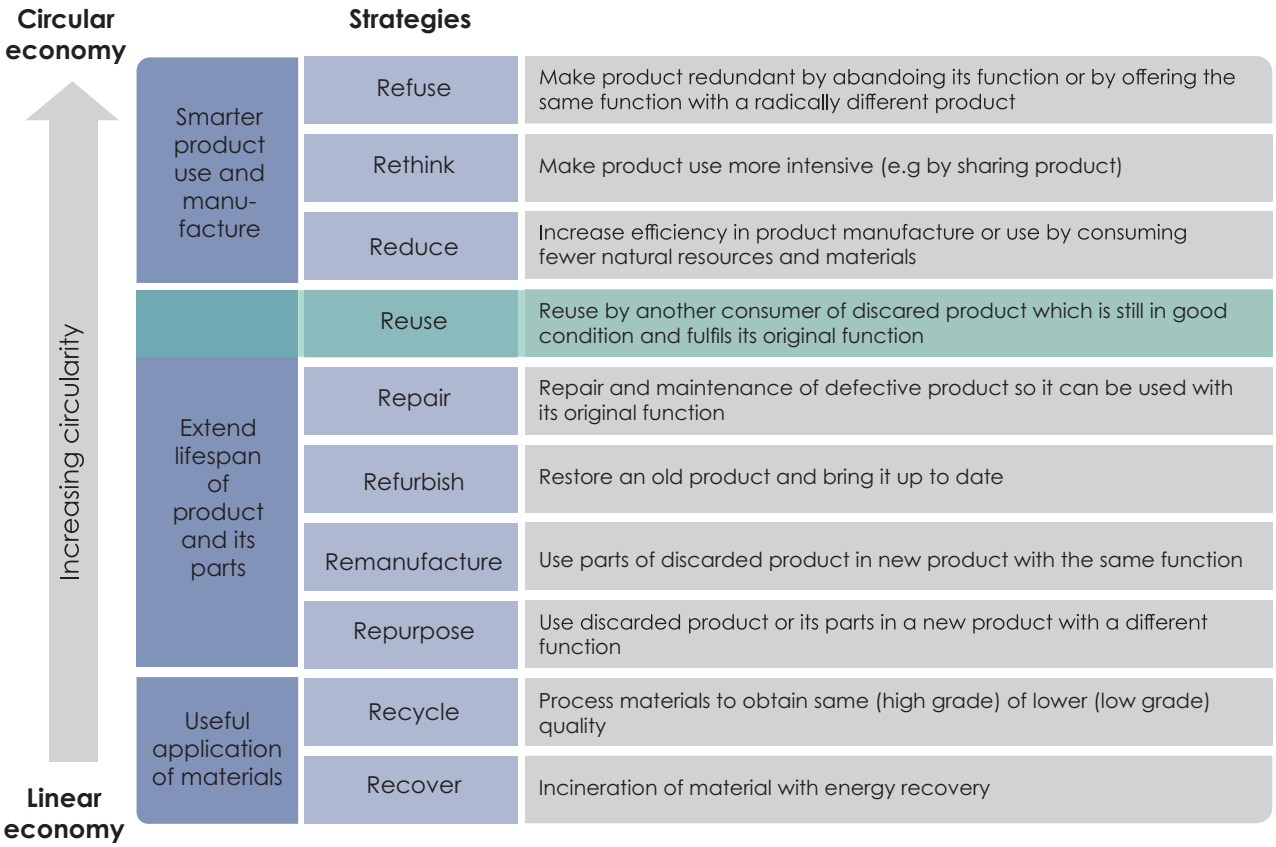


Figure 11: hierarchy in circular strategies (PBL Netherlands Environmental Assessment Agency, 2017)

2.2.2 Recovering medical devices from hygienic obsolescence

In the linear economy products are thrown away once they have become obsolete (at their end of life). Products are discarded when they no longer function, are no longer fashionable, no longer profitable, or not up to the current technological standard. In healthcare most products are thrown away due to what is called "hygienic obsolescence." (den Hollander et al., 2017). The device is no longer sanitary and safe to use on another patient. How can these products be recovered from obsolescence? This can be done through reprocessing. As defined by the European Commission "Reprocessing is the process of preparing a medical product for safe reuse through cleaning, disinfection, sterilisation and related procedures" (Reprocessing of Medical Devices, 2022).

When transitioning to more reusable products it is useful to consider the "Recovery Strategy" of medical products. The "Recovery Strategy" by Kane et al. (2018) can help to determine whether reuse is a viable recovery strategy for a particular product, or if refurbishment or recycling is more appropriate. Kane considers the product value and criticality. The criticality of a product is determined by the "Spaulding Scale" and determines how the product should be cleaned. The classification is dependent on the type of contact with tissue (see table). The table is based on a paper by MacNeill et al. (2020).

Risk level	Category	Contact tissue	Reprocessing requirements	Examples
Risk level	Noncritical	Intact skin	Low-level disinfection (e.g. alcohol wipes)	Stethoscopes, blood pressure cuffs
Inter-mediate	Semicritical	Mucous membrames	Intermediate- or high level disinfection with chemical disinfectants	Endoscopes, laryngoscope tongue blades
High	Critical	Blood and normally sterile tissue	Sterilisation with steam, ethylene oxide, or other chemical sterilants	Surgical instruments

Figure 12: Adapted Spaulding scale by MacNeill et al. (2022)

In general, the more critical the product, the more extensive and expensive the reprocessing for it to be reused. Therefore, the value of the product is also important for the recovery strategy. A high-criticality product with a low value is unlikely to be suitable for reprocessing and recycling will be a more appropriate option. Products that have a high value (often more technological products) that do not come into contact with patients will be best suited for refurbishment.

Figure 13: Recovery strategy (Kane, et al. 2018)

Example products in Figure 13:

1: Imaging equipment, 2: anaesthesia machines, 3: patient monitors, 4: furniture, 5: surgical 6: staplers, 7: hearing aids, 8: catheters, 9: endoscopes, 10: syringes, 11: bandages, 12: single use compression sleeves, 13: packaging materials

One tactic mentioned in the paper by Kane (2018) to circumvent the influence of criticality is the use of hybrid products. Hybrid products are part reusable and part disposable, whereby the disposable part is the product which comes in contact with the patient. The reusable part is considered non-critical and can therefore be recovered more easily.

What should be considered besides the products value and criticality? Not only can the costs of reprocessing outweigh the costs of discarding medical devices the environmental impact of reprocessing can also outweigh the environmental impact of the single-use devices(SUDs). To find out whether reusable products are indeed more sustainable than their disposable counterparts literature research was performed. This can be found in Appendix B: the sustainability of reuse. Here, ten research papers were evaluated, which compared the life cycle analyses of SUD's and reusable medical products. The conclusion was that in most cases (7/10) the reusable option was more environmentally friendly and more cost-effective. Additionally, transitioning to more renewable energy sources would make the reprocessing process less CO_2 intensive.

Figure 14: Image of Intubation with video laryngoscope

2.2 The case product: video laryngoscopes

The following section describes why the video laryngoscope was chosen to further investigate the reuse of medical devices in the intensive care at the Erasmus MC

2.2.1 Value and criticality determine reuse potential

The model by Kane as introduced in the previous chapter, is used as a framework to determine if a product can be reused or not. In the matrix, the level of criticality is specific since all products can be divided on the Spaulding Scale. However, the product value is not shown in concrete values on the axis. Therefore, the example products in the matrix are the only indication for the required value of a product to be in a particular category (e.g., refurbishing, recycling, reprocessing). Some example products within the reprocessing category are surgical shavers, surgical staplers, and hearing aids. None of these are specific to the ICU. However, a product that is frequently used at the ICU, which almost fits within the reprocessing category, is the video laryngoscope. Although it does not have an equally high value as the examples given by Kane, et al. (2018), it has a reasonable price of 35 to 42 Euros, which could potentially outweigh the costs of reprocessing.

The VL is used for intubation (Figure 14), a procedure where an air pipe is inserted into a patient who is unable to breathe independently. VL's fall in the semi-critical category on the Spaulding Scale, since it comes in contact with the mucous membrane in the inside of the patient's throat.

Figure 15: Image of a single-use video laryngoscope with external monitor (website manufacturer)

2.3.2 Frequent use

As mentioned, VL's are used frequently since most ICU patients are unable to breathe independently. Therefore, they need to be intubated. It is estimated that around 1800 VLs are used and thrown away each year at the ICU according to the data from the procurement department. The VL has a video port, camera and light source as shown in Figure 15. The external monitor is reused.

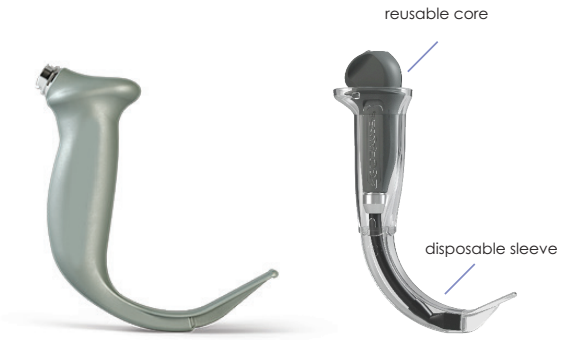


Figure 16: Image of a semi-reusable VL (right) and a completely reusable VL (left) (website manufacturer)

2.3.3 Reusable alternatives available

The VL already has reusable and semi reusable alternatives on the market (Figure 16), which are certified for reuse and thus considered safe. The reusable alternatives have a higher value than the single use VL's. The reusable core costs around 3800 Euros and the fully reusable VL costs around 5200 Euros.

The semi-reusable and reusable VL's can be used to understand the medical context and the barriers for reusing medical products at the ICU. Additionally, they can function as a pilot which could inspire the transition of other single-use products at the ICU.

Direct us video laryngoscopes

There are two types of laryngoscopes: direct laryngoscopes and video laryngoscopes. Direct laryngoscopes do not have a camera and are no longer the standard for intubation (Figure 17). Since the introduction of the VL's there has been a shift towards the use of VL's. VL's have shown to have an increased success rate of intubation, compared to direct laryngoscopes, with providers who are inexperienced in airway management (Russo, n.d). Since VL's seem to be the future of intubation I will be focusing on VL's.

Figure 17: Image of a direct laryngoscope (Website distributor)

Direct us video laryngoscopes

There are also two different types of VL's. Ones where the monitor is connected to the VL handle (Figure 18) and ones where the VL is connected to an external monitor. VL's with the monitor attached to the handle are particularly useful outside of the hospital since they are more compact and mobile. This project focusses on VL's with an external monitor, so that the existing external monitors that are already in use for the single use VL's do not have to be discarded.

Figure 18: Image of a Portable VL (website manufacturer)

2.3.4 Need for product-service scenarios

Both the single use as well as the reusable alternatives are more than just stand-alone products. Any VL is part of a service in the Erasmus MC. These products within a service will be referred to as product-service scenarios and scenarios in short.

This product-service scenario will differ from single-use VL, to semi-reusable VL to completely reusable VL. The overview in Figure 19 shows the core differences. These scenarios function as a starting point of the analysis.

They will be further investigated trough stakeholder interviews and observations to find out:

- what it entails to implement a particular scenario.
- what are the barriers and enablers are for a particular scenario.
- which scenario would be best for the environment and the organisation.

2.3.5 Balancing sustainability within the organisation

The goal of evaluating these scenarios is to balance the environmental and the organisational impact of the different scenarios. For instance, it could be that one scenario is more sustainable than the other, but it is very hard to implement in the current infrastructure and organisational setting. When that occurs, it will take more time to implement, or it could be met with resistance from stakeholders who face disadvantages from the particular scenario. It is important to balance all these factors in order to reach an optimal result for both the environment and the organisation. The desired environmental effects will only become reality when the scenario has actually been implemented.

The scenarios will be evaluated in section 3.3, with the knowledge gained from the stakeholder interviews, observations, and desk research.

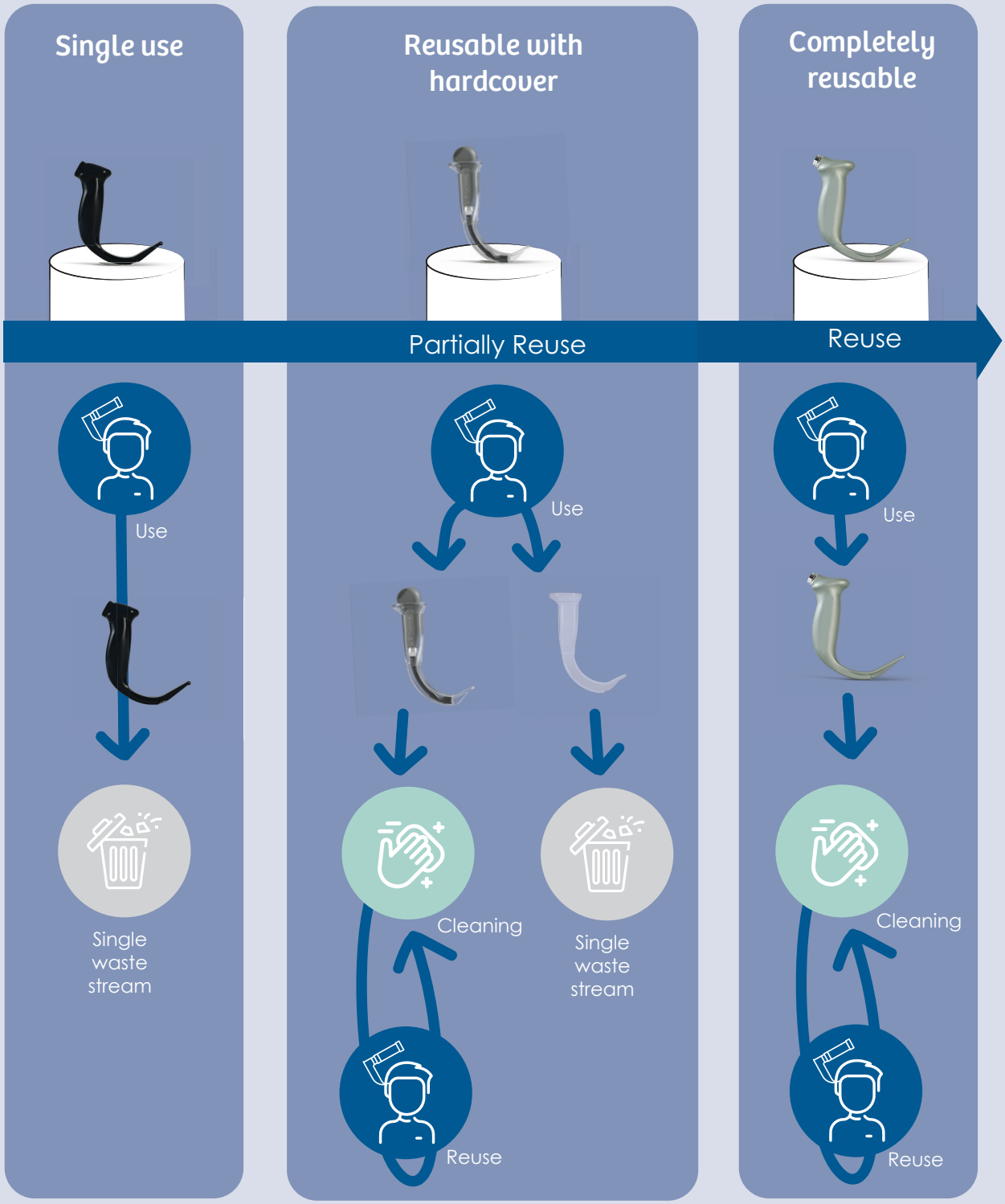


Figure 19: product-service scenario

2.1.3 Possible barriers for reuse

If there are reusable options for video laryngoscopes, why are they not implemented? Literature research was done to further explore this by asking following research question: "What are the barriers and enablers for implementing reuse of video laryngoscopes in the ICU?"

There is no research specific to the barriers to the reuse of medical devices within the ICU, but there are two papers regarding circular practices in healthcare in general and greening strategies within the OR. These were used to set up an overview of possible barriers for the reuse of VL, which will be evaluated in section 3.3, through stakeholder research.

The review by MacNeill (2020), which describes barriers to the circular economy, focuses more on the high-level organisational barriers. While the review by Wyssusek (2018), about current barriers to healthcare waste management initiatives in the Operating Room (OR) focuses more on the barriers at the department level. They have overlap in the barrier 'perceived infectious risk'. The list of these barriers may or may not apply to the reuse of video laryngoscopes, since these papers were not specific to the reuse of VL in the ICU. However, this gives a direction to investigate whether these barriers exist at the Erasmus MC, and if so, come up with solutions to overcome these barriers.

We can look at barriers and enablers from three perspectives: healthcare organisations, manufacturers, the government. Within the healthcare organisations we can also look at more staff related and behavioural barriers. These are shown in Figure 20.

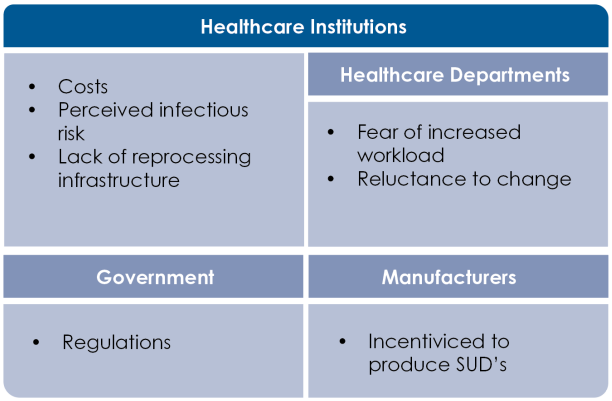


Figure 20: Categories of barriers for reuse based on MacNeill et al., (2020) and Wyssusek et al., (2018)

Healthcare institutions

Perceived infectious risk (patient safety issue)

McNeill, et al. (2020) state that the primary barrier against reuse is the perception that SUDs are safer than reusable devices. The perceived infection risk of reusing medical devices is agreed upon as a barrier by the authors of the second review by Wyssusek, et al. (2018). The topic of whether reusing medical devices poses more safety risks than disposables remain a heavily debated topic within literature. Muddying the discussion is the lack of distinction between the reprocessing of SUDs and reusable medical devices since SUDs devices are not designed to be reused. Designed for reuse or not, according to the US Food and Drug Administration the available data 'does not indicate that reprocessed devices currently in use pose an increased safety threat' (United States Government Accountability Office, 2008). Although, the reuse of medical devices does not cause more adverse events, the perception that it does can still influence the implementation of them.

Costs

Advances in material science made it possible for more complex medical products to be made of low-cost plastics (Kane et al.) The low costs of medical equipment have left the hospitals with little incentive to change towards reusable products. Although, my analysis in Appendix B shows that reusable products are often more cost effective than SUD's,

the perception is often that reusables are more expensive. Higher initial investment costs may play a role as well.

Lack of reprocessing infrastructure
Having a circular supply chain versus a linear supply chain greatly increases the complexity of operations within hospitals. The reprocessing of medical devices in house is an extensive process which requires infrastructure, logistics, specialised machines, trained employees, and a lot of know-how. Concerns about the costs, liability, and complexity of developing and maintaining this reprocessing infrastructure has led hospitals to continue to rely on SUD's or to outsource their reprocessing to third party commercial vendors (McNeill, et al. (2020).

Healthcare departments

Workload
The healthcare industry is already under a lot of stress with an aging population and personnel shortages. Due to this, many healthcare professionals are already at the limits of their capacity and spending extra time to work on sustainability initiatives, separating waste or disinfecting reusable devices manually can become a burden on the staff (Wyssusek, et al., 2018).

