MASTER THESIS

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July, 2025

Towards greener pulse oximetry

Product design enabling a seamless transition towards more sustainable pediatric pulse oximetry at Reinier de Graaf Gasthuis.

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Master Thesis
July 2025

In collaboration with
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Reinier de Graaf Gasthuis

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Acknowledgement

I would like to thank my supervisors, JC and Conny, for all their support and feedback throughout this project.

JC, your enthusiasm was very motivating and I appreciate all the many ideas you contributed and for connecting me with others.
Conny, thank you for the meetings where you provided valuable direction to help me stay on track. I'm also very grateful for the in-depth feedback on my report.

I would also like to thank Ayşegül for teaching me so much about co-creation and guiding me through the process. Thank you as well for the meetings in which you helped me structure my report, it was very helpful.

Thank you, Alie, for welcoming me into the hospital and introducing me to so many people. By including me in the office, I was able to meet many individuals who provided information and essential connections for conducting this research. I also really enjoyed the weekly "Keek op de Week" meetings with the other interns. These were always enjoyable moments in the week and a great opportunity to reflect and plan ahead.

A big thank you to everyone at Reinier de Graaf Gasthuis who was willing to help me by participating in interviews, allowing observations, and taking part in user tests.

Special thanks to Lindsay, Brigitte, Jasper, Alie, Carlo, Luc, and Djoeke for participating in the co-creation session.

In particular, I'd like to thank the pediatric Green Team for letting me join your meetings and for helping with interviews and connecting me with others.

Lastly, I'd like to acknowledge the LDE Thesis Lab and everyone involved for the inspiring sessions and ongoing support. These sessions taught me a lot about sustainable healthcare, also far beyond the scope of my project. It was very inspiring to see the bigger picture once in a while!

Enjoy the read!

Irene

Executive summary

According to the NFU (2024), pulse oximeters are the second most environmentally impactful disposable medical product in terms of CO_2-equivalent emissions. At Reinier de Graaf Gasthuis (RdGG), all departments have transitioned to reusable pulse oximeters, except for the pediatric units.

This graduation project, conducted in collaboration with RdGG, investigates the barriers to adopting reusable pediatric pulse oximeters and proposes a solution through product design.

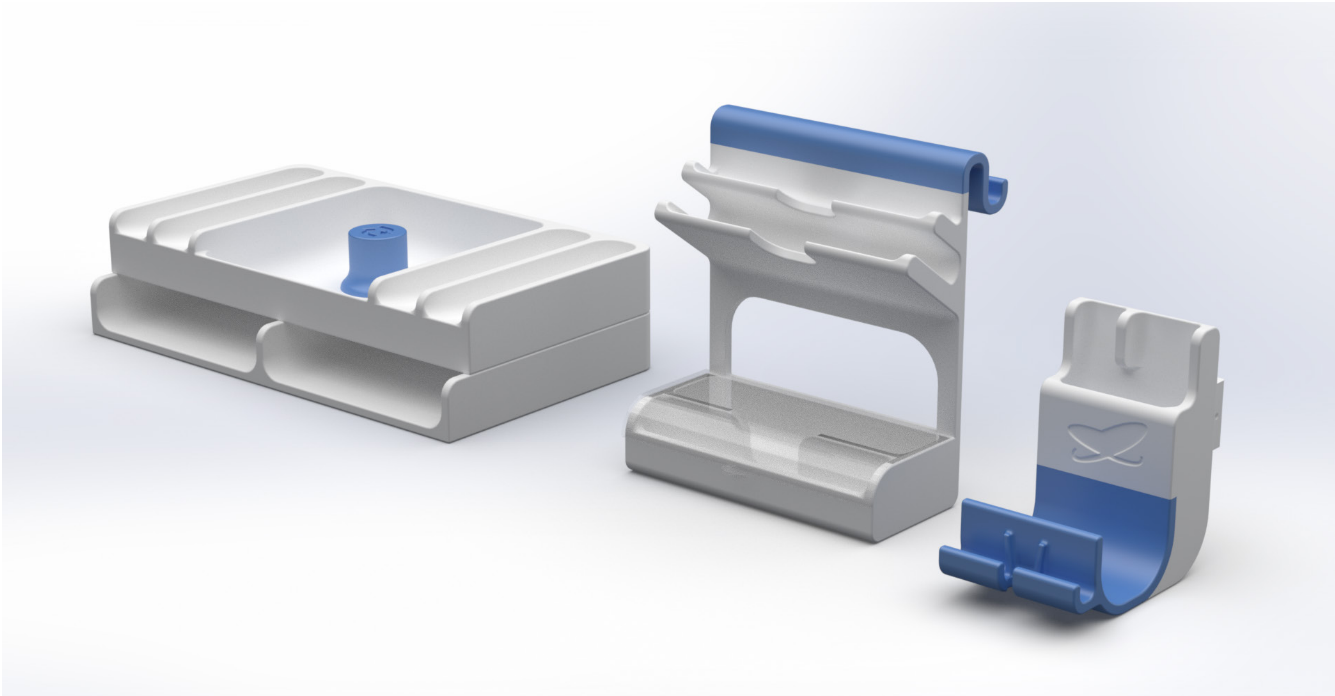
Initial research revealed that fully reusable pulse oximeters face several barriers in pediatric care, primarily due to concerns around hygiene, usability, and child- friendliness. Among the alternatives explored, a hybrid pulse oximeter, combining a reusable sensor with disposable adhesive stickers, was identified as the most promising solution for the pediatric context.

The goal of this project was to develop a user-friendly, cleanable, and sustainable storage solution that encourages nurses to use the hybrid pediatric pulse oximeter while ensuring safe storage for a long sensor lifetime. This led to the creation of the SatuSavers, a family of three product variants.

Of the three, the pole-mounted version was fully developed and tested for implementation. Through interviews, observations, co-creation, and prototyping, the design was refined to meet the criteria.

A full transition to hybrid sensors supported by the SatuSavers could lead to a significant reduction of environmental impact, alongside a cost reduction of up to 70.2% compared to the current use of disposable sensors.

The SatuSavers offer a practical and context specific solution to facilitate a seamless transition towards more sustainable pediatric pulse oximetry.



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Chapter 1 - Project introduction

In this introduction, the problem leading to this design project is explained and the scope is defined. The methods used to answer the three research questions are then explained.