Reluctance to change
To change current practices stakeholders, such as doctors, nurses and hospital administration must be engaged in the transition. Unfortunately, humans are conditioned to find comfort in the familiar and resist change, so they must be properly engaged to change. A lack of understanding can also contribute to a reluctance to change. If it is not clear why something needs to change, it is hard to motivate healthcare personnel to do so (Wyssusek, et al., 2018).

Manufacturers

Manufacturers are incentivized to manufacture SUDs.
The business models of most manufacturers incentivize single use disposables over reusable products since they maximise profits through high volume consumption. This is also believed to be enhanced by "manufactured obsolescence" through arbitrarily labelling products single-use or shortening 'best-before' dates (McNeill, et al., 2020).

Government

Rules and regulations
The paper by MacNeill (2020) mentioned that the lack of clear and consistent guidelines from different regulatory and oversight organisations has resulted in confusing standards for reprocessing of reusable medical devices. Since this paper investigates the barriers within a US context, this might not be the same for the Dutch and European regulation.
through arbitrarily labelling products single-use or shortening 'best-before' dates.

Which barriers are the most relevant for the VL?

Of all the barriers above, It is expected that the most important barriers to focus on for the VL are the (perceived) infectious risk, costs, lack of reprocessing infrastructure, fear of increased workload, and resistance to change.

The fact that manufacturers are incentivised to produce SUD does not appear to be a large issue for the VL specifically, since there are already reusable options of the VL. This, however, could be an issue for single use medical devices that currently have no reusable alternatives since manufactures will not be incentivised to create reusable options. Therefore, it is useful to consider when zooming out to other products at the ICU. This is similar to the barrier of 'rules and regulations' since there are currently no rules and regulations prohibiting the reuse of reusable VL. This may be different for other products.

Analysis

The analysis part aims to answer the research question: what are the barriers and enablers in the context of the ICU at the Erasmus MC? Since there is no literature specific to the reuse of VL's at the ICU, further research is needed in order to be able to implement reusable VL's successfully. A combination of stakeholder interviews, observations and desk research was used to create product-journey maps. This could help identify the actual barriers for the reuse of the VL, by understanding the stakeholders' current processes, decision processes and barriers they experience.

03.

3.1 Research set-up

In order to effectively analyse the findings from the stakeholder research a mixed set of methods was used to create a product journey of the single use VL and a proposed product journey of the reusable VL's. The results are essentially a combination of a product journey, customer journey and customer proposition. The product journey has its roots in circular design, while the customer journey and customer proposition evolved from the service design field (Stickdorn and Schneider 2011).

3.1.1 Product journey

In 2016 the design agency IDEO and the Ellen MacArthur foundation collaborated to create a 'product journey map' worksheet to help understand the cycles of a product or service. The worksheet requires you to fill in each step of a product or service from inception to its end-of-life in order to better understand what happens over time and how the lifetime of the product can be extended. Customer journey mapping, on the other hand, are a set of activities performed to analyse an existing service process (Følstad, et al., (2018)). This can consist of data collection with users, quantitative and/or qualitative data analysis. The findings are typically presented in a visual manner. A customer journey map usually maps the existing processes, while its counterpart the proposed customer journey map displays a future or 'proposed' journey map (Følstad, et al., (2018)).

Combining the methods

The product journey for this project follows the product and the user, but includes the touchpoints, actions, and experiences of the stakeholders. The product journey mapping of this project was done through stakeholder interviews and observations, combined with desk research and the graduation reports of A. de Ville (2022) and M. Maanicus (2022). For the creation of my product journeys, the product journey map and product journey proposition are created simultaneously as the interviewees were both asked to describe the existing processes as well as the possible 'to be' services of the reusable VL's. This was done to be mindful of the participants' time.

Usually a customer journey (it can also be a user) centres around the processes, touchpoints, and experiences of a single customer or user. Since the VL will be in touch with many stakeholders throughout its product-lifetime, this method alone is not fully sufficient. It was therefore adapted for this project to include multiple stakeholders. The journey of the VL will be followed, while taking in the different stakeholder actions and experiences. The product journeys are there to show the differences and challenges in the day-to-day operations with the different VL's.

3.1.2 Stakeholder interviews and observations

Interviews were done with stakeholders who are involved in the current journey of the VL and the reusable journeys. Stakeholders in the current product-journey who were interviewed include manufacturers, doctors, and nurses. Furthermore, employees at the CSD were interviewed. They are currently not involved in the product journey of the single-use VL, but this department could have a key role in reprocessing the fully reusable VL's in the future. Additionally, to the product-journeys, the procurement process was investigated. This was done to gain insight in the decision process of new products. Some stakeholders in the product-journey, such as doctors and medical device experts from the CSD are also involved in the procurement process.

The overall goal of the interviews was as follows:

- Understand the current product journey and procurement process.
- Find out what needs to change to implement different reusable options of the VL
- Understand barriers and enablers for the implementation of reusable VL's.

The sampling strategy for most of the stakeholders was to recruit 'key informants' who are knowledgeable agents in their field of expertise These consisted of manufactures, doctors, and nurses in the current journey and CSD employees in the journey of the fully reusable VL. To keep the report concise, the interviews with manufacturers were put in Appendix D. The core stakeholders are highlighted in light blue in the overview. A detailed overview of the participants and the type of conversations and activities can be found in the appendix as well (Appendix E).

Due to the exploratory nature of the research, semi structured interviews were held. This provided structure but also the ability to ask follow-up questions in the flow of the conversation. These interviews were not recorded to make the interviewees feel at ease and to invite them to an open discussion in which they could share their experiences and knowledge. To still capture valuable data without recording, notes were made during the interview as well as photos from the environment. Shortly after the interviews the notes were edited and expanded upon, since some of the notes during the interview were more condensed.

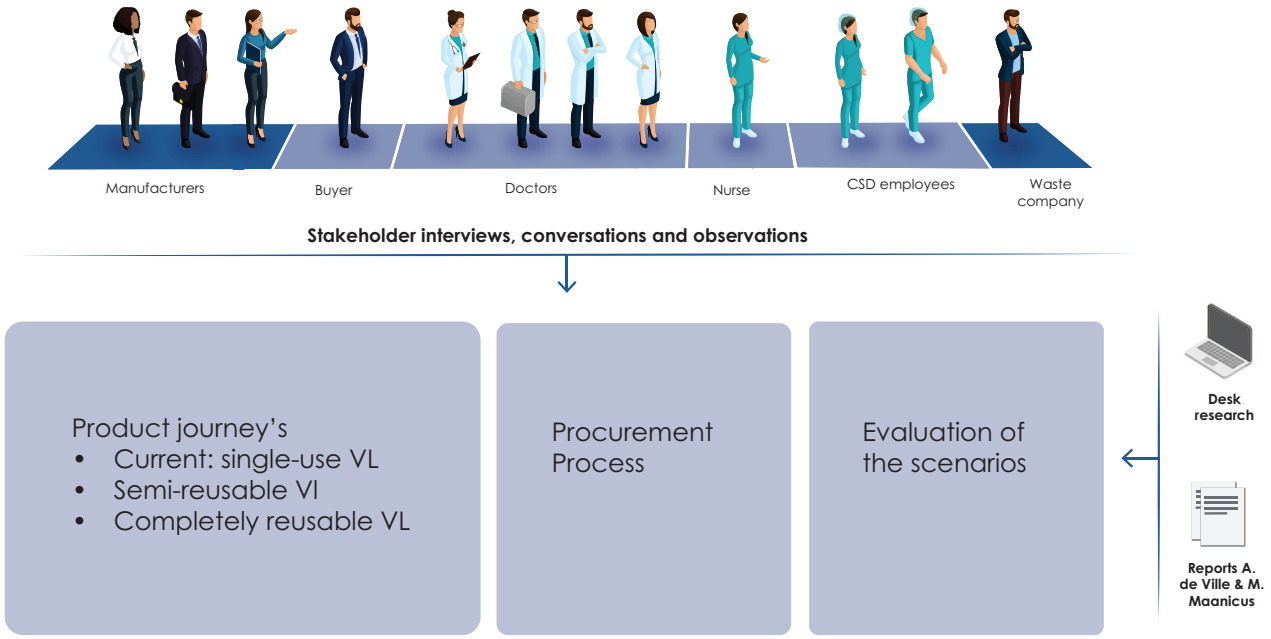


Figure 21: Overview stakeholder research

3.2 Research findings

The following section presents the layout of the ICU to provide context. After that the current product journey of the VL will be presented, followed by stakeholder interviews and the proposed product-journeys of the reusable alternatives. After that, the procurement process is discussed and the different VL's are evaluated.

3.2.1 layout of intubation at the ICU

The Intensive Care consists of four regular units (A, B, C and D) and a Thorax Unit. The Thorax Unit mostly hosts patients who are recovering from surgery in the area of the body between the neck and the abdomen, such as heart or lung surgery. Patients at the Thorax Unit are usually already intubated at the OR, so the focus is on the regular units.

Every (regular) unit has ten rooms, which are referred to as 'boxes' at the ICU. Usually, six to eight boxes are occupied. On average there are five intubations per day for the whole ICU, so around one or two per unit per day. Units A and B are connected through a break room and share a waste area, storage room and washing room. Materials for intubation are stored at both units in the hallway in an intubation kart. A layout of two ICU's is shown in Figure 22. The numbers correspond with the images in figure 23 and 24.

Waste management

In the patient's room (figure 23) there are three main bins; a bin for sharps (needles and other sharp items), a bin for linen (which will go to the laundry) and a bin for medical waste. Most of the waste from an intubation will go into the medical waste bin: the packaging of all the materials, mask, tubes, protective clothing, and the VL. At the end of the hallway is a room where the bags of medical waste are stored in large containers. The containers are brought to the central waste department of the hospital where they will be transported to a medical waste incineration facility. Currently no medical devices are reprocessed at the central sterilization

Figure 23: Image of ICU box (Patient's room)

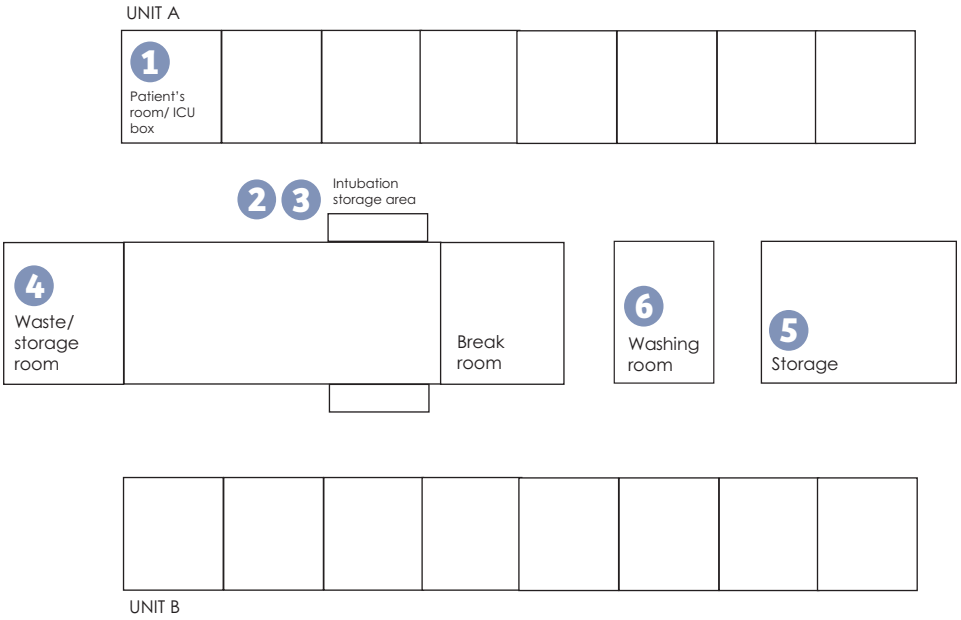
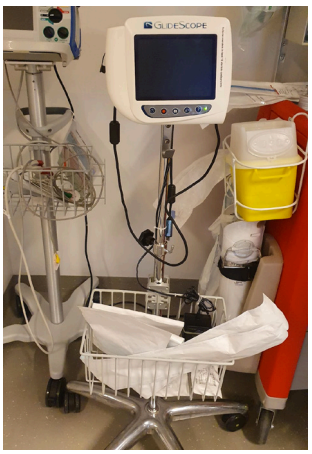


Figure 22: Schematic overview of two ICU units

2 Intubation kart in the hallway



3 VL monitor in the hallway

4 Waste area (with some extra storage)

5 Shared storage inbetween ICU units

5 Storage system where facility employees can scan codes is

6 Washing room (spoelruimte)

Figure 24: Images of the Intensive Care

3.2.2 current product journey of a single-use VL

The below overview presents a detailed journey of a single-use VL from production till incineration. The top part shows the general stages of the process, the 'touchpoints' show where the VL is at that moment and the 'actions' bar shows which stakeholders undertake which actions. Finally, there is a bar which shows the journey of a patient from being unstable, to being intubated, to being stable again.
Intubations at the ICU are usually 'crash' intubations, where patients are brought over from different departments when they have suddenly become in poor respiratory condition. The department with the unstable patient will call in advance, so that the medical staff can prepare a room and all the medical supplies for intubation. When the patient arrives, the patient is assessed, and the doctor determines an intubation procedure. After the intubation procedure the patient's breathing is taken over by a ventilator. Once the patient is stable, nurses will start cleaning up. They will throw away the VL and other materials used for intubation in the medical waste bin, wipe down the monitor and return the monitor to the hallway.

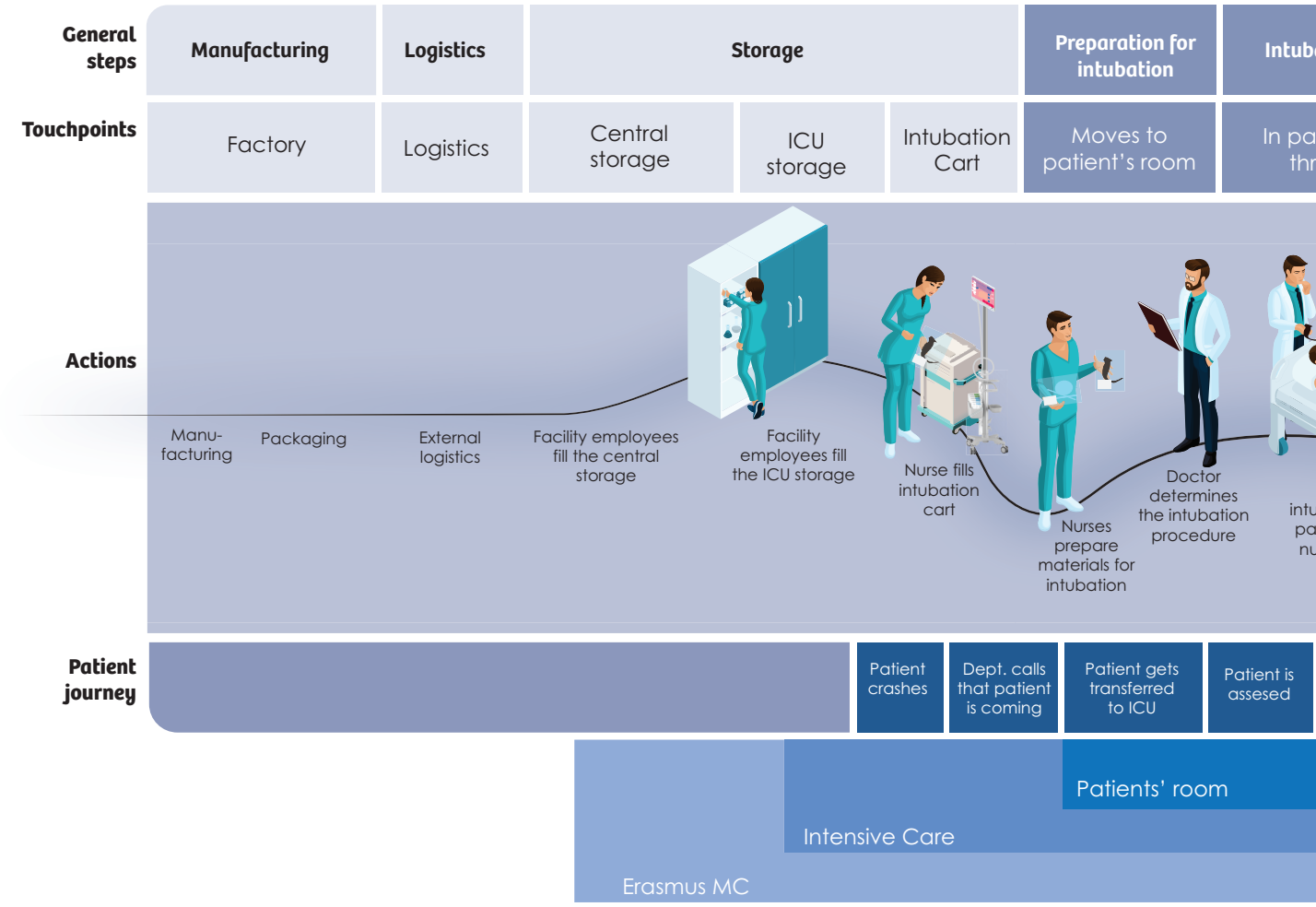
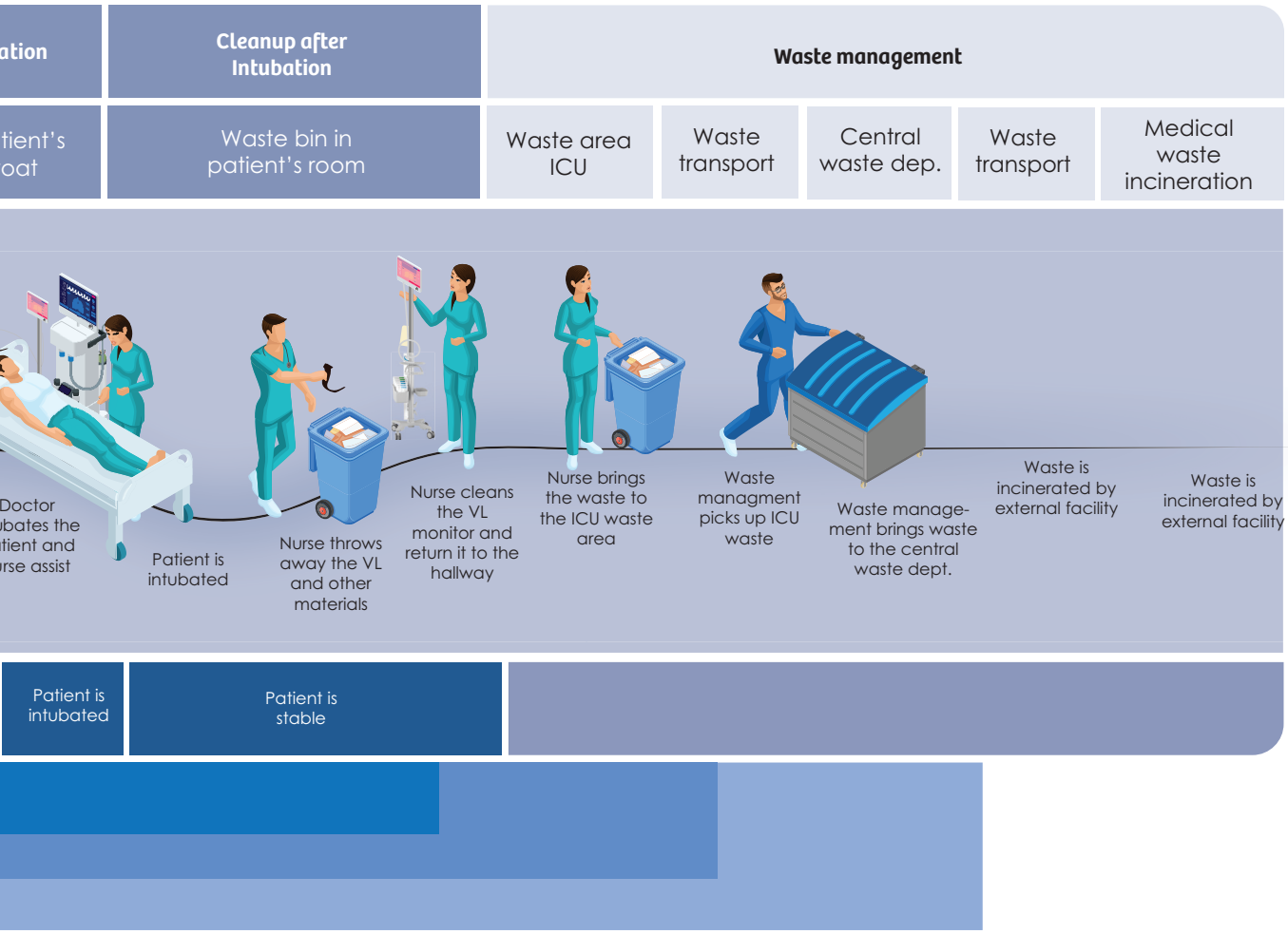


Figure 25: current product journey of the single-use video laryngoscope


ation
Cleanup after Intubation
Waste management
tient's oat
Waste bin in patient's room
Waste area ICU
Waste transport
Central waste dep.
Waste transport
Medical waste incineration
Doctor bates the tient and rse assist
Patient is intubated
Nurse throws away the VL and other materials
Nurse cleans the VL monitor and return it to the hallway
Nurse brings the waste to the ICU waste area
Waste managment picks up ICU waste
Waste manage-ment brings waste to the central waste dept.
Waste is incinerated by external facility
Waste is incinerated by external facility
Patient is intubated
Patient is stable

3.2.3 Stakeholder interviews: doctors, nurses and CSD

The interviews and interactions with doctors, nurses, and employees from the CSD are presented in the following section. After these interviews, the journeys of semi reusable and completely reusable VL will be presented.

Doctors

Four doctors were interviewed, two intensivists, one assistant doctor and an anaesthesiologist (who worked at both the ICU and the OR.) Three VL's were shown (single-use, semi-reusable and reusable), to make sure it was clear which specific video laryngoscopes were being discussed.

The doctors were asked:

- Which types of laryngoscopes and VL's they were using.
- What they were looking for in VL's.
- What did they think of using different VL's.
- What happens with the VL after intubation has taken place.

Two of the doctors said that mainly single-use VL's were being used because particularly younger doctors prefer them. They also said the Covid-19 pandemic had greatly increased the use of VL's over direct laryngoscopes, since they led to more successful intubation in an acute situation. The anaesthesiologist said that only for difficult cases, around 10% of the cases, video laryngoscopes were being used. For the other 90% cases he said direct laryngoscopes were being used. The assistant doctor said they used a semi-reusable VL.

Furthermore, the anaesthesiologist showed that there were many more options than this particular single-use VL at the OR department, such as a semi-reusable video laryngoscope by a different brand than the ICU ones. However, the intubation cart at one of the intensive care units mainly had disposable VL's and direct laryngoscopes with disposable blades.

All of the doctors interviewed said there wasn't a performance difference between the different VL's. The most important part of intubation is selecting the right size. One doctor said, "there is no holy grail size VL, it differs per person". Not only did they see little to no difference in the performance, they also did not see any safety issue with using reusable VL's. They made no distinction between the semi-reusable and the completely reusable either. One of the doctors referred to the VL as not a very high-risk product since it only touches the throat and is easy to clean.

Video laryngoscopes at the Leiden University Medical (LUMC)

In order to investigate which types of VL's other hospitals might be using, two doctors at the Leiden University Medical Centre (LUMC) were contacted. One of them said they used semi-reusable VL's and the other said they used fully reusable VL's. Similar to the doctors at the Erasmus MC, they probably use many different VL's and base their answers on the ones they use most frequently. The Erasmus MC might be able to learn from the Erasmus MC how they implemented the reusable VL.

Key takeaways doctors

- The interviewed doctors do not think there is a performance difference between single-use, semi-reusable or completely reusable VL. A VL's size that fits the patient's throat is what matters.
- The interviewed doctors did not see reusable VL's as a safety risk.
- There are many different types of laryngoscopes and video laryngoscopes at the ICU and the OR.
- The ICU at the LUMC uses completely reusable video laryngoscopes that are reprocessed at their CSD.

Source: Amazing Erasmus

Nurses

The research on nurses consists of two parts: The research by another graduation student and my own interview with an ICU nurse. Initially I thought that the research from the fellow graduation student M. Maanicus was insightful enough for this research to not require extra interviews, but later I saw the need for an extra interview. Maanicus interviewed nurses to identify motivators and barriers to sustainable behaviour in the ICU, which is very relevant to this research project. Nevertheless, some extra knowledge on the intubation procedure, workload and reusable VL alternatives was required to get sufficient insights for the implementation process of reusable VL's.

According to Maanicus (2022) the personal barriers to behave sustainably, currently perceived by the ICU's staff, can be divided into five main categories: lack of sustainable alternatives, time and convenience, responsibility, quality of care, and lack of knowledge. Each of the categories will be discussed in more detail in Appendix F: Research Nurses. Overall nurses are motivated to be more sustainable. Nevertheless, nurses perceive that they are held accountable for working more sustainably although they feel that it is primarily the responsibility of the management of the hospital to facilitate them with knowledge, time, and practical solutions. They need to be facilitated to find the right balance between providing quality care and acting sustainably.

The additional interview with the nurse took place in an ICU box and we took some time after the interview to look at the intubation kart, storage and washing room.

During the interview the nurse was asked:

- How they prepare for intubation and clean up after intubation.
- About her current workload and if she thought the reusable options were doable in her schedule.
- How and if they are involved in the decision process.
- How are changes communicated.

This information gathered from the nurse about the intubation process is described in the single-use VL journey in Figure 25. One of the key takeaways is that they always do 'crash' intubations, meaning that the time before intubation can be quite stressful. Needing extra preparation time before an intubation can be bothersome, but afterwards is much less problematic since the patient is stable by then. Furthermore, intubation can happen at any moment of the day, and the crash cart needs to be filled at all times. Refilling the intubation kart is by exception the responsibility of the nurses. After intubation nurses are required to refill the cart, and if this is not possible in their shift, they need to hand this over to the next shift. Most other items are refilled by facility employees, as well as the storage units.

Workload

When asked about the reusable alternatives the nurse said that they were very doable to execute, since they take very little extra time and ICU staff is very motivated to be more sustainable. She did however say that a transition of a product should be well thought out. It can be frustrating when nurses put in effort to try something out that has no possibility of succeeding due to obvious bottlenecks. She mentioned for instance that if there were to be a bin for CSD products, that it needed to be clear who was responsible for picking it up. Otherwise, it would just pile up and not be functional. When asked what a proper place was for the reusable VL she replied that the washing room was fine, since it is not that far away from the units ICU boxes.

Patient safety

According to the nurse, infection prevention is not really in favour of more reuse and that can be difficult when transitioning to more reusable products. However, she said that safety is highly dependent on how the products are cleaned.

Communication

Additionally, she said that the communication about changes in procedures and products should be well thought through. Sometimes nurses work at different units and having different pilots at different units can be confusing. Do you need to throw the VL away at unit A or not? Do they separate plastic bedliners at Unit D? It is hard to keep up with the protocols. Currently nurses are kept up to date with the newsletter and the informational slide show a TV-screen in the breakroom.

Key takeaways nurses

- The reusable alternatives are doable to implement in terms of workload.
- Nurses are motivated to facilitate sustainable initiatives.
- The product-services of reusable alternatives need to be well thought-out before implementing.
- Nurses need to be well informed about changes in procedures and differences between units need to be minimized.
- Preparation for intubation is in a high stress environment, clean-up is not.


Source: Radboudumc

Central Sterilisation Department

I was given a tour of the Central Sterilisation Department (CSD) by an expert in cleaning and disinfecting medical devices working there, as well as two interviews and a separate interview with the manager of the CSD.

Current processes

The CSD is responsible for cleaning, disinfecting and sterilising reusable medical devices for safe reuse within the Erasmus MC. They mainly clean products for the Operating Room and are conveniently located next to the ORs, where OR personnel can pick up their products in the storage in the sterile part of the CSD. Other departments are making use of the logistics department to pick up and receive devices. Currently there are no products going from and to the ICU, although that had been the case in the past before they transitioned to mainly single-use devices.

The reprocessing process consists of four parts: pre-cleaning, cleaning, disinfection, and sterilisation. The process is shown on the next page.

External reprocessing

The paper by MacNeill (2020) described that there was a shift towards hospitals employing external reprocessing facilities to outsource both the liability and the required infrastructure for reprocessing. To see whether the Erasmus MC was also moving in this direction I asked whether they were also employing external companies which was not the case. They only work with one external company which can serve as a backup facility in case of a power outage or technical difficulties. They had no intention of outsourcing products to other facilities.

Turnaround times

Slow turnaround times were mentioned as a risk of reusable video laryngoscopes in the graduation report of Ville, A. (2022), another graduation student from the Green ICU. The interviewed medical technician could not say exactly how long it would take for the VL to come in dirty and return clean, but she did say that the cleaning time of most devices was around four hours. Therefore, the CSD Manager was asked as well. He said that they could return a device in 6 hours if it was urgent. Generally speaking, however, it would take around 24 hours with a maximum of 48 hours.

Dirty devices arrive in metal nets by which they will be tracked. Here they will be pre-cleaned by hand and put in the ultrasonic cleaner if the particular devices are compatible with the ultrasonic cleaner.

After ultrasonic cleaning the dirty products move into the washing machines. These machines have different programs and specific devices will also be cleaned chemically. Furthermore, great care will be taken to make sure that products do not touch each other, since that will hinder proper cleaning.

Devices come out of the other side in the 'clean' area.

Decision making process

The CSD is involved in the tender process when it concerns reusable products that will need to be reprocessed. Manufacturers provide information about how their products need to be reprocessed and when the medical technician deems the products suitable for reprocessing at their facility the order can be approved. Usually when a new product is introduced the manufacturers will come to the hospital and give instructions on the correct cleaning procedure. After this you will find a summary of the process.

In the clean room the products get checked for cleanliness and function. Then they are weighed to check whether all products are on the net. After this they will be packaged in 'blue medical wrap' and moved to the autoclave.

Here the nets come out in the sterile part. The CSD employees will check whether devices have come out fully dry and check whether the autoclave program has run appropriately.

Equipement is storaged in the sterile side of the departement.

Other departments make use of the logistics department. Usually dirty equipement is picked up once a day and clean products are delivered once a day as well.

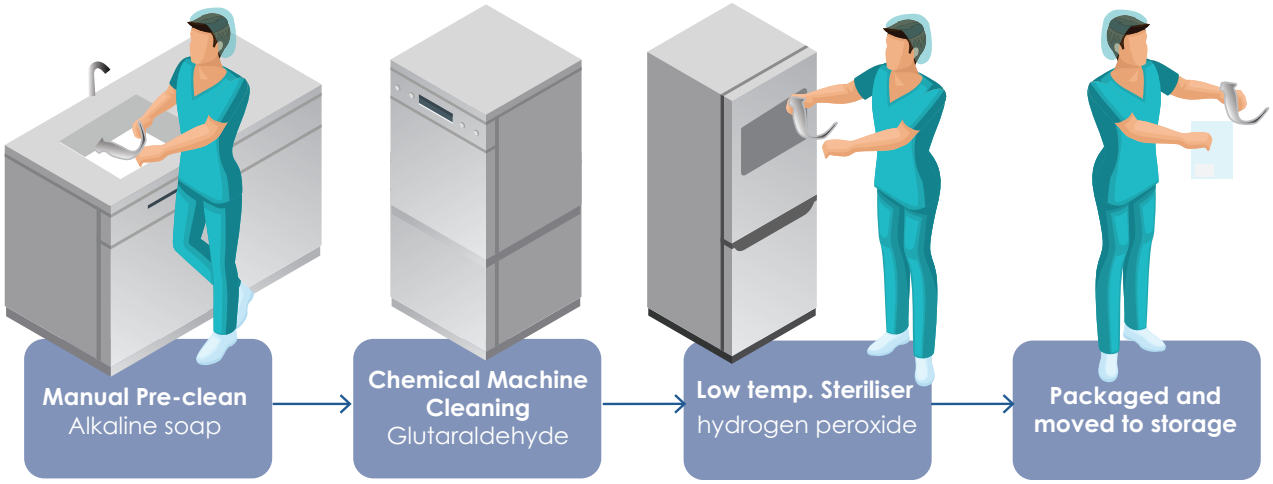


Figure 26: reprocessing process reusable VL

Reprocessing of the reusable video laryngoscope

A few weeks after my initial conversation with the medical technician I returned to discuss the reusable VL, with my reusable VL in hand which I had received from the manufacturer. It turned out that all the files of the reusable VL were already in the system since they had previously initiated a transition towards reusable VL's during the Covid-19 pandemic, when single-use VL's had become unavailable due to a high demand. However, as soon as the single use had become available again the procedure was halted.

There were no technical issues in the cleaning procedure (shown in figure 26), according to the medical technician. We discussed the cleaning guide from the manufacturer, which stated that the product could not be cleaned with ultrasonic, and not endure temperatures higher than 60 degrees Celsius, but that it could be submerged in liquid (not always the case). This means that the VL cannot go into the ultrasonic cleaner nor into the autoclave, which is standard for most other devices, but could be reprocessed in an alternative manner. To ensure proper sterilisation the VL needs to be chemically disinfected with glutaraldehyde, followed by a low temperature sterilisation machine, which sterilises at low temperatures with the use of hydrogen peroxide.

Sustainability and Costs

When asked about the sustainability of the reprocessing process, both the manager and the medical expert were sceptical about how sustainable reprocessing devices were, because the processes require a lot of water, energy, and aggressive cleaning supplies. Unfortunately, they did not measure the sustainability of their processes, so they could not provide any numbers. Similarly with the costs they were unable to give an estimate of the costs associated with cleaning on VL. The CSD manager did say that they had once experimented with passing on the cleaning costs to each department, but that they had failed to make the costs more transparent.

Researching the sustainability of the reprocessing process

According to the manufacturer of the low-temperature steriliser, the machine uses approximately 68% less energy to operate compared to steam sterilisers. Next to this, the machine does not use any water and since the glass plasma breaks down the residual hydrogen peroxide, only the safe elements of water and oxygen are left behind. The cleaning product glutaraldehyde on the other hand, is a commonly used disinfectant in the healthcare industry, but can be harmful for people who are frequently exposed to it, such as CSD personnel.

Additionally, it can affect the health of marine life, if exposed through hospital wastewater (Smith & Wang, 2006).

Capacity
The CSD manager said that they could take on the extra VL's capacity-wise. Since the VL's would be reprocessed in the machine for low temperature steriliser, which was not being used much. However, the CSD is already on the edge of its capacity due to a lack of employees, machines, and physical space, so it seems hard to imagine that the CSD would be able to take on more reusable products from the ICU.

Innovation
Currently, the CSD is not actively seeking out more sustainable methods to sterilise medical devices, such as gamma radiation, but they are actively innovating their department. They did invest in special cleaning equipment for a surgical robot and were investigating new technologies to shorten the dry time of endoscopes.

Key takeaways CSD

- The CSD does not measure the level of sustainability of their processes (energy consumption, water usage and toxicity of cleaning products) and it is thus hard to determine the sustainability of reusing VL's.
- The CSD is equipped to reprocess reusable VL's and has enough capacity in the low temperature sterilizer to facilitate this.
- The CSD does not have enough capacity (employees, machines, floor space) to take on more devices besides the reusable VL.
- The CSD is actively seeking out innovative technology to enhance their department.

3.2.4 Product journey semi-reusable VL

From the findings of the stakeholder interviews different product-journeys were created for the semi-reusable and completely reusable VL. This helps to compare the full product-service since it includes all the steps and stakeholders along the journeys from manufacturing to disposal and/or reuse.
Figure 27 shows the product journey of the semi reusable VL. The semi-reusable VL comes with a reusable core which can be attached to the monitor. Before intubation a hard plastic disposable sleeve is placed over the reusable core. The single-use sleeve will be disposed of in the medical waste bin. After intubation the VL monitor will return from the patient's room back to the hallway. Both the monitor and the VL core will be wiped down with a wet cloth. This process is very similar to the process of the single-use VL, the main difference being that the core needs to be cleaned as well. This process will cost maximum of 30 seconds more compared to the single-use VL.

Intubations at the ICU are usually 'crash' intubations, where patients are brought over from different departments when they have suddenly become in poor respiratory condition. The department with the unstable patient will call in advance, so that the medical staff can prepare a room and all the medical supplies for intubation. When the patient arrives, the patient is assessed, and the doctor determines an intubation procedure. After the intubation procedure the patient's breathing is taken over by a ventilator. Once the patient is stable, nurses will start cleaning up. They will throw away the VL and other materials used for intubation in the medical waste bin, wipe down the monitor and return the monitor to the hallway.