1.1 The problem

The Dutch healthcare sector is responsible for 7% of the national carbon footprint in CO_2 emission equivalents (NFU, 2024). With the healthcare sector growing rapidly due to ageing populations and expanding access in emerging markets (Deloitte, 2016), the volume of waste and its environmental impact is expected to increase. At the same time, healthcare waste poses a health risk: general medical waste from hospitals and clinics can lead to re-infection, and the UN estimates that over half the world's population is at risk of illness caused by healthcare waste (Kane et al., 2018).

Despite this problem, the number of medical devices intended for single use is growing (Hoveling et al., 2023). While these devices may improve clinical outcomes and reduce contamination risks, they also contribute to the rising tide of e-waste, one of the fastest-growing waste streams globally (Subhaprada & P, 2017). Recycling of non-infectious healthcare waste is still limited, resulting in significant material loss (Hoveling et al., 2023). Active medical devices, such as pulse oximeters, fall under EU-MDR as equipment powered by external energy sources (EUR-LEX, 2025), making them part of a growing category of complex devices with environmental implications. According to the NFU (2024), pulse oximeters rank second among disposable medical products with the highest environmental impact (kg CO2-eq).

An almost complete switch to reusable pulse oximeters has been made in all departments at Reinier de Graaf Gasthuis, except in the childrens' departments. The implementation of a (partly) reusable pulse oximeter for children results in specific challenges and requires a tailored solution.

1.2 Scope

This project will only look at the Reinier de Graaf Gasthuis. The focus will be on the children departments, these include:

Child & youth department (kinder & jeugd afdeling)

This department treats patients between 0 and 18 years old. Most of them, around 80%, are placed in isolation. Very sick patients and those with lung problems are continuously monitored on SpO2 with disposable pulse oximeters.

Maternity ward (kraamafdeling)

This department monitors newborns and their mothers in case of small health indications of either the mother or newborn. Sometimes the saturation of the newborn is measured as a short check-up with disposable pulse oximeters, for example when the baby had a choke incident or is grunting.

Obstetrics (verloskunde)

This department gives care before, during and shortly after a birth. The saturation of the mother is measured using a reusable pulse oximeter on the finger. If needed, the saturation of the baby is shortly measured as a check using a disposable sensor. If there is a health issue with the baby, it is transported to the maternity ward or neonatology.

Neonatology (neonatologie)

This department treats sick babies or babies who were born too early. Most patients need to be monitored continuously.

The outpatient clinic is left out of scope as these have a relatively low use of disposable pulse oximeters and the clinic differs a lot from the children's departments in use and workflow.

1.3 Aim and research questions

Designing an intervention to ensure a seamless transition to more sustainable pulse oximeters in the children's departments of Reinier de Graaf Gasthuis.

Research questions:
1. What are the main barriers to switching to reusable instead of disposable pulse oximeters for pediatric caregivers at Reinier de Graaf Gasthuis?

2. What does the current system for pulse oximeter use look like, and what are its pain points?

3. What intervention is needed to overcome the most important barriers, ensuring a seamless transition?

1.4 Methodology

To answer each research question, different methods have been implemented.

1. What are the main barriers to switching to reusable instead of disposable pulse oximeters for pediatric caregivers at Reinier de Graaf Gasthuis?

To explore the barriers to switching to reusables, a systematic literature review was first conducted to identify general barriers. Then, interviews were conducted to examine the specific barriers faced by pediatric caregivers at Reinier de Graaf Gasthuis in switching to reusable pulse oximeters. A comparison between the two was made to verify the barriers.

The **systematic literature review** was conducted using the database Scopus to find the selected papers. The following keywords were used to search the database:(“Circular economy” OR “reusable devices” OR disposable OR single-use) AND “medical devices” AND (barriers OR challenges OR implications). The Scopus search was conducted in article title, abstract and keywords without restriction of time, in January 2025, and resulted in 81 papers. The articles (Jessica F Davies et al., 2024)(Tamara Hoveling, 2024)(Rumana Hossain, 2024)(Andrea J. MacNeill, 2020) were found as the basis of this analysis. Via snowballing 11 more articles have been found. A total of 15 articles have been analyzed for this review.

After the most insightful papers were selected, all barriers mentioned in the papers were listed in a table. The barriers were analysed by clustering the types of barriers into the categories made by Hoveling et al. (2024). Only the barriers that were both relevant to healthcare providers and could be influenced by industrial design were selected. By focusing on barriers that can be addressed through design, it ensures that the results are useful for creating reusable medical products that healthcare providers are more likely to use instead of disposable alternatives. The complete tables can be found in appendix A.

The **interviews** were conducted with 10 participants between the 3rd of March and the 1st of April. Due to the time constraints of healthcare workers, the interviews lasted no longer than 15-20 minutes. Five nurses, three department managers and two doctors were interviewed. From each department within the scope, at least one nurse was interviewed. Notes were taken during each interview.

All barriers mentioned by each participant were placed horizontally in a table. Similar barriers mentioned by different participants were grouped vertically. These similar barriers were then combined into overarching categories, resulting in a total of 12 distinct barriers. Finally, the barriers were ranked on how frequently they were mentioned.

2. What does the current system for pulse oximeter use look like, and what are its pain points?

This question was answered by **observational research**. The workflow regarding pulse oximetry of three nurses (one from Child and Youth, one from Neonatology, and one from both the Maternity Ward and Obstetrics) was observed while asking questions. All three observations took place after an interview from research question 1. At the Child and Youth department, actual work with children was observed. At Neonatology, the Maternity Ward, and Obstetrics, it was not wished to enter patients' rooms. Therefore, the nurses were asked to mimic the steps they normally take to measure the saturation of a patient, but in an empty room. Meanwhile, questions were asked regarding pain points of their steps.

Moreover, different stakeholders in the process of pulse oximetry were identified to make a stakeholder map. Another observational study was done with the identified 'kastscanners' to learn more about the logistics of refilling the disposable products. Their work from taking in newly delivered boxes to placing them in the correct storage rooms, to reporting the stock back to procurement was observed.

The results from the observations were visualized into product journey maps. These maps included drawings of each step, from refilling the storage rooms to disposing the sensor. The total amount of used sensors in 2024 was also mentioned per department.
For each step, things that were found to be going well and things that were found to be pain point were listed below.

3. What intervention is needed to overcome the most important barriers, ensuring a seamless transition?

To design a tailored solution, a **co-creation session** of one hour was held on the 10th of April. The goal of the session was to validate the outcomes of the research and to collect wishes and ideas for improvements to the current scenario and a potential reusable pulse oximeter.