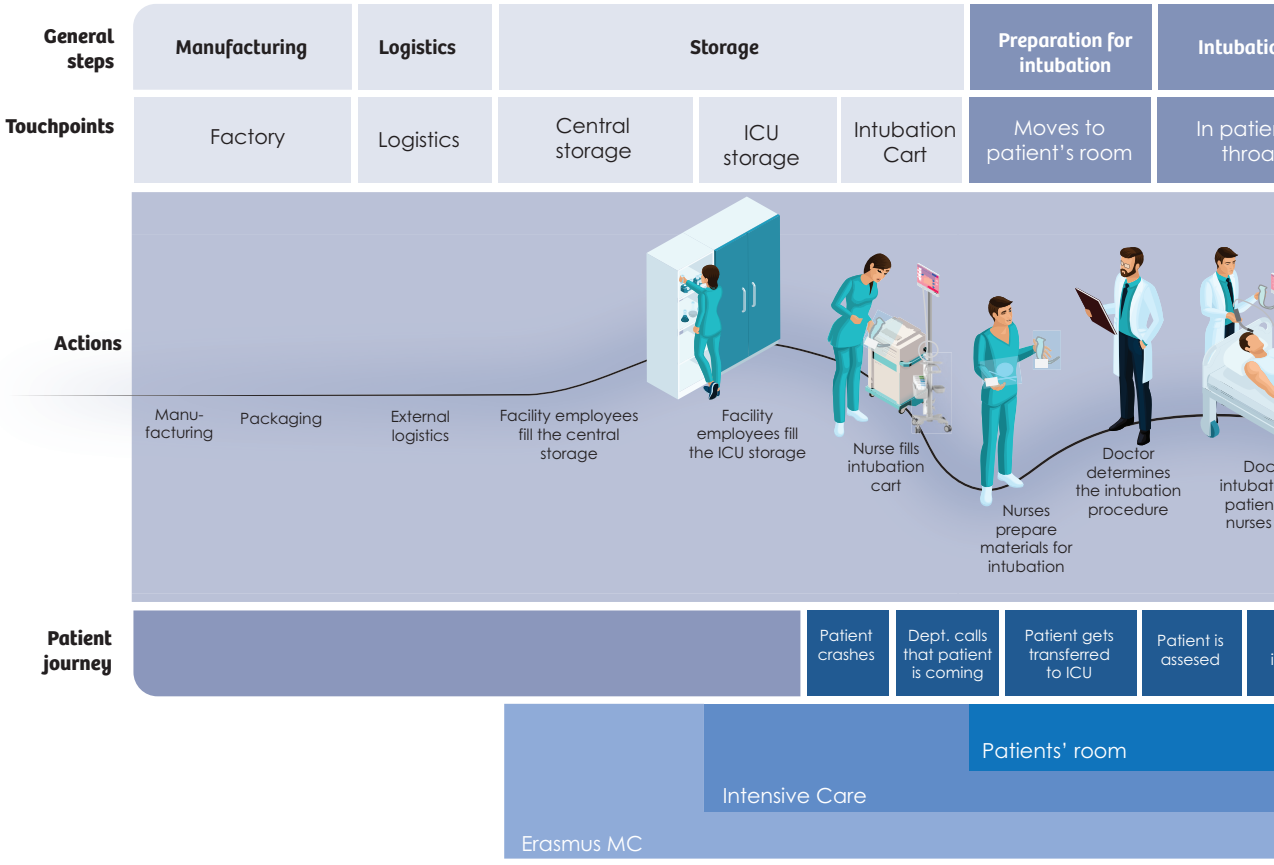
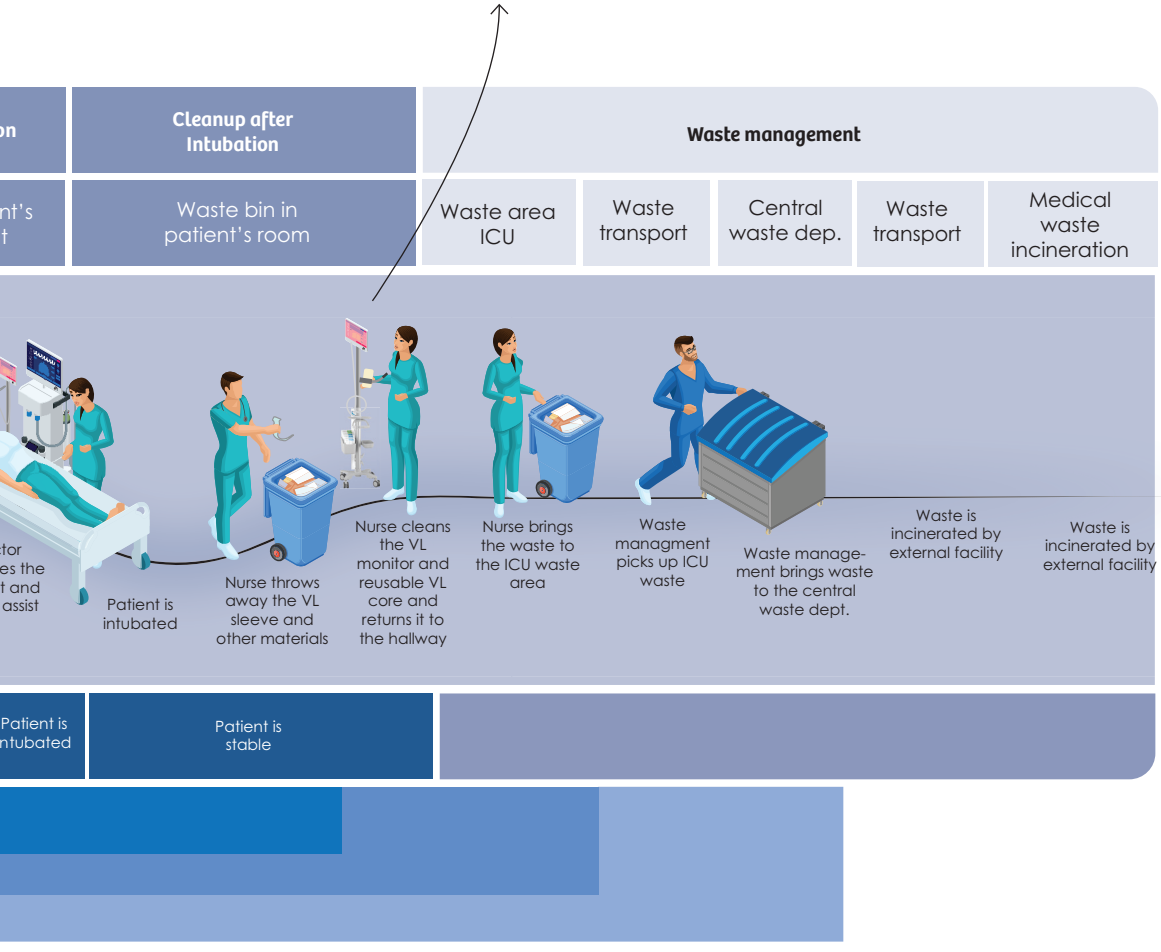


Figure 27: Product journey semi-reusable video laryngoscope

Clean-up procedure

Key difference single use VL and semi-reusable VL

The main difference between the single-use and the semi-reusable journey is that the core of the VL will remain with the monitor and will need to be cleaned with a wet cloth.

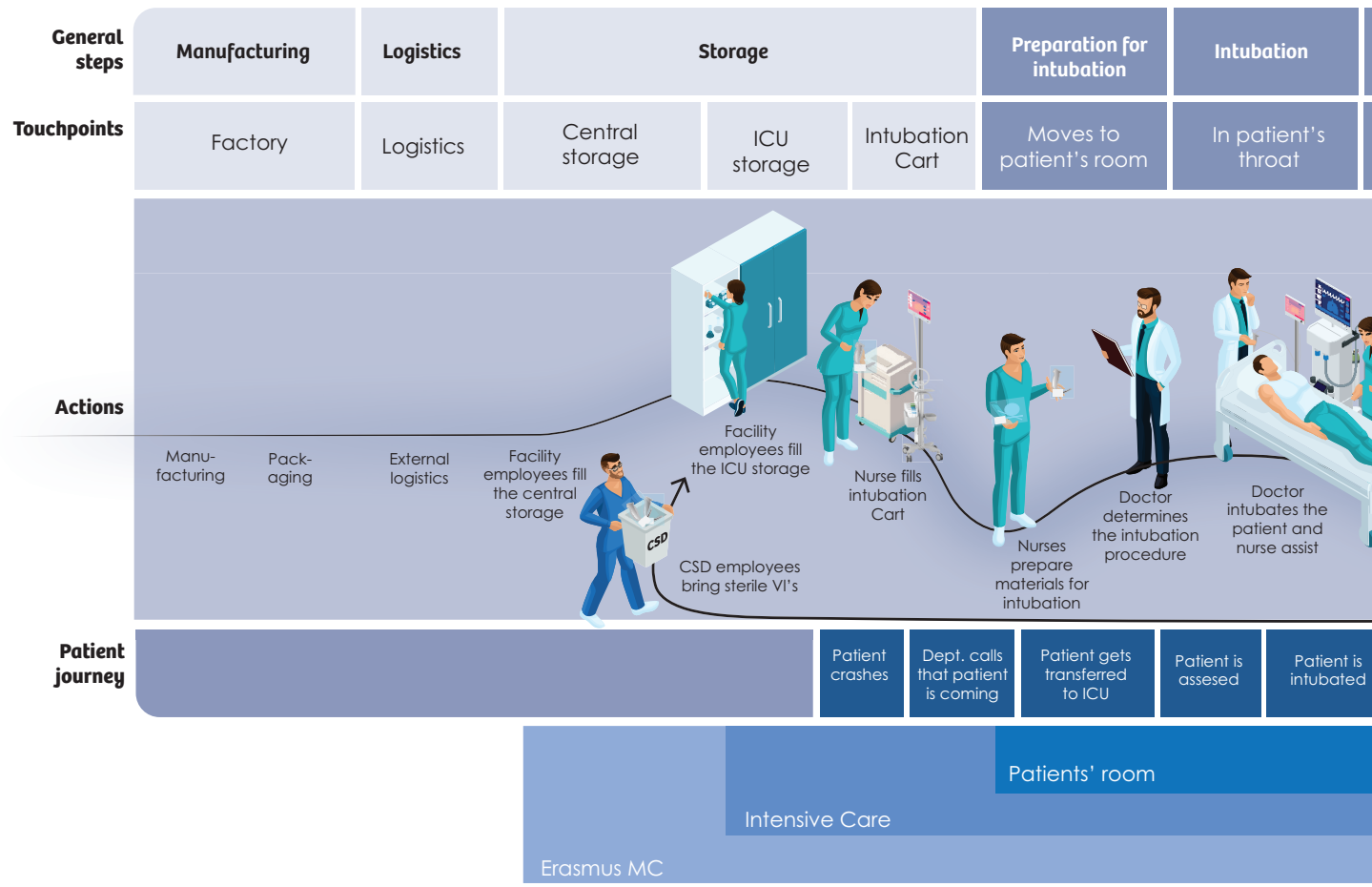


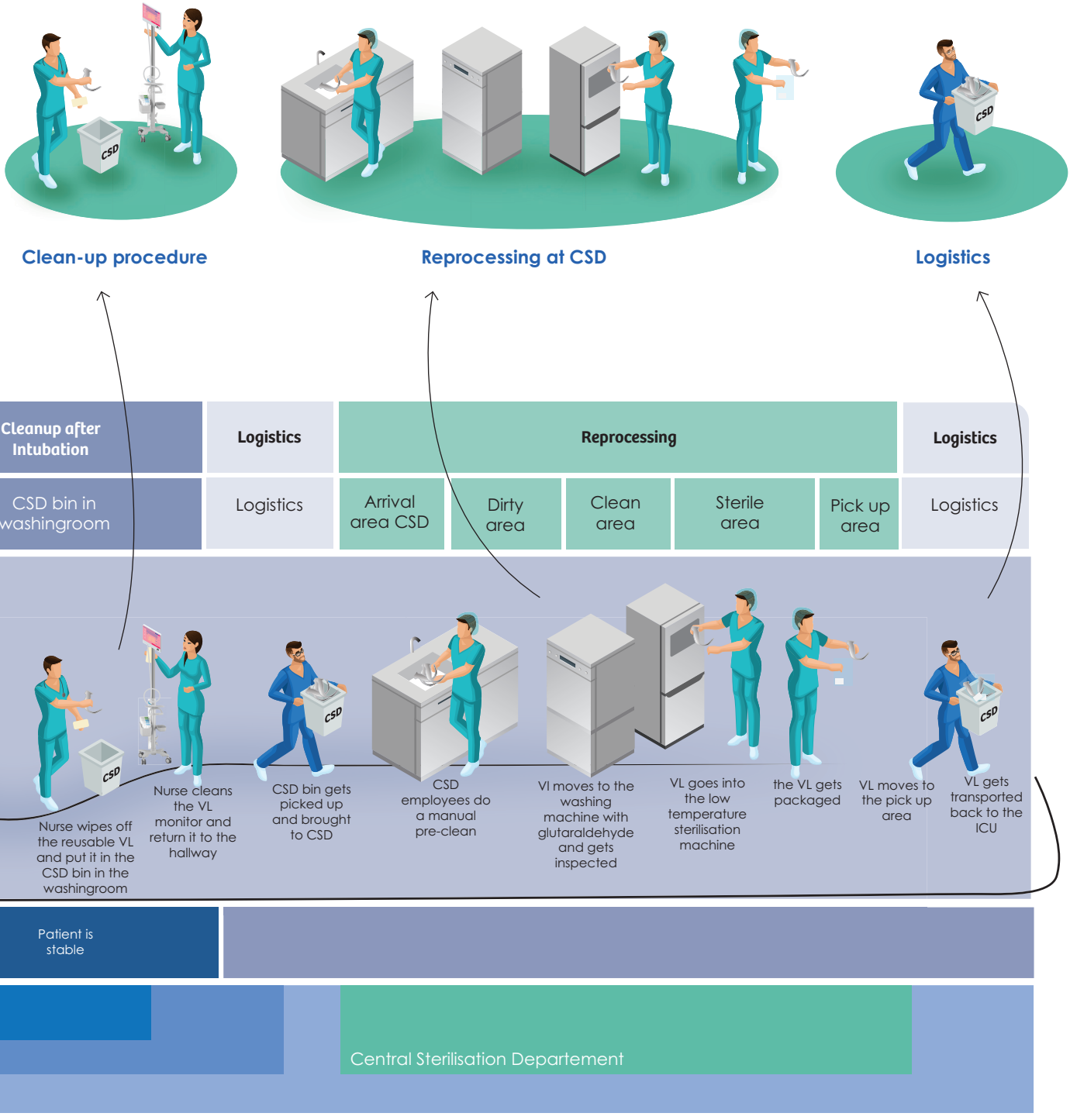
3.2.5 Product journey reusable VL

Below the product journey of the fully reusable VL is presented (Figure 28). It does not include the management of waste, although packaging of the reusable VL will still be thrown away. In this process the reusable VL will be wiped off with a wet cloth and brought to the washing room to be put in a CSD bin. This is estimated to take about 1 min of work extra for the nurses compared to the single use VL. This bin will be picked up by facility employees and brought to the CSD. Here the VL will be processed as discussed in section 3.1.3 about the CSD. After cleaning the VL will be returned by facility employees and put into the storage room.

Key difference single use Vl and reusable VL

The main differences in the product journey are the clean-up procedure at the ICU by the nurses, the added reprocessing at the CSD and the added logistics to and from the CSD.




Clean-up procedure
Reprocessing at CSD
Logistics
Cleanup after Intubation
Logistics
Reprocessing
Logistics
CSD bin in washingroom
Logistics
Arrival area CSD
Dirty area
Clean area
Sterile area
Pick up area
Logistics
Patient is intubated
Nurse wipes off the reusable VL and put it in the CSD bin in the washingroom
Nurse cleans the VL monitor and return it to the hallway
CSD bin gets picked up and brought to CSD
CSD employees do a manual pre-clean
VI moves to the washing machine with glutaraldehyde and gets inspected
VL goes into the low temperature sterilisation machine
the VL gets packaged
VL moves to the pick up area
VL gets transported back to the ICU
Patient is stable
Central Sterilisation Departement

3.2.6 Procurement process

A process which does not occur on a day-to-day basis, like the product journeys, is the procurement process. However, since this is the process where decisions about product purchases are made, it is useful to understand how these product choices are made.

The procurement department is responsible for purchasing medical products and services. Departments within the hospital do their own procurement and have the freedom to choose the type of medical devices of their preference. The procurement team takes care of the buying process. Usually, the need for a product arises in the ICU staff meeting and is communicated to the procurement team. Since the Erasmus MC is a public organisation, the buying process has to adhere to European tender rules, to minimize the chances of favouritism and corruption. This means that when the value of a purchase surpasses the value of 250.000 Euros over a period of 4 years excluding VAT a formal tender needs to be set up. The tender process requires a project team to be set-up with medical technicians, doctors, and procurers who determine the requirements for the product. Then suppliers can offer their products to be evaluated. The project team will elevate all offers and choose the best one. Usually this is based upon quality and price. Finally, the board of directors has to sign off on the deal. The tender process is as outlined by a fellow graduation student by A. Ville (2022) in Figure 28.

During my research I had two interviews with a buyer from the procurement team of the ICU, who was specifically focussing on sustainable buying. One of the key learnings is that while sustainability is considered and there are buyers who are motivated to procure more sustainably, it is not (yet) used as a parameter in the tender process. Tenders can already be quite complex and including sustainability will make it even more complex. However, the buyer said that we need to prioritize sustainability if we want to make change. Secondly, the buyer said that you need to be very careful with doing pilots with reusable products, outside of the formal public tender, since it can be perceived as favouring a particular manufacturer. This can disrupt the formal tender process. Finally, it is important to be mindful of current contracts and stock. Contracts need to end before purchasing new and/or different products and stock from SUD's needs to be emptied before transitioning towards reusable options.

Key takeaways procurement

- Sustainability is considered by buyers but is not included as a parameter in the tender process.
- Pilots with reusable products outside of the formal tender can disrupt the procurement process.
- Be mindful of current contracts and stock.

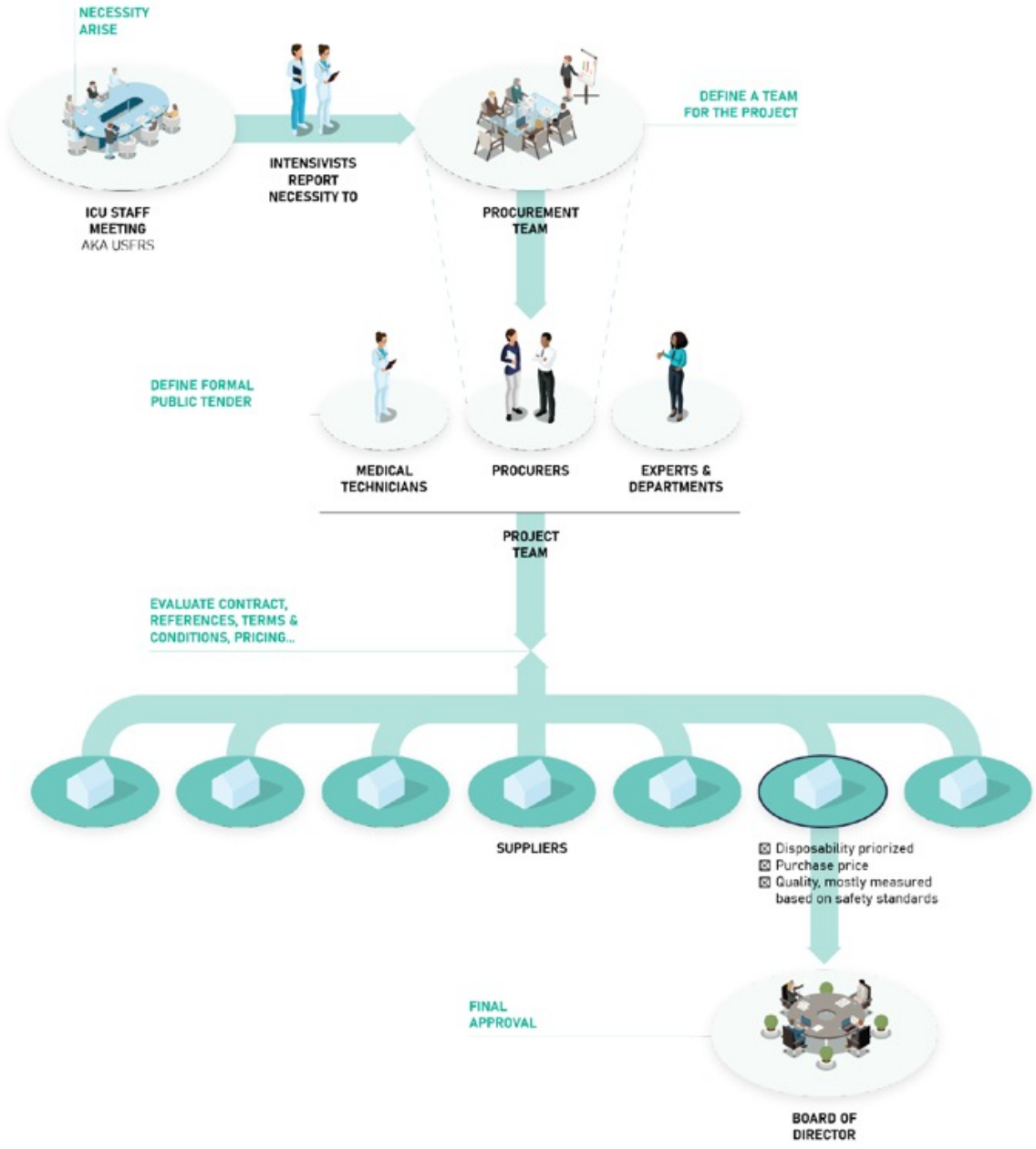


Figure 29: Procurement process by A. Ville (2022)

3.3 Evaluating the scenarios

In this chapter the different VL scenarios will be compared in order to determine the right strategy for the ICU at the Erasmus MC. The main goal being: how can we balance sustainability and the organisation?

3.3.1 Evaluation criteria

In section 2.1.3 possible barriers were found in literature that could apply to the implementation of reusable VL's. The barriers for healthcare institutions were patient safety, regulation, fear of increased workload, resistance to change, lack of reprocessing infrastructure, and costs. The scenarios will be evaluated with the use of these barriers, to find out if and how they are present in the different scenarios. Since a more sustainable ICU was the main objective of this report, we will start by evaluating the sustainability of the scenarios. To compare the scenarios an overview was created in Figure 31.
Some additional considerations for the implementation of the different scenarios will be mentioned after the evaluation criteria.

Sustainability

It is difficult to determine how much more sustainable the reusable VL alternatives are compared to the current single use VL. What makes determining the sustainability difficult is the lack of data regarding sustainability in the manufacturing process (more on this in Appendix C: Manufacturers) as well as the reprocessing process. Manufactures have no insight in the environmental impact of their products and the CSD at the Erasmus MC does not measure the energy and water consumption during reprocessing.

When it comes to the semi reusable VL we can at least say that the most important components of the VL are reused (the camera, video port, light source) and the environmental costs of recovering this part are very little. The wipe used to clean the monitor can be used to clean the reusable core of the VL as well, so does not require extra cleaning supplies. A very rough estimation would be that you safe at least 2/3 of the CO_2 emissions through reusing the core. The VL sleeve which is disposed of has potential to be recycled in the future, since it is made of one single type of plastic and there are already recycling tests running in the hospital with the same type of plastic.

There are currently no papers comparing the sustainability of single use VL, to semi-reusable VL's or fully reusable VL's. However, the sustainability of reusable products in general was investigated in literature during this thesis, which can be found in Appendix B. The study by Sherman, et al. (2018) is the most representative to give an indication to the sustainability of reusable VL's, since it compared the environmental differences between reusable and single-use laryngoscopes. This was done through a comparative Life Cycle Assessment (LCA). Overall, the reusable steel laryngoscope handle and blades were by far more environmentally friendly. The reusable handles generated 16-18 times less CO_2 during their lifetime, compared to the single use plastic ones. Similarly, the reusable blades generated 5-6 times less CO_2 emissions, compared to its plastic single-use counterpart. The fully reusable VL can probably best be compared with the reusable blades, since the VL is high-level disinfected as a whole.

This comes down to an estimation of an 66% improvement for the semi-reusable VL and a 600% improvement for the fully reusable VL, compared to the single use VL. Take in mind that the values for the CO_2 emissions of the reusable VL's are incredibly rough estimations and will need to be calculated in further research to present higher accuracy. Then finally, sustainability is more than just CO_2 footprints. The toxicity of cleaning supplies to employees and groundwater should be considered as well.

Patient safety

The barrier of patient safety is two-fold: On the one hand we have the actual patient safety and on the other hand we have the perceived patient safety. I found that reusable video laryngoscopes are safe for reuse and are also considered to be safe for reuse by doctors.

There is research that reusable laryngoscopes have caused cross infections, but this happened in cases where decontamination was insufficient. The lack of standardized cleaning procedures caused laryngoscopes to be low level disinfected, while high-level disinfection is required for safe reuse (Berahou et al., 2021). So reusable laryngoscopes (and thus video laryngoscopes) are safe for reuse, providing they are properly (high-level) disinfected or sterilized. The reusable VL's presented in this project are certified and considered safe for reuse according to regulations, provided they are cleaned according to the cleaning-guide of the manufacturer. Furthermore, the semi-reusable is already being used at the OK, so patient safety cannot be an issue for the Erasmus MC. Finally, when it comes to the perceived patient safety, doctors in the interviews did not perceive the reusable alternatives as less safe.

Although the main goal of strict rules surrounding patient safety is to be able to give the patient the safest care possible as well as keeping employees safe. Liability can also play a role for hospitals. With single-use VL's all the responsibility for a sterile VL is with the manufacturer. This is also the case for the single use sleeve. For the fully reusable VL's the CSD, and thus the Erasmus MC, will carry the responsibility for safe sterilisation and thus the corresponding liability.

Regulations

As mentioned in the previous section about patient safety, the reusable VL's in this project are certified for reuse. The manufacturers of the reusable VL's did clinical research to ensure the product is safe for (re) use and the product needs to be cleaned according to the cleaning requirements of the manufacturer.
According to EU regulations it is allowed to reprocess reusable medical devices. Member states are even allowed to determine whether they allow the reprocessing of SUD's. In May 2021 the Dutch 'law medical devices' (Wet Medische Hulpmiddelen) took in effect which allows the reuse of devices intended for single use. However, the requirements for reprocessing SUDs are strict. They need to adhere to the same safety standards as a new medical device (Ministerie van Volksgezondheid, Welzijn en Sport, 2022).

Workload

Although the extra workload associated with a fully circular ICU, in the form of separating and pre-cleaning devices, is important to consider in order to not overload nurses. The extra workload associated with semi-reusable and fully reusable VL's seem manageable according to the interviewed nurse. Assuming that the nurses will clean the VL core and reusable VL with wipes they were already using for the clean-up of the monitor, the extra actions (cleaning and walking) will account for 30 extra seconds for the semi-reusable VL and 1 min extra for the fully reusable VL. Nurses are willing to go the extra mile to facilitate sustainable initiatives, but they need to feel like their extra efforts pay off. If they feel like the reusable VL adds to a more sustainable ICU they are willing to walk to the extra room. Additionally, the nurses need to be well informed of the new procedures in order for them to properly execute them.

Resistance to change

During my research I did not experience a lot of resistance towards reusable VL's. Actually, the opposite, I found willingness to change. This 'barrier' is better considered as an enabler. Most stakeholders felt bad about the enormous amounts of waste produced at the ICU and felt sustainable initiatives were necessary. Nurses for instance are open to sustainable initiatives, according to Maanicus and my interview with a nurse, as long as they feel like their actions make a difference and they are properly informed and facilitated.

CSD and logistics

All the machines required for the reprocessing of reusable VL's are already present at the CSD of the Erasmus MC. Therefore, the transition to reusable VL's does not require high investments in the cleaning equipment. Furthermore, the CSD is at the maximum of their capacity but can reprocess the reusable VL's. The number of VL's that will need to be reprocessed is not that high (compared to other products) and the low temperature steriliser has enough capacity since it is currently not used that much. Capacity will only become an issue when more product besides the VL will be reused at the CSD. A shift towards more products being reprocessed at the CSD will require large investments to scale up the CSD capacity through extra employees, machines, and floor space. Outsourcing of reprocessing or automation can also be options to facilitate the reuse of more medical products.

Although there are currently no logistical operations between the CSD and the ICU, setting these up seems feasible. The ICU and CSD are on the same floor and not that far away from each other. Previously, there have been logistical operations between the CSD and the ICU before the transition towards disposables and it is therefore hard to image logistics as a true barrier in the transition towards reusable VL's.

Costs

It is often believed that reusable products are more expensive than single-use products since single-use products have become incredibly affordable. Literature research in Appendix B already showed that this is usually untrue when comparing the products over their lifetime. This is also the case for the reusable VL's. Both the scenarios are determined to cost less. The full calculations and assumptions can be found in appendix G.

The prices of the VL's were acquired through a manufacturer of VL's. These prices may differ slightly as they depend on the contracts made with the procurement department.
It is assumed that 40 reusable VL's are required to have enough sizes available and that they will be replaced every fifteen years. There is no insight in the costs of reprocessing at the Erasmus MC, but it is estimated that this will cost around 5 Euros per intubation. This is based on the paper Sherman et al. (2018), which determined the life cycle costs of direct laryngoscopes. The paper determines that the reprocessing costs of the blades per use are 2.10 USD and the handles 2.39 USD, when both reprocessed in an autoclave. This comes down to around 5 Euros per device. The paper did not include the costs of logistics, so an extra buffer of 2 Euros per VL is added to the price.

For the semi-reusable VL it is assumed that 4 cores are necessary, one at each unit, and that they are replaced every 1.5 year, after 2000 cycles of use. The costs of waste management of the single use VL and VL sleeve are not included in the calculation.
The semi-reusable VL 's will pay themselves back in the first year. While the fully reusable VL requires an investment of 208,000 Euros to buy the initial reusable VL's but will be more affordable than single use after only four years. After four years the hospital will start saving 40,000 Euros a year, compared to the single use VL. Over a timespan of 10 years this will come down to 288,000 Euros saved.

Product	Price per item (Euros)	Number of cycles
Single-use VL	32,50- 42,30	1
Semi reusable core	3800	2000
Single-use sleeve	25	1
Reusable VL	4950- 5445	3000

Product	Costs (Euros)/ year*
Single-use VL	66,600 Euros/year
Semi reusable	58,680 Euros/year
Fully reusable VL	Initial investment of 208,000 Euros + yearly costs of 12,600 for logistics and CSD (for 10 years)

** Calculated using 1800 VL's annually*

Figure 30: Table with costs of different VL's

3.3.2 Evaluation overview



	Single-use VL	Semi-reusable VL	Completely reusable VL
Patient safety	Safe for patients (responsibilty with manufacturer)	Safe for patients (responsibilty with manufacturer)	Safe for patients (responsibilty with hospital)
Workload	No added workload	Extra workload nurses of 30 seconds	Extra workload nurses of 1 min + added work-load for logistics and CSD employees
CSD and logistics	No added CSD and logistics	No added CSD and logistics	Added CSD and logistics, but no need to invest in new reprocessing equipement
Costs	66,600 euros/ year	58,680 euros/ year	Initial investment of 208,000 euros + yearly costs of 12,600 for logistics and CSD
Sustainability	Not sustainable - base level	Approx. 66% less CO2 emissions compared to single-use VL	Approx. 6 times less CO2 emissions compared to single-use VL + toxicity of gluteraldehyde

Figure 31: Evaluation overview

Other considerations for implementation

Considerations for both reusable VL's:

- If reusable VL's are implemented, it needs to be communicated properly. Otherwise, it might occur that nurses will accidentally throw away the reusable VL's.

Considerations for the semi-reusable VL:

- The semi-reusable VL core's will need to be replaced after their maximum number of cycles has been reached. This is hard to track, but it can also be determined that they need to be replaced approximately every two years.
- Enough sleeves in different sizes need to be available.

Considerations for the completely reusable VL:

- The reusable VL will need to be tracked in order to determine the number of reprocessing cycles. Tracking is done with a chip in the VL. Reusable VL's will need to be replaced after their maximum number of cycles has been reached.
- There need to be enough reusable VL's available at the ICU at all times. This includes different sizes of the VL.
- Having fully reusable VLs makes the hospital more resistant to supply chain issues in times of crises. But also has to have enough VL's present in the case of the next pandemic.

3.3.1 Concluding the evaluation of the scenarios

The hypothesis at the beginning of this research was that there are significant barriers hindering the implementation of reusable VL's. But after careful investigation and evaluation it was determined that the barriers are actually minimal. It can be concluded that both the semi-reusable and the fully reusable are suitable to be implemented at the ICU. The semi-reusable scenario is the least drastic of the two since no extra logistics or reprocessing at the CSD is required, while still making a positive environmental impact.

However, the goal of the Erasmus MC is to be a frontrunner in sustainability and have a fully circular ICU by 2030. The semi-reusable option is not fully circular, since the VL sleeve is still a disposable product. In order to be fully circular, the disposable sleeves will have to be recycled or the semi-reusable VL will eventually need to transition to the fully reusable VL. This cannot be the most efficient way. The semi-reusable VL can be seen as a quick win for sustainability, but the fully reusable VL can contribute more effectively to the end goal of a fully circular ICU. Additionally, it can be used a way to restart the connection with the CSD, where other products could latch onto as well as make the hospital more resilient to supply chain issues.

The fully reusable VL is less expensive in the long run, compared to the single use VL, but requires an investment of around 200,000 Euros. Although the cost-benefits of the reusable VL are not instant, the environmental benefits are. If the Erasmus want to reach their sustainability goals and continue to be a frontrunner in sustainability, they should invest in reusable VL's.

Conceptualisation

In the previous chapter the different products were analysed using product journeys and evaluated through criteria based upon the barriers form literature. It was decided that the implementation of the fully reusable VL fits the ambitions of the Erasmus MC best. In this part two of the final research questions will be answered:

- How can the reuse of video laryngoscopes be implemented at the Erasmus MC?
- What could be the next steps in transitioning similar products (to the video laryngoscope) from single use to reusable?

Here recommendations for the implementation of the reusable VL and the implementation of other products, similar to the VL will be presented.

04.

4.1 Recommendations for implementing the reusable VL

The barriers for the implementation of reusable VL's turned out to be minimal compared to the ones in literature, mainly due to the specific product characteristics and available infrastructure at the Erasmus MC. Nevertheless, there are some questions left on how to actually implement the reusable VL. How do we spark the actual change of the product, and do we best facilitate and communicate with stakeholders? On the next pages, suggestions for an implementation process are given.

4.1.1 Suggested implementation process

The overview shows the steps that need to be taken in order to implement the VL, as well as the different routes of expanding the VL's impact. In short, the implementation process needs to be kickstarted through the set-up of a tender, followed by a pilot, pilot evaluation and expansion of the pilot in order to ensure proper implementation. The different steps will be elaborated upon in the next section and visualized in Figure 32.

Kickstart implementation

The first step that needs to be taken is introducing the necessity for reusable VL's in the ICU staff meeting. The sustainability Lead, who is the head of the Green Team, is present at the ICU staff meeting and has the ability to bring up this up. Here it is important that the other staff members understand that is it safe, practically possible with the existing infrastructure, cost effective and most importantly estimated to emit around six times less CO_2 emissions than the current single use VL. It can be used as good example for other products. No sacrifices need to be made, besides the initial investments. Summarizing the findings of this research in a comprehensive overview can help to convince the other staff members. After convincing them, a tender for reusable video laryngoscopes will need to be set-up with the procurement team. It is important to evaluate the current contracts and stocks, to determine the right timing. This is best done by the procurement department.

Setting up a pilot

Although the nurse in my research explained that a pilot, which leads to different procedures at different units can be confusing, it still seems to be the best approach to introduce the reusable VL. This way the service can be improved before scaling up to the rest of the units within the ICU, reducing the risk of large-scale issues.

Before executing the pilot, the new VL needs to be introduced at the CSD and at the ICU. The CSD already has an existing process to introduce new products. Usually, the manufacturer of a product will come by the hospital to give a tutorial on the proper cleaning processes. This will be summarized and used as a guide for the CSD employees.
The ICU employees will then need to be informed of the reusable VL through the newsletter, TV slides, posters at the intubation kart and clinical lessons. They take place daily, during the transfer of the day shift to the night shift. By having four ways of informing staff, the staff can be well informed, even if they miss one or two information channels.

My main advice is to explain in depth the driver (sustainability) and the incentive (cost reduction) for this transition as well as the next steps in the pilot process. Knowing how much more sustainable the reusable VL's are, motivates the nurses. Being aware of a timeline when the pilot will transition to the whole ICU will help them understand how they are contributing to the bigger picture of a more sustainable ICU.

When it comes to practically facilitating the nurses in reusing the VLs, a proper collection place is important. According to the interviewed nurse, the washing room seems the best place to collect them. This is a central point in the ICU and could therefore be easily used for other reusable products too. Having multiple points, might spare a couple of steps, but could also lead to confusion.

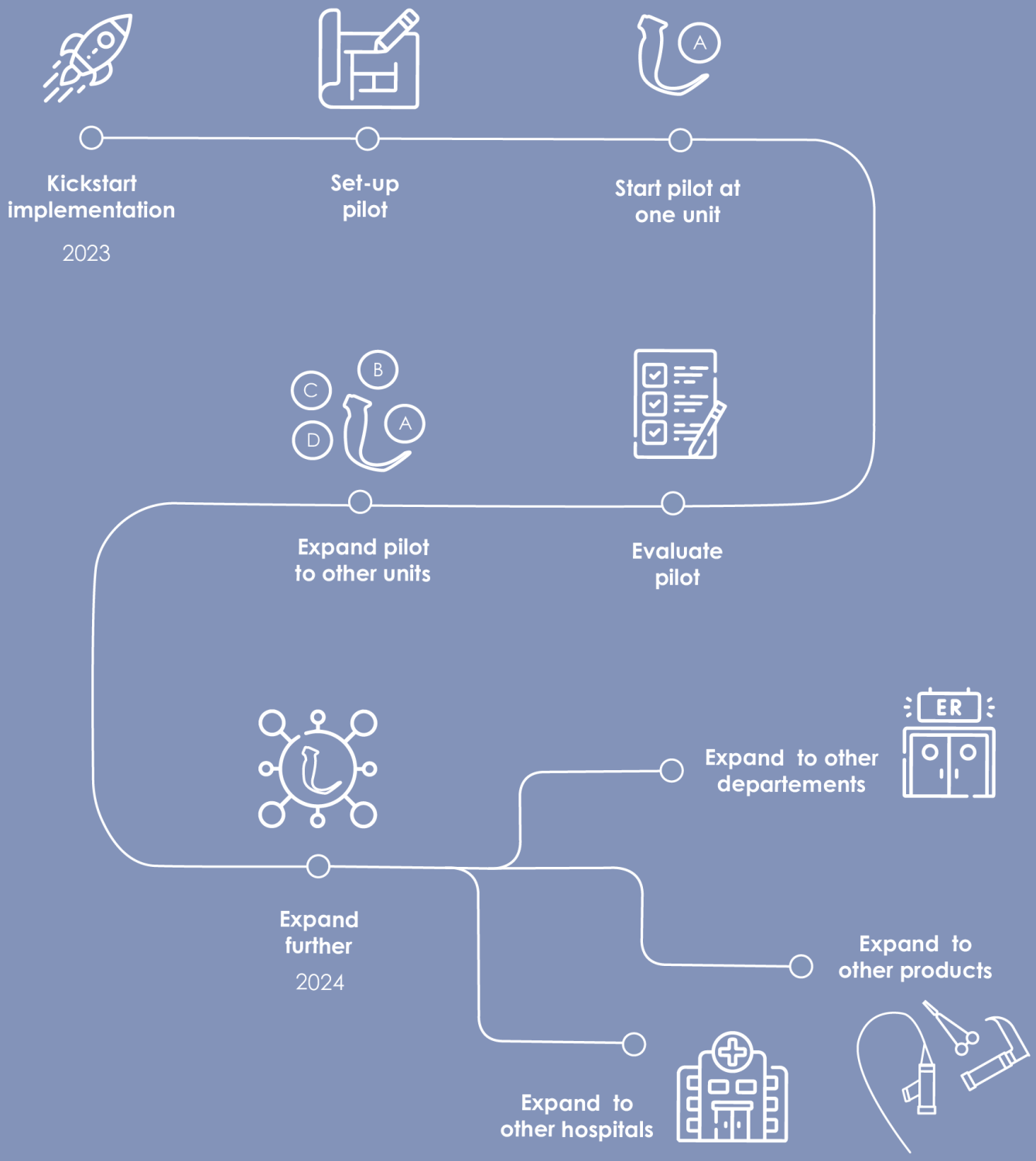


Figure 32: implementation plan

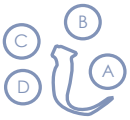
Executing the pilot

During the pilot it is very important to ensure that there are back-up single use VL's available in the case the reusable VL's are not back in time from the CSD. Additionally, the CSD will need to track the number of times the VL's are reprocessed.