The participants of the session were all, at some point, involved in the process of pulse oximetry. The stakeholders present included a pediatric nurse, a representative from infection prevention, two from medical instrumentation, the sustainability coordinator, a clinical physicist, and two others from TU Delft.

The session was recorded and transcribed afterward. The post-its created by the participants during the session were also analyzed. The results of the session include an overview of the ideas discussed and a visual representation of the wishes and interests of all stakeholders.

1.5 The project team

Advisory team
Jan-Carel Diehl is the chair and Conny Bakker is the mentor for this project.

Jan-Carel Diehl is a professor in Design for Inclusive Sustainable Healthcare at the Faculty of Industrial Design Engineering as well as a Medical Delta Professor at the Erasmus Medical Center.

Conny Bakker is professor of Design for Sustainability and Circular Economy at the faculty of Industrial Design Engineering. Her expertise lies in the development of design methods for circular and sustainable product-service systems.

Reinier de Graaf Gasthuis
This project is conducted in collaboration with Reinier de Graaf Gasthuis. My supervisor at the hospital is Alie Rozendal, the sustainability coordinator.

Reinier de Graaf Gasthuis is the oldest hospital in the Netherlands. The main location is in Delft, but there are also two branches in Voorburg and Naaldwijk. It is part of the 'Samenwerkende Topklinische Ziekenhuizen' (STZ), a group of hospitals that focus on both high-quality patient care and medical research, education, and innovation. The hospital is also working closely with universities and colleges. In 2023, it launched the Living Lab, a space where students and researchers can collaborate on medical advancements (Reinier de Graaf, n.d.).

Reinier de Graaf Gasthuis will be shortened to RdGG from now on.

Thesis Lab 'Groene Zorg'
This project is part of an interdisciplinary thesis lab organized by LDE Centre for Sustainability. In these labs, you work on your individual master thesis based on a real challenge while collaborating with other students with common topics

LDE Centre for Sustainability and Medical Delta are together organizing the Thesis Lab 'Green Healthcare'. Medical Delta is a transdisciplinary collaboration of more than 500 researchers from Erasmus University, Erasmus MC, TU Delft, LUMC, Leiden University, and four universities of applied sciences in South Holland. Together with companies, healthcare institutions, and governments, they work on innovative solutions for healthcare. The main challenge of this thesis lab is to find out what is needed to implement and sustain green solutions in the Dutch healthcare sector (Interdisciplinary Thesis Labs, n.d.).

Project background

Chapter 2 - Pulse oximetry

This chapter explores the working of pulse oximeters, the different types of sensors, and current trends in pulse oximetry to create a clear understanding of the context for the design.

2.1 The working of pulse oximeters

Pulse oximetry is a non-invasive method used to measure the oxygen saturation (SpO2) of blood, giving insights into the respiratory function of a patient. It measures arterial oxygen saturation in the blood. Arteries carry oxygen-rich blood from the heart to the organs and tissues. The SpO2 gives insights in the systemic oxygen levels. These levels are more indirect, as changes appear later in the systemic circulation (Koninklijke Philips N.V., 2020).
The device works by emitting two different wavelengths of light by light-emitting diodes, often red and infrared light, through the tissue, see figure 2.1. This can be on a fingertip, toe, hand, foot or earlobe. A light sensitive detector on the opposite side of the measuring site detects the amount of light absorbed by oxygenated and deoxygenated hemoglobin. The oxygen saturation levels can then be calculated. Pulse oximeters are used in all parts of the hospital for continuous monitoring of patients or doing check-ups.