Evaluating the pilot

Evaluation during and after the pilot is necessary to ensure that issues that have occurred during the pilot do not occur when expanding to the other units. Are there enough VLs? Are they back in time? Are they being used as expected? How does the ICU staff experience the changes? Is the collection bin really in the right place? It is not only useful to evaluate the specifics of the product-journey, but also evaluate the procedure of the implementation of a reusable product. Did the staff feel like they were properly informed? How would they prefer to be informed in the future?

Since ICU staff are often asked to fill in surveys, I would suggest approaching doctors and nurses in person, to combat survey fatigue. Asking a couple of evaluation questions during less busy moments in their shift could be an effective approach to gain qualitive data quickly. The person asking the questions should not be a superior and answers should be reported anonymously to ensure the most honest answers.



Scale up to other units

After gathering all the information about what went well and what not during the pilot, alterations should be made accordingly. Not only to the physical processes, but also to the way stakeholders are informed.

Finally, before expanding, the other units need to be informed of the reusable VL's. After having done that, the improved process can be implemented to other units.

Scale up further

After gathering all the information about what went well and what not during the pilot, alterations should be made accordingly. Not only to the physical processes, but also to the way stakeholders are informed. Finally, before expanding, the other units need to be informed of the reusable VL's. After having done that, the improved process can be implemented to other units. After implementing the VL throughout the ICU there are different avenues to expand the impact of the implementation of the reusable VL. The VL is not only used in the ICU at the Erasmus MC, but also in other situations.

The ICU green team could inform ICUs at other hospitals about the opportunity to reuse VL's as well as providing them with useful insights about implementation. This can be done through the national initiative of the 'Groene IC' (the Green ICU). The Groene IC collects sustainable advice from different hospitals in order to spread knowledge and tips about sustainability. Currently the (national) Green ICU mentions reusable and semi-reusable options on their website, but I believe more information is needed to convince hospitals to make this switch.

Besides other ICUs, the ICU could inspire the transition of reusable VL's at other departments within the Erasmus MC since the ER and OR also use VL's. They could easily be approached through their respective Green Team. By sharing how they are implemented at the ICU, the other departments can learn more quickly what is necessary in order to implement reusable VL's. Although the specific conditions at the departments might be very different, they do make use of the same CSD, so some parts of the product-journey are the same.

3.3 Reusing other medical devices at the ICU

Not all the products at the ICU are currently suitable for reuse. There are many products which are low value, high criticality and have no reusable alternatives. These are products such as nitrile gloves or bandages. For these products it is best to further research their recyclability, as well as reduce or rethink their use.

There are two similar products to the VL, which are disposable but have reusable alternatives. Direct laryngoscope blades (handles are reused) and bronchoscopes. Bronchoscopes are used to examine the patients' airways and can be high-level disinfected chemically at the endoscope area at the CSD. Laryngoscopes blades are made of stainless steel and suitable to be sterilised in the autoclave. Specific reprocessing instructions may vary depending on the manufacturer. These could all be collected centrally in the washing room, just like the VL, since when and how they are used is very similar.

Furthermore, a product which is suitable for reuse, but not particularly similar to the VL are scissors. They are used for a broad variety of procedures and have reusable options which are suitable to be reprocessed in the autoclave. Due to the scissor being used more often than the VI and for a variety of procedures further research is appropriate. Depending on the use-case it could be a nuisance for nurses to walk up and down the washing room each time they use a scissor. Analysing whether the washing room is just as appropriate could be beneficial for nurses. Although the VL, bronchoscopes, laryngoscope blades and scissors might not be collected at the exact place in the ICU they can still make use of the same logistical carts to and from the CSD.

Eventually, moving to a circular ICU and CO_2 neutral hospital more and more products will be reprocessed at the CSD. Not only the ICU will need to reprocess more medical devices, but other departments at the Erasmus MC will also need to do that. This means that the CSD will run into capacity issues due to the lack of space, machines, and employees. It is therefore necessary for the Erasmus MC to further investigate the expansion and automation of the CSD in order to be able to meet the hospitals future demands.

3.3 Improving the sustainability of the reusable VL

After implementing the fully reusable VL, there are still opportunities to improve the sustainability of the VL and its service. In my opinion, expanding the number of different reusable products at the ICU should be a higher priority, since it will most likely have a bigger impact in a shorter timeframe. Nevertheless, these suggestions to improve the sustainability of the VL are shared to provide the Erasmus MC with a source of inspiration.

Takeback system
In order to create a fully circular system the reusable VL's will need to be recycled at the end of their product life. Efforts could be made to set up a take back system with the manufacturer of the VL's. The VL's are not certified to be reused more than 3000 times, so currently they will need to be discarded after completing their use-life. By returning them to the original manufacturer the materials could be reused. Since the current manufacturer has no infrastructure to facilitate the recycling, this is not an easy task. This is highly dependent on either the procurement department or Erasmus MC's own waste management.

Supplychain transparency
Additionally, it is valuable to find a manufacture who has insight into the supply chain and who can ensure that the products are produced environmentally friendly and ethically. During my interviews with manufacturers, I found that there were manufacturers of VLs who were working on creating more insight. The report of the interviews can be found in Appendix A.

Green energy and replacing glutaraldehyde
The sustainability impact of reusing VLs, and other products in general, will improve significantly when transitioning into using green energy. Hereby the energy usage during reprocessing can be considered as CO_2 neutral. Secondly the Erasmus MC can replace the toxic cleaning product glutaraldehyde, to mitigate its negative effects. According to the United States Environmental Protection Agency there are several hydrogen peroxide-, peracetic acid-, and orthopalahaldehydebased high-level disinfectant solutions which could replace glutaraldehyde (the Environmental Protection Agency (EPA), 2022). A table these alternatives can be found in appendix I.

Introducing reusable packaging
Finally, the reusable VL's, just like the single use VL's, requires packaging to ensure that it stays clean before use. Although this a small part of the impact of the VL it is still necessary to rethink if we were to move to a fully circular ICU. They need to be either made of recyclable material, biobased material, or reusable packaging. A 2016 paper by Stiegler et al. compared the use of 'blue wrap', packaging which is often used for surgical tools, to reusable aluminium hard cases. The use of reusable container halved the environmental impact. This could be an option for the VL as well, although further research particularly regarding the usability and logistics is required.

Conclusion

The last chapter of this report wraps up the project with the final conclusion, discussion, limitations, and a personal reflection.

05.

5.1 Conclusion

My initial assignment was to *find out how the ICU can become more sustainable through overcoming organisational challenges hindering the implementation of reusable video laryngoscopes.*

Hospitals want to reuse more medical devices, but according to literature, concerns with patient safety, liability, the costs, and complexity of developing and maintaining in-house reprocessing infrastructure and logistics have left hospitals with a complex organisational challenge. Through my research I found reusable alternatives to the single-use VL. A combination of stakeholder interviews, observations and desk research was used to create current and proposed product-journey maps of the single-use, semi reusable and fully reusable VL. Through understanding the stakeholders' current processes, decision processes and experiences the impact on the organisation of the different alternatives could be evaluated.

Evaluating the scenarios was done through translating the possible barriers from literature into criteria. In addition to the translated barriers, sustainability was used as an evaluation criterion, since making the ICU more sustainable was the main goal of the project. Contrary to the original research question, the barriers for implementing the reusable VL turned out to be minimal. It can be concluded that both the semi-reusable and the fully reusable are suitable to be implemented at the ICU. The semi-reusable VL seems to require the least change from the organisation, but the fully reusable VL contributes better to the end goal of a fully circular ICU in 2030, notwithstanding its higher up-front cost.

When it comes to the implementation of the reusable VL the most important aspects to consider are sparking the initial implementation and communicating and facilitating nurses. The implementation processes need to be kickstarted through the set-up of a tender, followed by a pilot, pilot evaluation and expansion of the pilot in order to ensure proper implementation.

After implementing the VL I identified three products which could follow in the footsteps of the reusable VL: Laryngoscope blades, bronchoscopes, and scissors. Laryngoscope blades and bronchoscopes can be collected in the same place since the use-case of them is very similar to the VL. Scissors will require further research but follow a similar journey to and from the CSD.

This report brings value to the ICU of the Erasmus MC through identifying that the Erasmus MC has the resources and capabilities to implement the reusable VL's, as well as presenting recommendations for the implementation process.

5.2 Discussion and Limitations

In order to determine whether this project was successful, the three lenses of innovation, introduced in the project approach, will be used.

The model provides the following three questions:
- Is the design what people desire? (desirability)
- Is the design technically and organisationally feasible? (feasibility)
- Is the design financially viable? (viability)

Desirability
As explained before, desirability consists of more than just what the people want. It also needs to add value to society. That is achieved through providing a way of implementing more sustainable reusable VL's. Throughout my research I spoke with many stakeholders who felt bad about the enormous amounts of waste produced at the ICU and who were willing to put in extra effort to facilitate more sustainable processes.

Feasibility
Feasibility was elaborately investigated through researching the available reusable VL's and the Erasmus MC's current reprocessing infrastructure. It was discovered that the there are appropriate options available, which can be safely reused in the existing reprocessing infrastructure.

Viability
The viability of the implementation of reusable VL's was researched through literature and making well considered assumptions about how many VL's would be necessary and how long they would last. It turned out that the reusable VL requires an investment of 200,000 Euros, but breaks-even with the single use VL after only 4 years. Although it would be a smart financial choice I did not research whether the Erasmus is willing to make the investment.

Although, this project has come to fruition through extensive research, limitations apply and need to be discussed. Since there are many stakeholders involved in making healthcare more sustainable and the project needed to be completed in a limited timeframe, it was not possible to speak with everyone involved. Therefore, concessions were made with whom to speak with. Although, the mayor stakeholders were interviewed I believe that some additional knowledge about the logistical processes could have been valuable to be able to present a more detailed implementation process. Similarly, a more in-depth interview with infection prevention could have uncovered more 'latent' barriers to reusing the VL. Generally, it was difficult to arrive at experiences, attitudes and latent wants and needs, since large parts of the interviews consisted of getting the facts on the table. Some information seemed simple to gather at face value, but due to the complexity of the Erasmus MC it was even complicated to find out how many VL's were used, how much they cost, which ones are used and how they were cleaned. Moreover, the interviews initially had a broader scope than 'the barriers for implementing reusable VL's, so not all the time with the interviewees was used effectively.

Besides the formal interviews, I had many informal interactions with people at the Erasmus MC during lunch breaks, my participation at a sustainability healthcare hackathon and the Green Team meetings. Although I gathered a lot of information as well as attitudes towards sustainability, they were difficult to translate to the academic report. Therefore, some knowledge will be lost.

Due to the lack of data about the sustainability of the production and reprocessing of the different VL's the estimations of their sustainability are very rough. This is unfortunate since reliably knowing how much more sustainable a particular action is could help convince skeptical stakeholders. Further research about the sustainability of the different medical devices at the ICU is necessary to make the right decisions as well as convince stakeholders.
The emphasis of this project was mainly on determining which option was best in terms of sustainable impact and impact on the organisation. Consequently, less time was left to provide the Erasmus with a highly detailed implementation process.

5.3 Personal reflection

Writing my thesis has been one of the most challenging projects I have ever done. I highly underestimated how difficult it was to work alone – not necessary getting my ass up to work, but the ability to brainstorm with a team and standing by your ideas together. It is so much easier to be confident in your ideas when you have discussed them with other people. During my project I have tried to combat the 'being alone with just my ideas' by sharing my project as much as possible. Friends, people in the lunch break at the Erasmus, doctors in my personal and family. This made my more confident in pitching my ideas as well as sparking new ones.

Eventually the key to finishing my project was accepting that I needed to focus specifically on reusing the VL to be able to produce a coherent story. Initially, I was also investigating recycling, different reprocessing methods, circular business models and ideating on automating the CSD. After accepting that parts of my work would not reach the final report or even an appendix, my story became much clearer. 'Killing my babies' was the hardest part but working on these additional topics did broaden my view enormously. Another key learning was embracing the complexity of the project and not trying to engineer my way out of it. As long as I kept my evidence and opinion separated, I was able to make choices.

Although the project was sometimes difficult, I greatly enjoyed my experience at the Erasmus MC. Particularly seeing parts of the hospital I would never have gotten to see if I was just a regular visitor were truly exiting. I also discovered that I was much more of a climate activist than I expected. Reading about and experiencing how unsustainable the healthcare sector still is, is truly shocking. I hope to be able to contribute to this topic in the future.

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06.

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Appendix A

Future developments influencing the need for circularity

The future cannot be predicted, but it is interesting to consider factors or trends that may have a significant impact on the need for circularity or may change some of the assumptions on which the Erasmus MC is weighing its approach to sustainability, need for acceleration of the implementation of circular concepts, or may force a different route.

From a high-level perspective, I would like to briefly highlight climate change, carbon pricing, new energy infrastructure and availability of sustainable alternatives, policies and legislation, public opinion, health care regulation, geo-political issues, energy prices, access to and availability of raw materials and precious metals, pandemics, demographics and availability of workers and technological developments.

Climate Change
Climate change continues to put pressure on finding alternatives for fossil fuels and carbon-based products. Under the EU Green Deal (European Green Deal, 2019) huge investments are made in among others alternative energy like wind, PV and fuels like hydrogen. This will have a profound impact on the energy landscape in The Netherlands and Europe influencing prices and availability, creating possibilities for other more sustainable solutions.

Policies and legislation
Policies and legislation to Increase Carbon Tax or equivalent instruments (EU Emissions Trading System (EU ETS), 2021) and CBAM, the Carbon Border Adjustment Mechanism (Press Corner European Commission, 2021) under the green Deal to price carbon content of products coming from outside the EU are to expect to increase the price of products with a large footprint. Further legislation is to be expected, either coming from the EU or Dutch government. Currently the draft text of the CSRD Corporate Sustainability Reporting Directive (Sustainable Finance Package, 2021) is made available. This directive forces large corporations to report their sustainability. This reporting foresees among others extensive reporting on carbon footprint. It is expected that other organisations will have to follow this later.

Public Opinion
Public opinion plays an important role for organisations, and it is expected that larger transparency and detailed reporting influences public opinion. We also see that public outcry (Koijck, 2021) puts pressure on Institutions to improve circularity.

Health Care regulation
Regulation will continue to change and may impact sustainability requirements. It is not clear what the impact will be yet.

Geopolitical situation
The events in the Ukraine have demonstrated that global business is not a protection against a state taking land by force and destabilising the power balance in Europe (The Economist, 2021). The current world balance of power is currently shared between The West (North America, Europe and their allies), Russia, and China. This war has driven energy prices through the roof, but also restricted access to specific raw materials and increased food prices.

Energy prices
Due to the war, sanctions, and reduction of gas delivery from Russia the price of gas has soared (Dutch TTF Gas Sep '22 Futures Interactive Chart, n.d.). The price of electricity has soared as well (Statista, 2022).

Raw Materials
Most of our raw materials are sourced worldwide, and a less stable trade would possibly make certain materials either less available or more expensive (Desjardins, 2020).

Pandemics
Even before the COVID-19 pandemic the open system of trade was in trouble (The Economist, 2020). It has shown that the long supply chains are extremely vulnerable. Add the current geo-political issues to this picture and clearly self-reliance has become a key issue for Europe. Other pandemics may come up with similar effects causing disruptions and shortages in the supply chain.

Demographics
The Netherlands has seen declining birth rates and a greying population (Bevolking | Vergrijzing, n.d.). This is a double-edged sword, since the elderly will require more healthcare, while the working population is declining. The changing demographics and the availability of workers will require new solutions to be able to keep the healthcare sector afloat.

Technological developments
We need new Technological Developments to cope with many of the challenges ahead, but we also need processes and designs that foster new solutions. Technological developments will come in several categories:

- Better health care technology: new technology for better, faster, and safer operating procedures.
- Deployment of more recyclable designs and materials: new and better materials that are better recyclable.
- Scarcity and therefore most likely cost driven developments will drive new materials as a replacement for expensive and scarce materials that may become unavailable.
- Better reprocessing technology: new technologies for cleaning and disinfecting equipment and tools that allow more circular use.
- Low carbon technologies: technologies that require less energy or have a smaller GHG footprint in their life cycle.
- Any combination of the above driving recyclability and cost reduction

In conclusion, many factors may drive the need for sustainability and circularity. It is not just reporting, public opinion, energy prices, health care policies. These factors are interlinked, and the environment of the Erasmus MC is constantly changing, at an ever-faster pace. We need to put processes in place that constantly foster new solutions, evaluate those on their impact on operational processes, cost, and sustainability and circularity.

Appendix B

The sustainability of reuse

According to the principles of the circular economy the reuse of products should be more sustainable than the disposal of products since the value created during manufacturing, assembly and retail is retained through reuse. However, the reprocessing of medical devices can be an energy intensive process and therefore it is not guaranteed that the environmental impact of disposal of the product after single use outweighs the environmental impact of the reprocessing. Next to researching the sustainability of reusable and SUDs, I analysed whether reusing devices would be more cost effective than throwing them away. If so, this could incentivise hospitals to transition to reusables, not only for the environment, but also for the benefit of reducing costs.

The goal of this literature research is to answer the questions:

- Are reusable medical products more sustainable than disposable medical products throughout their product lifetime?
- Are reusable medical products more cost effective than single use medical products throughout their product lifetime?

My approach for this part of the literature research was to find Life Cycle analyses(LCA's) which compared reusable and disposable medical products. A LCA is a methodology which considers the environmental impact of a product or service throughout the product's lifespan. The outcomes are often expressed in the amount of CO_2 emissions. To find appropriate studies I used the keywords; comparative LCA, life cycle analysis, LCA, reusable, single use, disposable, medical equipment, medical products and sustainable. This search led to many studies of which I selected the papers which compared disposable and reusable medical products. I excluded studies which did an LCA of a disposable or reusable medical product, but did not compare the two, since independent LCA studies can be hard to compare to each other due to vastly different circumstances. I eventually ended up with a selection of ten papers which compared LCA's of disposable and reusable medical products. Two out of the ten compared a semi reusable product to a single-use product, but I also included them as I was curious to learn if hybrid products could also be more sustainable.