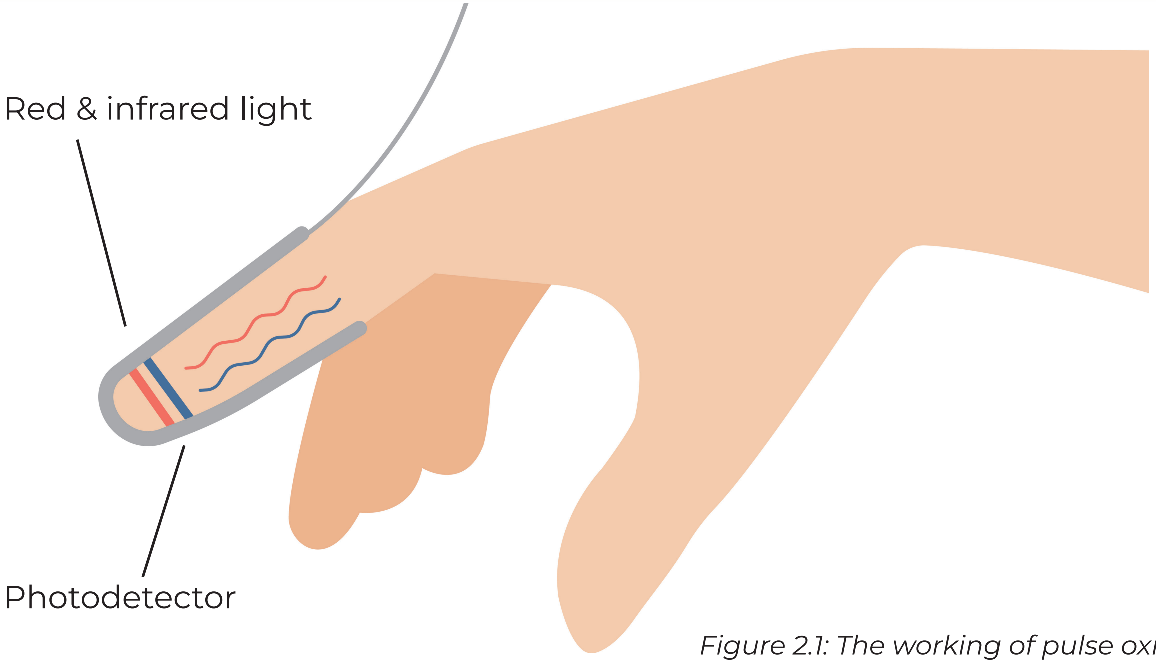

Figure 2.1: The working of pulse oximetry

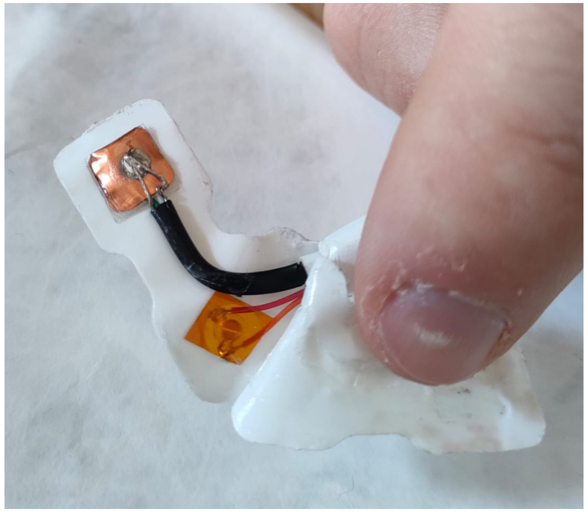

Figure 2.2: components of a disposable pulse oximeter

2.1.1 Placement of pulse oximeters

The correct placement of the sensor depends on the weight of the patient. For babies weighing less than 3 kg, the sensor should be placed either on the foot or the palm of the hand. In some cases, a pre-ductal and post-ductal saturation measurement is done, where sensors are placed on both the hand and foot to detect any differences.
For infants weighing between 3 and 20 kg, the sensor should be placed on the big toe. For patients weighing over 20 kg, the sensor should be placed on the fingertip. See table 2.1 for an overview.

While designing for pediatric saturation measurement, the multiple places of use based on the patient's weight should be considered.

2.2 Types of pulse oximeters

The main types of pulse oximeter probes commonly used in pediatric patients are reusable clip probes, reusable glove sensors and single-patient adhesive probes, see figure 2.3-2.5. Reusable clip probes offer benefits such as rapid deployment, ease of use across various body sites, and cost-effectiveness. In contrast, single-patient adhesive probes provide advantages such as a potentially lower risk of infection transmission, secure attachment in patients with excessive movement, and the ability to monitor from areas beyond the fingers, nose, ears, and forehead. These adhesive probes are particularly suited for continuous SpO2 monitoring (Al-Beltagi et al., 2024).

Weight of patient	Placement of the sensor	Type of sensor
<3 kg	Foot and/or hand	Neo/adult
3-20 kg	Big toe	Infant
>20 kg	Fingertip	Neo/adult

Table 2.1: Placement and type of sensor per weight category

Figure 2.3: Reusable clip probe (Live Action Safety, n.d.)

Figure 2.4: Reusable glove sensor (Philips, n.d.)

Figure 2.5: Single-patient adhesive probe (Nonin Medical Inc, 2025)

2.2.1 Types of products used at Reinier

At Reinier de Graaf Gasthuis, reusable pulse oximeters from Philips are used for adult patients. The M1191BL glove sensor and the M1194A ear sensor are available. The Philips M1133A disposable wrap sensor is used only at the ICU when reusables do not work, for example, when the hands of a patient are too cold to measure the saturation.

For children, they mostly use disposable pulse oximeters, see figure 2.6. At the SEH, they use the disposable Nellcor Neonatal-adult Oximax SpO2 sensor. At the children's departments, they use the disposable Masimo RD SET Infant, Neo and Newborn neo. The Newborn neo sensor is attached with Velcro instead of the plaster-like structure of Infant and Neo. The difference between the infant and neo sensors lies in the weight category, which affects the distance between the light source and photodetector.

Extra stickers are available for the Masimo Neo and infant sensors, shown in figure 2.7. A used sticker can be removed and replaced with a new one to extend the sensor's lifespan. This is only intended for longer use on a single patient, not for reuse on different patients.

Only the reusable child glove sensor and ear clip from Philips are used in the OR. At the child- and youth department, the reusable clip sensor from Masimo is occasionally used, see figure 2.8. This sensor is connected to a separate device and is used only for short measurements on the fingers of older children.

Figure 2.6: Types of sensors from left to right: Masimo RD SET Newborn Neo, Neo, Infant, Nellcor Neonatal-adult Oximax

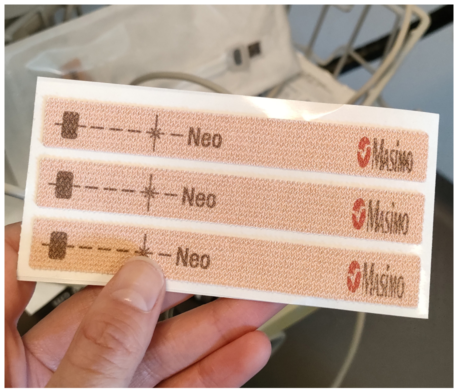

Figure 2.7: Extra Masimo stickers

Figure 2.8: the reusable Philips glove sensor (left) and ear-clip (middle) and Masimo clip sensor (right)

2.3 Developments and trends in pulse oximetry

Recent developments in pulse oximetry include near-infrared spectroscopy (NIRS). This measures the regional oxygen level in a mixture of arterial, venous and capillary blood in tissues. Shown in figure 2.9 is an example of a product using this technique is the head sensor, enabling detecting early changes in oxygen balance (Masimo, n.d.). New technologies are also focusing on wearable devices that continuously monitor oxygen saturation in various settings, such as during sleep or physical activity. An example is the 'Dream Sock', shown in figure 2.10. Additionally, multi-wavelength oximeters are emerging, which can offer more accurate readings by compensating for certain variables like skin pigmentation or movement.
Apart from new and better technologies, many different forms of sensors are developed. In pediatric care examples are reusable soft wraps (figure 2.11), attachment rings (figure 2.12), forehead sensors using reflectance instead of transmissive pulse oximetry (figure 2.13) and partly reusable sensors (figure 2.14). A pilot with headband sensors is now done at the cardiology department of Reinier de Graaf Gasthuis, showing the possibility of new products being implemented at children departments as well.

While designing for pediatric saturation measurement, these trends of partly reusable sensors and different body placements should be taken into account.

Figure 2.9: Example of a NIRS using sensor (Masimo, n.d.)

Figure 2.10: Example of a wearable device for continuously monitoring oxygen saturation

Figure 2.11: Reusable soft wraps

Figure 2.12: Attachment rings

Figure 2.13: Reflectance forehead sensors

Figure 2.14: Partly reusable pulse oximeters

Chapter 3 - Impact and circularity of pulse oximeters

This chapter highlights the impact of pulse oximeters and explores suitable circular design strategies to reduce this impact.

3.1 The impact of pulse oximeters

Disposable pulse oximeters contain electronics, which lead to a high impact compared to their weight. According to the NFU (2024), pulse oximeters have the second most highest impact of all medical disposable products in UMC's, see figure 3.1. According to the study of Duffy et al. (2023), disposable oximeters produce around 23.4 kgCO2e per day in the case of 150 patients per day. This impact is for 74% created during the production phases, the rest is made in transportation and the disposal of waste. Reusable pulse oximeters produced 3.9 kgCO2e, 4.9 kgCO2e, 5.7 kgCO2e in low, moderate and high use scenarios. They found that reusable pulse oximeters only need to be used 2.3 times in order to match the impact of one disposable pulse oximeter. Another study showed that they could reduce the average cost of pulse oximetry readings by 56% by switching from disposables to reusables sensors (Arciaga et al., 2019). This shows the impact disposables have on the expenses of hospitals.

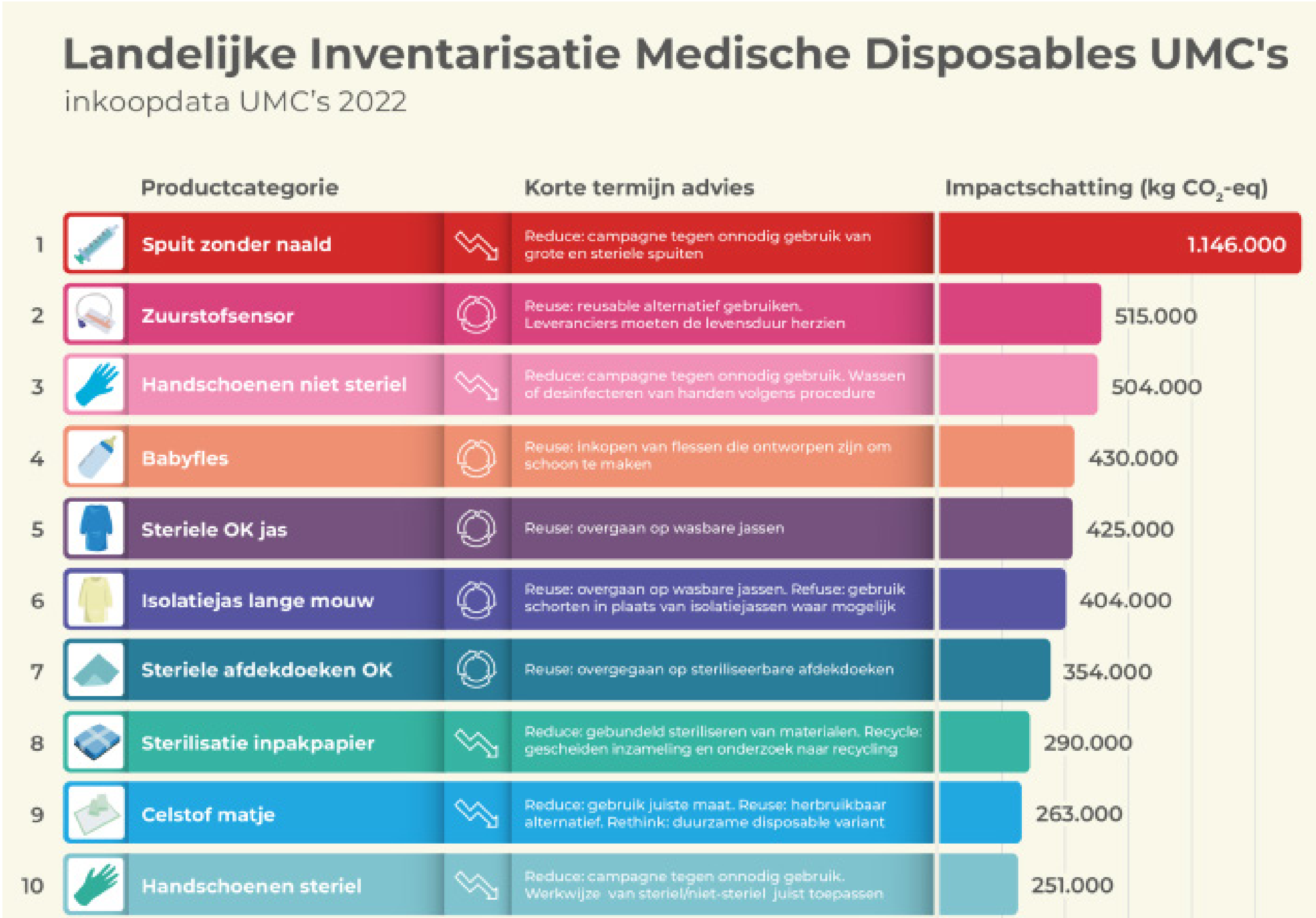

Figure 3.1: Total impact in UMC's per product category, with the pulse-oximeter in second place (NFU, 2024).

3.1.1 The impact at RdGG

At Reinier de Graaf Gasthuis, the environmental impact can vary depending on factors like the transport distance, the specific type of disposable or reusable pulse oximeter used and the cleaning habits of staff members. The impact also differs per department due to the different amount of disposables used.

The total amount of bought pediatric pulse oximeters in 2024 at Reinier de Graaf Gasthuis is 4564. Buying these disposable sensors for all children departments has cost the hospital in 2024 alone almost 50.000 euros.

The amount of pediatric pulse oximeters used, and thus their impact and costs, will increase in the near future. It is expected that in the coming years there will be more pregnancies and births in the region around Reinier de Graaf Gasthuis than nationally. At the same time, the average age of the mother at the birth of the first child is increasing, which gives an increased risk of complications (Reinier de Graaf Gasthuis, 2021). Moreover, in the near future, all newborns in Reinier de Graaf Gasthuis will be measured on saturation one hour postpartum, which will apply to approximately 3300 babies each year.

For this project, the pediatrics clinic is left out of the scope because this clinic is relatively big, with 2760 patients in 2024, while using a relatively low amount of sensors. This means that one sensor is used for less than 1 in 16 patients, while in the child and youth department, obstetrics, and neonatology, the ratios are approximately 1:1, 1:8, and 1:1, respectively. Additionally, how the clinic operates and its use of pulse oximeters are very different from those in the other departments, making comparison more difficult. That is why for the ease of the project while achieving a big impact, this clinic is not included in the research.

The maternity ward also has a relatively low use of sensors, but this department works closely with obstetrics. If a change is made in the obstetrics department, it would have direct influence on the maternity ward. That is why the maternity ward is included in the scope.

3.1.2 Product movement

One of the reasons for a high usage of pulse oximeters are the transfers of patients and the need to switch sensors. Children are moved through the hospital during their stay. Most children from the child and youth department arrive at the hospital through the SEH, sometimes by ambulance. Most patients from the neonatology and maternity ward are born in the obstetrics department. If departments use different sensors, they must be changed when a patient is transferred.