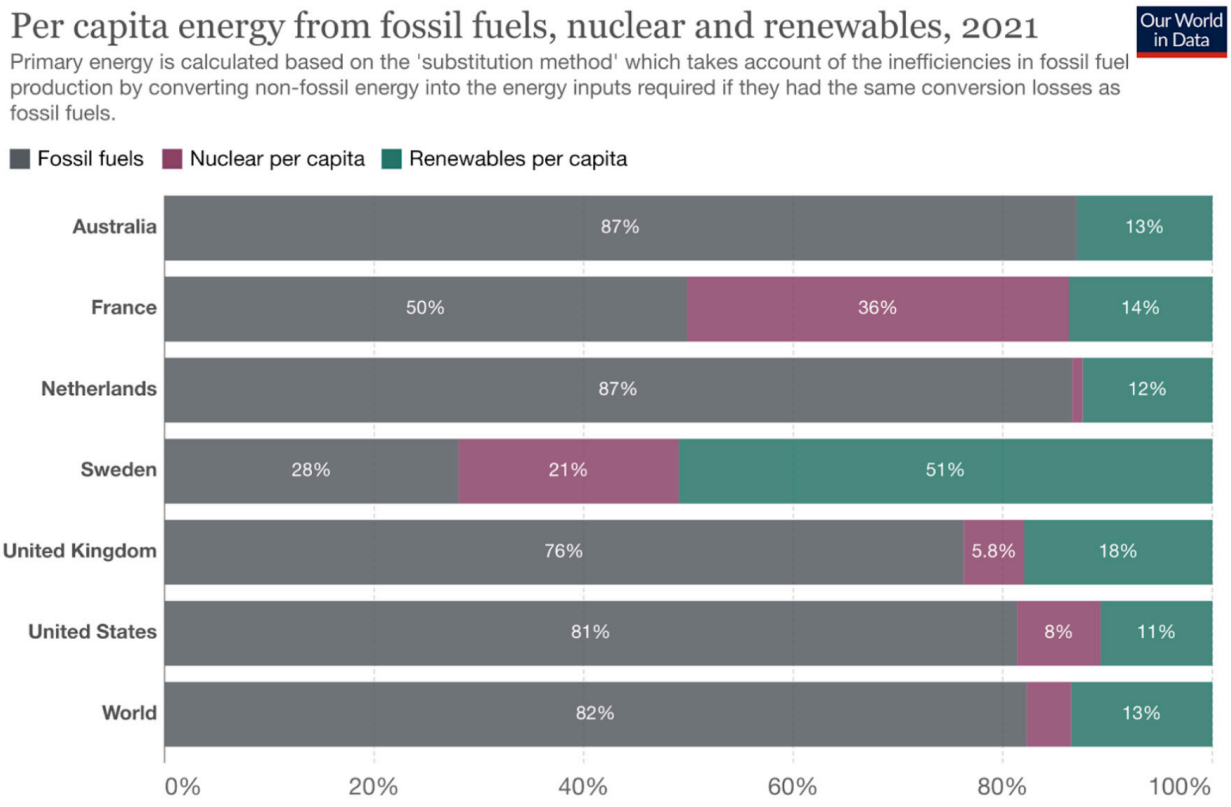
I looked at studies comparing single use and reusable surgical drapes, anaesthetic equipment, anaesthetic drug trays, laryngoscopes, surgical scissors, laparoscopic instruments, bronchoscopes, vaginal specula, sterilisation packaging and spinal fusion surgery instrument sets. Of these ten studies, seven studies determined that the reusable medical products had environmental benefits. An overview of the studies (in random order) can be found in table on the next right.

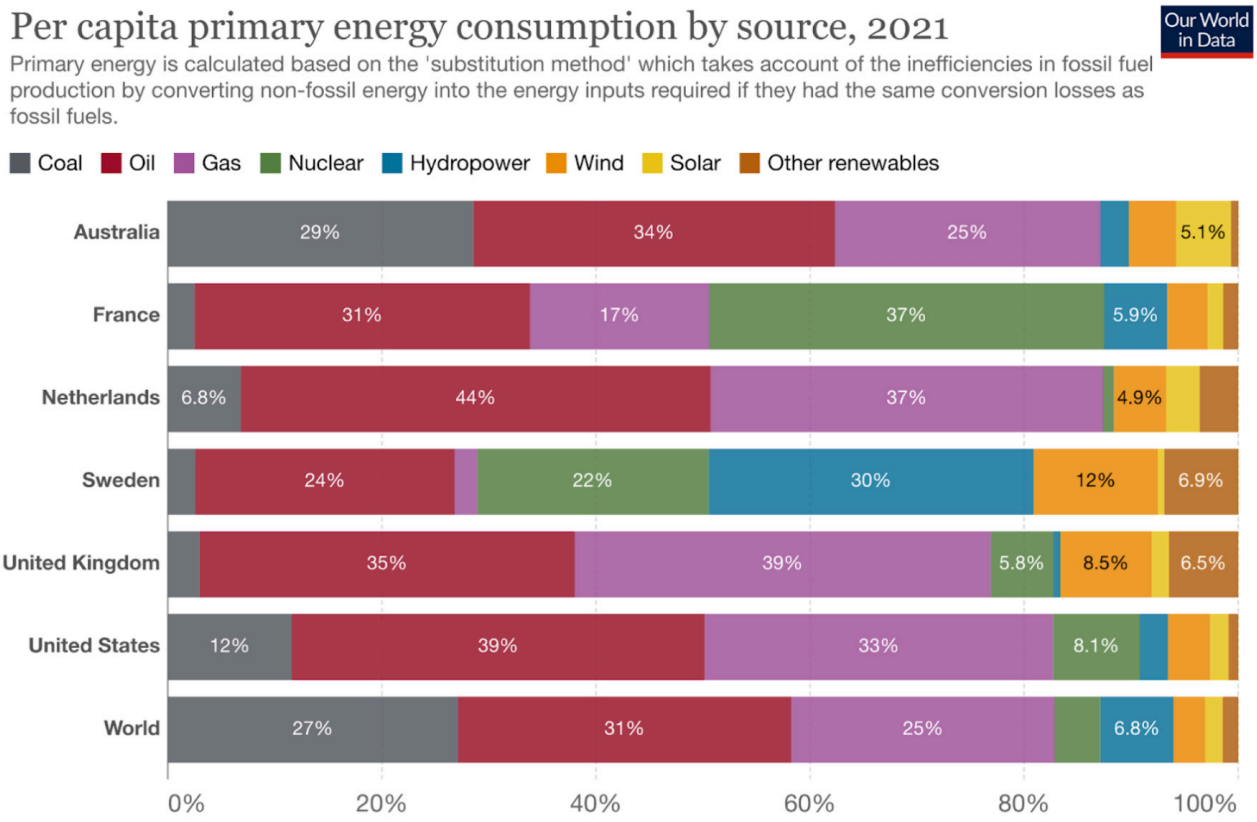
Product, study, and notes	Environmental benefits	Cost benefits	Country
1. Surgical drapes (Dettenkofer, et al., 1999) This study compared single use drapes to reusable cotton drapes combined with a reduced set of impermeable single-use drapes, so the reusable in this study is a partially reusable product.	no	yes	Germany
2. Anaesthetic equipment (McGain, et al., 2017) This paper investigated the effects if they were set in countries with different energy sources. In the USA and UK there was an environmental benefit, but this was not the case for Australia.	Partially	yes	Australia but compared with energy mix USA and UK
3. Anaesthetic drug trays (McGain, et al., 2010)	yes	yes	Australia
4. Laryngoscopes (Sherman, et al., 2018)	yes	yes	US
5. Surgical scissors (Ibbotson, et al., 2013)	yes	yes	Germany
6. Laparoscopic instruments (Rizan, et al. 2022) Hybrid surgical instruments, which contain both single-use and reusable components were researched in this study, potentially bringing together advantages from both approaches.	yes	yes	US
7. Bronchoscopes (Sørensen, et al., 2018) Study was paid for by a manufacturer of single-use bronchoscopes and although no conflicts of interest were reported, it is appropriate to be cautious of the reliability of the results.	inconclusive	not included in the study	European set-up
8. Vaginal specula (Donahue, et al., 2020)	yes	not included in the study	US
9. Sterilisation packaging (Friedericy, et al., 2021) Eco-costs (environmental costs over time), were included in this study, but not the cost of the products over their lifetime.	yes	not included in the study	Netherlands
10. Spinal fusion surgery instruments (Leiden, et al. 2020) There was only an environmental benefit when the sets were reprocessed through gamma radiation. There was no environmental benefit when using an autoclave.	yes	yes	Germany

Most of the before-mentioned papers (7/10) reported an environmental benefit when reusing the medical products and all of the papers who analysed the costs of reuse (7/10) reported a reduction in costs when reusable products were used instead of single-use products.

sustainability is context dependant

Although most of the papers reported a net positive environmental effect in the form of reduced CO_2 emissions, it is not as simple as saying "reuse is always more sustainable." A different context or reprocessing technique can have a significant effect on the sustainability of the process. For instance, the study by McGain et al. (2017), compared the CO_2 emissions of disposable and reusable anaesthetic equipment, but also compared these with the energy source mixes of different countries. Switching an operating room to reusable anaesthetic equipment in the UK would lead to a 84% CO_2 reduction, a 48% reduction in the USA and a 10% CO_2 increase in Australia. The energy mix per country turned out to heavily influence the sustainability of the transition. Australia's energy is mainly sourced from coal, while the US uses more gas and the UK uses more renewables. Brown coal produces approximately double the carbon emissions compared to gas and at least six times more than wind power. Currently, the Netherlands has a similar percentage of energy sourced from low-carbon sources (renewables and nuclear) as Australia, but sources less polluting forms of fossil fuels.





Although this gives an idea of the sustainability of reusing medical devices per country, the energy source per healthcare facility may vary as well. So, the impact of reprocessing will not be the same for all hospitals in the Netherlands. Currently the Erasmus MC is not powered by renewable energy, but according to their sustainability goals they will be fully powered by green energy in 2030.

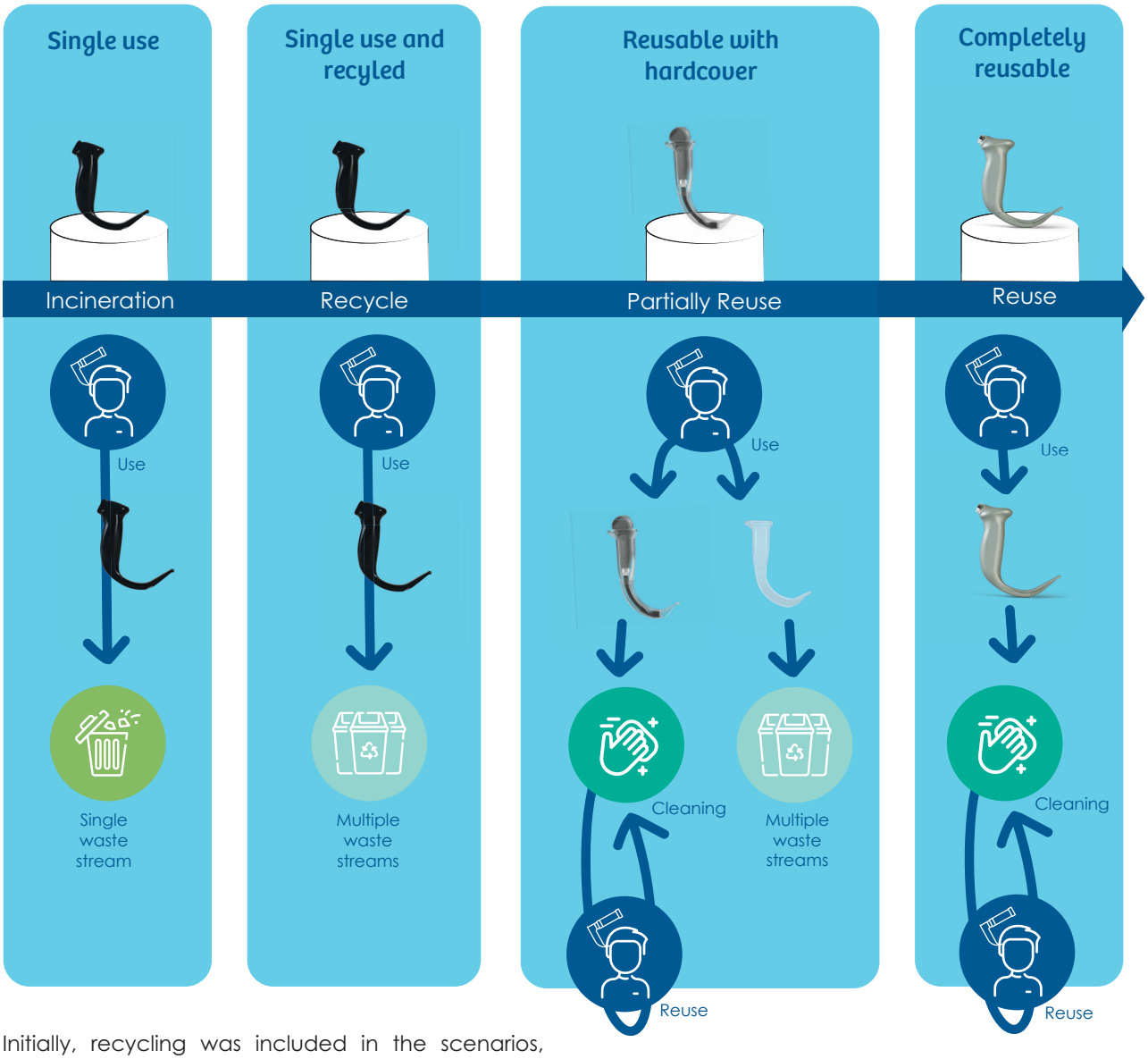
The influence of reprocessing techniques

The paper by Leiden et al. (2020) did a LCA of a disposable and a reusable instrument set for surgery and found that there was no environmental benefit to the reusable kits if steam sterilisation was used to clean them. The energy usage for the cleaning process was too high to reach a break-even point. With the use of gamma radiation as a sterilisation technique, however, it was possible to have a net positive environmental effect since the gamma radiation requires little to no energy for the sterilisation process. Nevertheless, coming back to the importance of energy-mix, in a county such as Sweden or France (as shown in the overview) the environmental impact of steam sterilisation would have been lower since the autoclave would have been powered with more low-carbon energy sources. Therefore, the benefit of gamma radiation is higher in countries that are more reliant on fossil fuels, such as the Netherlands or Australia.

In conclusion, reuse is generally more environmentally friendly and cost effective than single-use products. Even more promising is the fact that transitioning to more renewable energy sources will lead to lower CO_2 emissions during the reprocessing process.

Appendix C

The recycle scenario



Initially, recycling was included in the scenarios, because it could be a step in the right direction, before implementing reuse scenarios. However, it eventually did not make the final report, since it did not add to the overall story. There are two main reasons. Firstly, that it is not that impactful for the VL, since it is low on the R-ladder and secondly, it turned out that the product was very difficult to recycle.

Appendix D

Interviews manufacturers

During this project I spoke with three manufacturers who produced both single-use and reusable video laryngoscopes. With one of the manufacturers I had a follow-up interview.

Insight in the level of sustainability of their products

I asked the manufactures the following question about their single-use and reusable options: "Does your company have any insight into the sustainability of their products or supply chain? (e.g., Energy consumption during production, CO_2 emissions or a Life Cycle Analysis)" The sales manager of a Chinese medical equipment manufacturer replied (via a LinkedIn chat) with "You are the first customer we have ever had to ask this question", followed by a ''No". The other two manufacturers, a Canadian and a German company, replied that they had gotten this question more often in recent years but that they had no sustainability information readily available. The German manufacturer was currently working on measuring the footprint of their operations and the Canadian manufacturer had a sustainability workgroup. So currently none of the manufacturers had data available on the sustainability of their products. The German manufacturer also stated "I feel like the blame [of unsustainable single-use products] is often put on manufacturers, but I believe that hospitals are often unable to manage the logistics and responsibility of reusing products. Hospitals are complacent."

Why offer reusable products?

If most of these companies had no insight into the impact of their products, why would they even offer reusable or semi-reusable options? When asked, all of the manufacturers replied that they were selected because of the cost benefits for hospitals. When I went to check their websites, I also found that sustainability was not mentioned on the products pages of the reusable VL's (source websites manufacturers). Mainly performance and durability were mentioned as benefits of the reusable VL.

Two of the manufacturers (Canadian and German) were willing to have a follow-up meeting to share some of the research from this research. I held this follow-up meeting with one of the manufacturers and also took the change to ask some further questions. Besides the sales manager, the European manager of the company was also present. This gave me the feeling that they were taking the discussion about sustainability seriously.

Willingness to change

In the follow-up interview I focussed on learning about their willingness to become more sustainable and/or change their business model. When I asked them "What would it take for them to become more sustainable?" they replied with "If more hospitals would ask us to be more sustainable or if our competitors would do so". Additionally, they said that they believed that producing sustainably would double or triple their costs and that that would simply be too much to be profitable.

Changing business model

I also asked them about changing their business model to a lease model for VL's, since leasing models could motivate manufacturers to create more long-lasting products. They believed that this would not be an interesting business model for the VL since they do not require a lot of maintenance and leasing would therefore not add much to the hospital. They did have a bladder scanner within their product portfolio that they would lease, since that device is a high investment for hospitals and requires a lot of maintenance so to extend such a lease contract with additional services becomes a relatively easy process.

Waste takeback

On the manufacturer's website I found that they collaborated with a recycling company for their US market to take back some of their single-use products, including the sleeve for the semi reusable VL and the single-use VL entirely. The folder states: "As more than 5 million tons of medical waste is disposed of annually, we're very aware of the impact single-use medical devices can have on our environment. That's why we've partnered with [a recycle company] to help divert waste away from

our landfills and oceans." I asked them if this was also available in the European market. They said they wanted to launch this program to the EU market but that it was very difficult to enrol since there is not one large European waste party to collaborate with and it would therefore require a lot of collaboration with many small parties. Something they were not ready for.

To conclude, the manufacturer seemed interested in sustainability and took a lot of time and effort to meet in person at the hospital to have this discussion. They were willing to consider creating more environmental products if that were to give them a competitive advantage or if there was a financial incentive to do so.

Key takeaways Manufacturers

- Manufacturers do not have data available on the sustainability of their production, but some are working on collecting these data.
- Manufacturers experience more questions from hospitals about the sustainability of their processes.
- Manufacturers are willing to produce more environmental products if that were to give them a competitive advantage or if there was a financial incentive to do so.

Appendix E

Overview stakeholder interviews

Role	Dep/Org	Activity
Buyer	Procurement, Erasmus MC	2x conversation 1.5h, email contact
Expert Medical Devices	CSD, Erasmus MC	tour of department and questions during (1.5h), email contact, 1h face-to-face interview
Sales Manager	Manufacturer	phone and email contact, provided laryngoscope models, 1h face-to-face conversation
Manager Benelux	Manufacturer	1h face-to-face conversation
Sales Manager	Manufacturer	questions through LinkedIn
Sales Manager	Manufacturer	Phone call
Team manager	CSD, Erasmus MC	1h conversation
ICU doctor	ICU, Erasmus MC	Group conversation
ICU doctor	ICU, Erasmus MC	Group conversation
Anaesthesiologist	ICU, OK	Tour of OK and ICU, Group conversation
ICU Pharmacist, Lead Sustainability	ICU, Erasmus MC	Weekly contact, my personal coach
ICU Manager	ICU, Erasmus MC	Speaker at sustainability hackathon
Different people from ICU at Green Team meetings	ICU	Bi-weekly (about 6 meetings)
Project leader waste management	Waste management	Presented at a meeting with all the Green Teams within the hospital, follow-up email
Nurse	ICU, LUMC	Nurse contacted an intensivist for me
Intensivist	ICU, LUMC	Answered questions through LinkedIn
Expert infection prevention	Erasmus MC	Phone call
Nurses	Erasmus MC	Half hour interview

Appendix F

Research nurses

Excerpt from Maanicus' interview section report on medical staff speaking about personal barriers that are averse to sustainable behaviours. (See pages 24 to 27 of "Sustainable Intensive Care: Identifying motivators and barriers to sustainable behaviour among intensive care employees" (2022).