This leads to unnecessary waste. Figure 3.2 shows the places the sensor is used and the possible patient transfer routess. The red arrows indicate when a different sensor is required, while thicker arrows indicate the biggest patient transfer flows in the hospital.
The hospital will replace outdated Philips X2 monitors over the next three years, starting with pediatric departments. They will make the shift to Nellcor SpO_2 technology instead of a combination of Philips, Masimo and Nellcor. After this transition, extra sensor use during patient transfers will be reduced a lot, leading to less waste of material and money.
Each department will individually decide whether they want to use reusable or disposable sensors. All current reusable Philips sensors will be replaced with Nellcor reusables. The future scenario is illustrated in figure 3.3, showing a reduced need for sensor changes between departments. This transition is a great opportunity to switch to a more sustainable sensor, as the 'broodjes' need to be replaced and caregivers need to already adapt to new equipment.

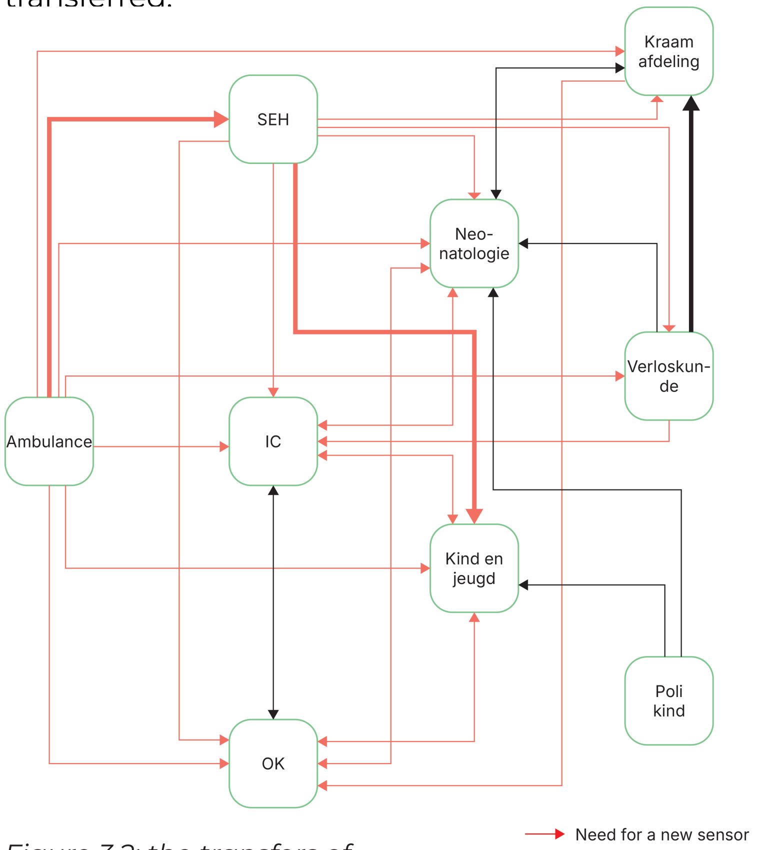

Figure 3.2: the transfers of pulse oximeters

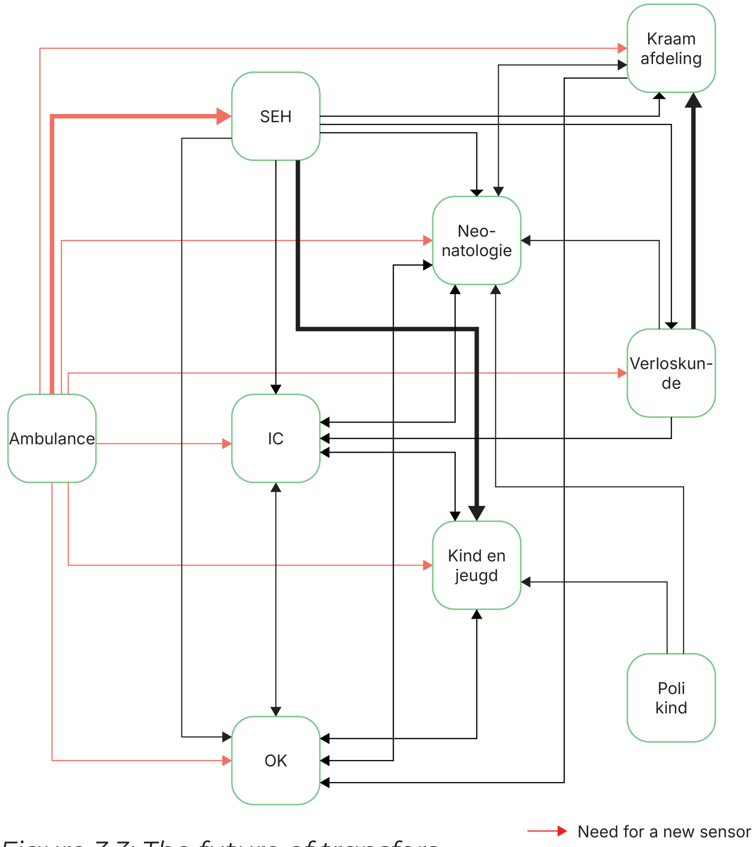

Figure 3.3: The future of transfers after transitioning to Nellcor

3.2 The circular economy

A circular economy is a system that aims to reduce waste by reusing, repairing, and recycling materials, in order to make the most of available resources (Moreno et al., 2016). It focuses on keeping products and materials within the economic system for as long as possible. This can be done by extending the life of products or by "looping" them back into the system through reuse or recycling (Hollander et al., 2017). The principles and strategies of a circular economy are often illustrated using the butterfly diagram, shown in figure 3.4. The diagram shows the continuous flow of biological and technical materials through cycles of reuse, refurbishment, and recycling. Products that are designed to support this system are called circular designs and are developed using one of the r-strategies, see figure 3.5. The ways of recovery are ranked in the r-ladder according to the 'inertia' principle of Walter Stahel, which says "Do not repair what is not broken, do not remanufacture something that can be repaired, do not recycle a product that can be remanufactured. Replace or treat only the smallest possible part in order to maintain the existing economic value of the technical system." (Stahel, 2010)