Personal barriers
The personal barriers to behave sustainably currently perceived by the ICU's staff can be divided into five main categories: lack of sustainable alternatives, time and convenience, responsibility, quality of care, and lack of knowledge. Each of the categories will be discussed in more detail below.

1. Lack of sustainable alternatives
The category that appeared most strongly from the interviews was a lack of sustainable alternatives. Some interviewees believed that, while being motivated to behave sustainably, a sustainable option is often not provided. A lack of sustainable alternatives thence appears to be a substantial barrier to sustainable behaviour, as these are not provided (enough) and therefore intrinsic motivation to make sustainable choices cannot be manifested. Nevertheless, the interviewees also highlighted several initiatives that are currently taken to improve sustainability. Some interviewees argued that the sustainable initiatives often suffer from flaws or shortcomings, which makes this option not suitable for use. Even when these sustainable alternatives are provided, flaws or shortcomings may hamper the application of these alternatives by employees, which, in consequence, prevents a sustainable development.

2. Time and convenience
Another barrier that appeared from the interviews was time. As doctors and nurses from the ICU experience high time pressure and quality of care has priority, sustainable options should not take a considerable amount of extra time or compromise the quality of care. Yet it seems that currently the sustainable option costs more time or effort than the unsustainable option. With ICU employees working under high (time) pressure, sustainable alternatives taking extra time (and effort) is perceived as a substantial barrier to engage in these actions. Besides the fact that some interviewees believed they do not have enough time, some interviewees also admitted that the convenient option is often preferred over the sustainable option. Even in cases where time itself is not a barrier, a trade-off is made between time and convenience, with convenience often being the preferred option.

3. Externalising responsibility
Responsibility as a barrier occurs in two different forms. Firstly, some interviewees believe they cannot make a difference individually and secondly interviewees perceive a choice is not provided due to dependency of other parties. When the interviewees were asked the question to what extent they believed they were able to change the situation, most interviewees stated that their individual actions would be insignificant and addressed the necessity to make sure everyone is involved. Furthermore, the interviewees were asked about their perception on the final responsibility of a more sustainable ICU, which led to some conflicting responses. Two different perceptions could be identified from the answers given. A first group of interviewees share the opinion that the management of the hospital is responsible for a more sustainable ICU, whereas a second group believes that improving sustainability at the ICU is a shared responsibility of everyone involved within the ICU. Some interviewees believe that they cannot influence the situation because they do not have a choice, as they are highly dependent on other parties making the decisions for them, both internally and externally related to the hospital. One specific topic that was raised several times was the use of disposable equipment, which is imposed on the employees to avoid cross-infections throughout the department. If such measures are imposed on the employees, it is not allowed to deviate from them, making it a significant barrier to ICU employees to behave sustainably.

4. Quality of care

Quality of care as a barrier was also mentioned often during the interviews. It was made clear during the interviews that the first priority of ICU employees is quality of care. It appears that a conflict arises when it comes to the effect of sustainable alternatives (e.g., cleaning of used equipment instead of disposing of all used equipment) on the quality of care (e.g., patient safety and especially infection prevention). As some interviewees feel uncertain about the impact of sustainable alternatives on patient safety, this is currently perceived as a barrier to engage in such actions. Because in every choice made by ICU staff, the quality of care is considered the most important factor.

5. Lack of knowledge

The last personal barrier perceived by ICU employees is a lack of knowledge, not on sustainability or sustainable behaviour itself, but on sustainable initiatives that are taken. Interestingly, almost every interviewee seemed aware of the fact that the ICU has a substantial negative impact on the climate. Information that is not provided on sustainable initiatives can thence be seen as a barrier. Mostly as no information is given on the impact of these initiatives, this may result in the sustainable initiatives not being experienced as effective and therefore may not be applied broadly among ICU employees.

Appendix G

Cost calculations

Cost calculations Reusable video laryngoscopes

```
> restart;
```

Fixed numbers

```
> SU_VL_price := 37;
```

$$SU\_VL\_price := 37 \quad (1)$$

```
> semi_VL_core_price := 3800;
```

$$semi\_VL\_core\_price := 3800 \quad (2)$$

```
> semi_VL_sleeve_price := 25;
```

$$semi\_VL\_sleeve\_price := 25 \quad (3)$$

```
>  fullyRe_VL_price := 5200;
```

$$fullyRe\_VL\_price := 5200 \quad (4)$$

```
> repro_costs := 7;
```

$$repro\_costs := 7 \quad (5)$$

```
> n_intubations;
```

$$n\_intubations \quad (6)$$

```
> n_semi_core := 4;
```

$$n\_semi\_core := 4 \quad (7)$$

```
> n_fully := 40;
```

$$n\_fully := 40 \quad (8)$$

```
> semi_cycles := 2000;
```

$$semi\_cycles := 2000 \quad (9)$$

```
>  fully_cycles := 3000;
```

$$fully\_cycles := 3000 \quad (10)$$

Costs SU a year

```
> cost_SU := SU_VL_price·n_intubations;
```

$$cost\_SU := 37\, n\_intubations \quad (11)$$

Costs Fully

```
> lifetimeVLs[years] := evalf(n_fully·fully_cycles / n_intubations);
```

$$lifetimeVLs_{years} := \frac{120000.}{n\_intubations} \quad (12)$$

```
> investfully := n_fully·fullyRe_VL_price;
```

$$investfully := 208000 \quad (13)$$

```
> costsfully := n_intubations·repro_costs + investfully;
```

$$costsfully := 7\, n\_intubations + 208000 \quad (14)$$

Costs Semi

```
> lifetimesemi[years] := evalf(n_semi_core·semi_cycles / n_intubations);
```

$$lifetimesemi_{years} := \frac{8000.}{n\_intubations} \quad (15)$$

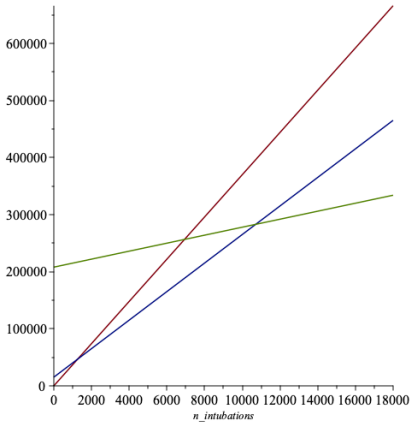
```
> investsemi := n_semi_core·semi_VL_core_price;
```

$$investsemi := 15200 \quad (16)$$

```
> costsemi := n_intubations·semi_VL_sleeve_price + investsemi;
```

$$costsemi := 25\, n\_intubations + 15200 \quad (17)$$

$$plot([cost\_SU, costsemi, costsfully], n\_intubations = 0..(18000));$$
#red = SU, blue=semi, green = fully



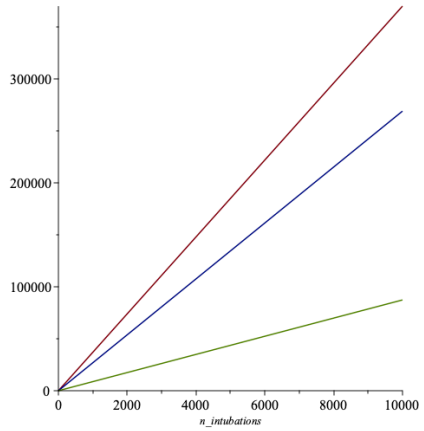
$$costsemi\_spread := n\_intubations \cdot semi\_VL\_sleeve\_price + \left(\frac{investsemi}{\frac{n\_semi\_core \cdot semi\_cycles}{n\_intubations}} \right);$$

$$costsemi\_spread := \frac{269\ n\_intubations}{10} \quad \textbf{(18)}$$

$$costfully\_spread := n\_intubations \cdot repro\_costs + \left(\frac{investfully}{\left(\frac{n\_fully \cdot fully\_cycles}{n\_intubations} \right)} \right);$$

$$costfully\_spread := \frac{131\ n\_intubations}{15} \quad \textbf{(19)}$$

$$plot([cost\_SU, costsemi\_spread, costfully\_spread], n\_intubations = 0..(10000));$$
#red = SU, blue=semi, green = fully



$$lifetimesemi2[years] := evalf\left(\frac{n\_semi\_core \cdot semi\_cycles}{n\_intubations} \right);$$

$$lifetimesemi2_{years} := \frac{8000.}{n\_intubations} \quad \textbf{(20)}$$

Appendix H

Alternatives glutaraldehyde

Overview of EtO and Glutaraldehyde Alternatives

Product (Vendor)	Application	Cost	Comments
EtO Alternatives			
Sterrad (Advanced Sterilization Products)	Enclosed sterilization processor with 45-minute cycle time	Processor $65,000 to $130,000 Hydrogen peroxide cassettes $216 to $265 per case ($43 to $53 per cassette, or $9 to $10 per cycle)	Generates hydrogen peroxide gas plasma from 58% hydrogen peroxide solution
Steris 20 (Steris Corporation)	Sterilization in 12 minutes at 50 to 55 °C; instruments "patient ready" in less than 30 minutes	Processor $18,200 Peracetic acid cups $128 per case ($7 per cup)	0.2% peracetic acid (diluted from 35%)
Glutaraldehyde Alternatives			
Cidex OPA (Advanced Sterilization Products)	High-level disinfection in 12 minutes at 20 °C	$25 per gallon	0.55% OPA solution: exposure limits not yet determined
Sporox II (Sultan Chemists)	High-level disinfection in 30 minutes at 20 °C	$25 per gallon	7.5% hydrogen peroxide
Sterilox (Sterilox Technologies Inc.)	Cycle time is 10 minutes for high-level disinfection	Rental of generator $15,000 year costing approximately $1–$3 per cycle, depending on use	System generates hypo-chlorus acid Currently used in Europe as liquid chemical sterilant; FDA pre-market clearance pending

Table adapted from Sustainable Hospitals Project web site. Costs provided are vendor list prices; actual costs may vary significantly under contract agreements.

Appendix I

Project brief

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name	Veerle Koot
initials	
student number	
street & no.	
zipcode & city	
country	
phone	
email	

Your master programme (only select the options that apply to you):

IDE master(s):	IPD / DfI / ★ SPD
2nd non-IDE master:	
individual programme:	- - (give date of approval)
honours programme:	Honours Programme Master
specialisation / annotation:	Medisign
	Tech. in Sustainable Design
	Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair	Jan Carel Diehl	dept. / section:	SDE/DfS
** mentor	Maaike Kleinsmann	dept. / section:	DOS/MOD
2nd mentor	Nicole Hunfeld		
	organisation: Erasmus Medical Center		
	city: Rotterdam	country:	the Netherlands

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

comments (optional): Nicole Hunfeld will be the client from this graduation project. As the project leader of the Sustainability Intensive Care Unit at Erasmus MC, she will be the main contact point with Erasmus MC organization.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

TU Delft

Procedural Checks - IDE Master Graduation

APPROVAL PROJECT BRIEF
To be filled in by the chair of the supervisory team.

chair Jan Carel Diehl date 17 - 03 - 2022 signature jdi ehl Digitally signed by jdiehl Date: 2022.03.17 16:35:02 +01'00'

CHECK STUDY PROGRESS
To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: ____ EC

Of which, taking the conditional requirements into account, can be part of the exam programme ____ EC

List of electives obtained before the third semester without approval of the BoE

YES all 1st year master courses passed

NO missing 1st year master courses are:

name ____ date __ - __ - ____ signature ____

FORMAL APPROVAL GRADUATION PROJECT
To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: APPROVED NOT APPROVED

Procedure: APPROVED NOT APPROVED

comments

name ____ date __ - __ - ____ signature ____

TU Delft

Personal Project Brief - IDE Master Graduation

The Green ICU: Future vision for reprocessing medical equipment — project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 15 - 02 - 2022 — 23 - 07 - 2022 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

The healthcare sector provides access to high-quality healthcare but is also responsible for a severe environmental impact. The Erasmus Medical Center (MC) in Rotterdam and the Faculty of Industrial Design Engineering of the TU Delft have initiated a series of graduation projects to design sustainable solutions specifically for the Intensive Care Unit (ICU). This in order to start a transition towards a Sustainable Intensive Care Unit.

There are many stakeholders for this project; Erasmus MC, IDE, patients, doctors, nurses, cleaning staff, producers of medical equipment and the environment. Below I will explain the wants and needs of a few. Erasmus MC wants to transition to a more sustainable hospital, while retaining high standards for patient safety. Next to patient safety they would wish to minimize an increased workload for the hospital staff and keep the sustainable care affordable. Patients will want to receive the 'best' care, while medical staff will want to provide this care to them. Producers of medical equipment will most likely be open to more sustainable products and services as long as it's financially viable. Lastly the biggest beneficiary of this project would be the environment. Reusing medical products will lead to less waste and will minimise the depletion of earth's resources. I want to add that this list consists of my assumptions and will need to be substantiated during my graduation project.

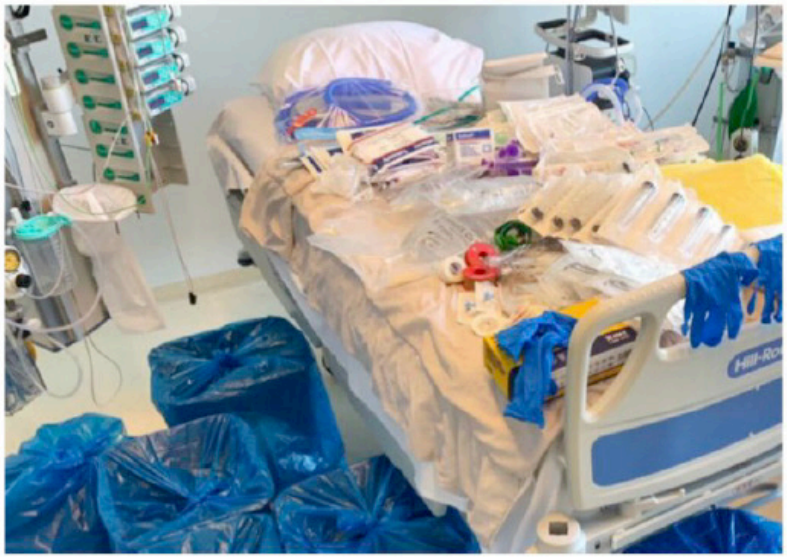
The opportunities of this project lie in new technologies for reprocessing medical equipment and the option to create new services and business models supporting the medical equipment. Especially zooming out and looking at the whole system of medical equipment could be valuable when tackling this challenge. On the other hand, limitations lie in the willingness of the hospital to invest time and money in sustainability instead of solemnly focussing on patient safety, affordability and convenience. Other limitations could be having access to the IC unit and ICU staff while we are still battling a pandemic.

space available for images / figures on next page

Personal Project Brief - IDE Master Graduation

TU Delft

introduction (continued): space for images



Healthcare sector 7% of national ecological footprint

ICU: 8 waste bags per person per day

Even more visible during Covid

image / figure 1: Waste generated per day per person in the ICU (image by Leo Heunks)

TO PLACE YOUR IMAGE IN THIS AREA:
- **SAVE THIS DOCUMENT TO YOUR COMPUTER AND OPEN IT IN ADOBE READER**
- **CLICK AREA TO PLACE IMAGE / FIGURE**

PLEASE NOTE:
- **IMAGE WILL SCALE TO FIT AUTOMATICALLY**
- **NATIVE IMAGE RATIO IS 16:10**
- **IF YOU EXPERIENCE PROBLEMS IN UPLOADING, COVERT IMAGE TO PDF AND TRY AGAIN**

image / figure 2:

Personal Project Brief - IDE Master Graduation

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PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

There are many different single-use products within the hospital that, within time, need to be transitioned to reusable products. The issue I will address is how to get there? How do we make the right choices over time and what does that mean for the organization? To keep the scope manageable I will focus on just two products within the ICU.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

I will analyze two single-use medical products, the video-laryngoscope and ECG sensors, in order to design a method to improve the EMC's decision making when it comes to reusing and reprocessing medical products.

For my project I will be investigating two single-use medical products, in order to deepen my understanding of the medical waste ecosystem at the Erasmus MC. I will investigate the video-laryngoscope and ECG sensors. I have chosen these specific products because they have very different characteristics. The video-laryscope is large in size, mainly used in one department, expensive and relatively small quantities are used. Compare this to a ECG sensor which is small, used in different departments, relatively expensive and used in large quantities. Another IDE student has already investigated the reprocessing of the video-laryngoscope, giving me the opportunity to build upon her project.

I will be investigating these products through three lenses; that of the organization, the people and the product itself. What are the consequences of reusing and reprocessing medical equipment for these elements. Does the hospital need an extra department for the reprocessing? Does this add to the workload of staff? Or do these single-use products need to be redesigned in order to be used again? All questions I plan on answering.

In this project I aim to deliver a method or approach for the hospital to make better organizational decisions when it comes to the reusing and reprocessing of medical equipment. What type of equipment should they be buying? Should they be leasing equipment? Should they be outsourcing the reprocessing?

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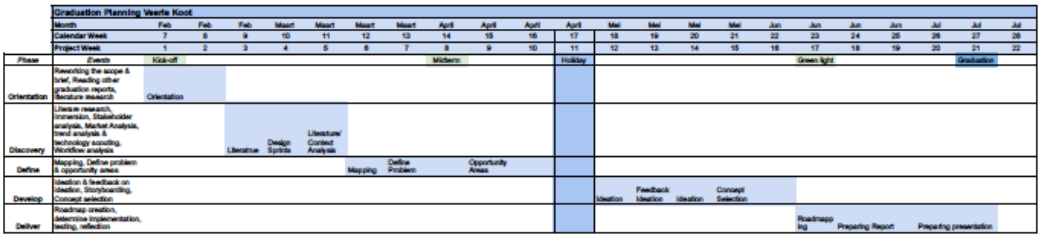
PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 15 - 2 - 2022 23 - 7 - 2022 end date



Since I will be graduating full time, I will be working on the project for 20 weeks. I will be taking a week off in the middle of the project, so I will complete the project in week 21. The project will consist of five phases: Orientation, Discovery, Define, Develop and Deliver.

The key dates:
Midterm (4 t/m 8 April 2022)
Green light (6 t/m 10 Jun 2022)
Graduation (4 t/m 8 Juli 2022)

Weekly planning:
I will be working at the Erasmus MC on mondays and tuesdays, working at home on wednesdays and I will be at the library on thursday and friday. Over time I plan on working more at the EMC.

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MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

Firstly, during my masters I greatly enjoyed my Design Strategy Project for Barco Healthcare. I found healthcare to be a very challenging and exciting context due to its many stakeholders. Secondly, during my bachelors I did the elective circular design and did a sustainability focussed bachelor's final project. In this graduation project I can combine my interest and expertise while designing for something I wholeheartedly believe in: sustainable healthcare.

My personal ambition in this project is to show that I can grasp very complex systems and make them understandable. As well as bringing together the wants and needs of different stakeholders. Furthermore, I want to show that I can communicate through visualization and show not only a cool idea but focus on how it could be implemented.

What I want to learn throughout this process is to be more decisive in my choices and explore methods on how to feel confident in my choices. Secondly, I want to be more hands-on. I want to emerge myself in the context and speak to as many people as I can. Finally, I want to get into the nitty gritty of technical solutions and show how to implement them.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.