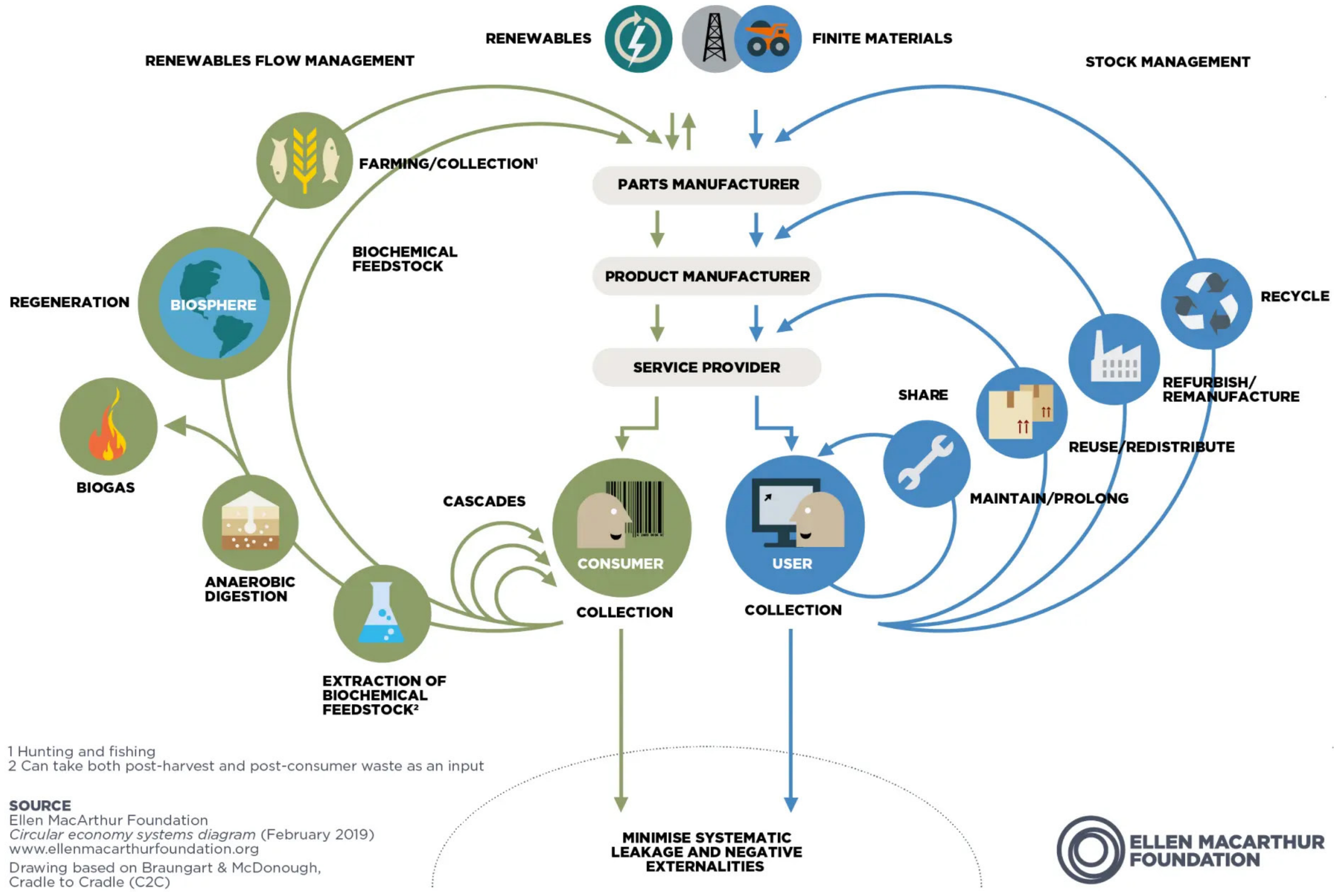

Figure 3.4: the butterfly diagram (Ellen Macarthur Foundation, 2021)

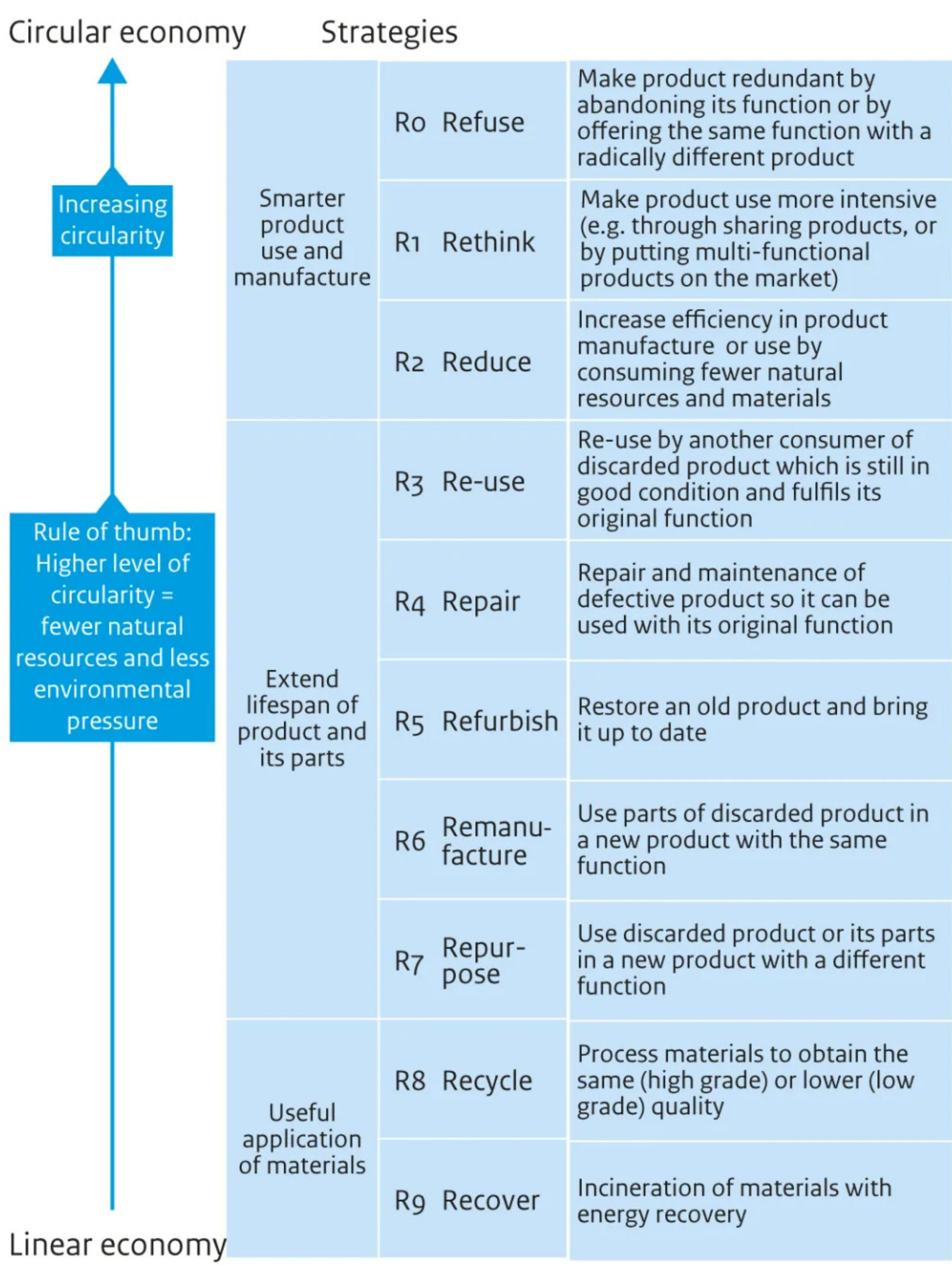

Figure 3.5: the r-strategies (Potting et al., 2017)

3.2.1 Circular economy in healthcare

Medical devices that can be reused or recycled help reduce waste, save valuable materials, and lower the carbon footprint of healthcare. For instance, studies show that switching to reusable medical devices can cut emissions by up to 63% compared to disposable ones, although reusable devices may use more water (Keil et al., 2022). Despite the benefits of reuse, healthcare has been slow to adopt reusable products (Ertz & Patrick, 2019). Challenges are among others strict regulations and concerns about contamination. The widespread use of single-use devices also shows worries about patient safety, supply chain issues, and limited awareness of the environmental harm caused by disposable products.

3.2.2 Opportunities and challenges for recovery flows of pulse oximeters

In the long-term, strategies of refuse (R0) and rethink (R1) could lead to the biggest impact. Saturation measurement could for example be combined with blood pressure and ECG in one product, only needing one product instead of three. A washable sticker, like the Scarban washable and adhesive silicone tape, could lead to a much longer use of adhesive sensors. Also, new technologies measuring saturation without touching the patient, like remote photoplethysmography for measuring heart rate, could remove the problem of cleaning reusable sensors.

Lastly, designing a product connected to the monitor via bluetooth or wifi could reduce the impact of the cable.

Reuse (R3) is the most common circular strategy for medical devices. As stated by Hoveling et al. (2024), 95% of all medical devices that used a circular strategy, were reusable for more than one product life cycle. Despite this, the healthcare sector still relies heavily on single-use products. This shift toward disposables began in the 1970s, driven by advancements in material sciences. Before this development, most products were originally designed to be reused (Rutala and Wever, 2008). However, there have been some incidents in the past with reprocessed single-use devices, resulting in a lack of trust in reuse (Drues, 2015). Moreover, it costs manufacturers more to label a product as reusable, while limiting the sale of their new products. As a result, some manufacturers intentionally design devices to discourage or prevent reuse (Kane et al., 2018). In order to make the pulse oximeter reusable, the product should be redesigned in a way that stimulates reuse. Moreover, barriers like safety concerns should be tackled.

The strategies Refurbish (R5) and remanufacture (R6) are mostly used for expensive and complex equipment, like medical imaging equipment and patient monitors. The pulse oximeter does not fall in this category. Repair (R4) is mostly done on devices with a longer life, so the refurbished/remanufactured products are likely repaired multiple times in their life (Kane et al., 2018). Currently, reusable adult pulse oximeters at Reinier de Graaf Gasthuis are also not repaired as Philips does not take them back for repair. An opportunity could be to make in-house repair possible at Reinier de Graaf Gasthuis by arranging the needed tools and knowledge to do basic repair. This could be done for example by the medical technicus, who at the moment only test the reusable sensors whether they are still working.

Recycling (R8) is very low in the ladder, meaning it is one of the last resorts with still a big loss of value. The recyclability of products depends on the type of materials used. A big barrier of recycling medical products are the regulations of medical waste that is potentially contaminated. There are technologies available to sterilize this infectious waste, but this is expensive (Chartier, 2014). Therefore the most commonly used method is still incineration (World Health Organization, 2005).

3.2.3 Conclusion

Any new pulse oximeter should be designed to be recycled, as it can be expected that the technologies for sterilizing and recycling infectious waste will improve and be more viable. For an impact in the short-term, the use of disposable pulse oximeters should be reduced and steps should be taken to make the transition to reusable pulse oximeters possible.

3.3 Conclusion

The impact of disposable pulse oximeters is high due to the electronics in the sensor. The end of the sensor containing the photodetector and light emitter is therefore the most valuable part. Last year, 2546 disposable sensors were used at Reinier, and this number is expected to increase in the coming years. Reuse is the most commonly used circular strategy for reducing the environmental impact of similar medical devices. Meanwhile, reduce can also lead to a quick reduction of impact.

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Chapter 4 - Barriers to reusing medical devices

A literature review and interviews have been done to answer the first research question: What are the main barriers to switching to reusable instead of disposable pulse oximeters for pediatric caregivers at Reinier de Graaf Gasthuis?

Frameworks to replace single-use devices and general barriers to achieving a circular economy have been examined in previous papers (Vanderwee et al., 2024; Abreu et al., 2002), but there has been no specific focus on the barriers for healthcare providers like nurses and physicians for choosing a reusable option instead of a disposable one. Health care providers are end users of medical devices, they make clinical decisions that determine the necessity and volume of resource use. For many medical devices, there are already reusable alternatives available. Hospitals sometimes have both the reusable as well as the disposable option of a device available, healthcare providers can in this case select between the options, influencing procurement volumes (Hennein et al., 2022). It is expected that if a reusable pulse oximeter is implemented in pediatric departments, there will be a disposable back-up available as patient safety will always be a priority. This method of using reusables but with disposables as a back-up is now also the case for adult departments at Reinier de Graaf Gasthuis. Insights into the choice between reusables and disposables are needed to decrease the use of disposables as much as possible.

4.1 Barriers in choosing reusable medical products

First, a literature review is conducted on barriers for healthcare providers in choosing reusable medical products over disposable alternatives. Here, a summary of the four different categories is presented. The full literature review can be found in appendix A.

4.1.1 Safety barriers

Multiple safety barriers make healthcare providers hesitant to choose reusable medical products over disposable alternatives. A common barrier is the perception that single-use disposables are safer, as they come pre-sterilized. This reduces worries about contamination due to human error and cross-infection. Some papers found that some healthcare professionals doubt whether reusable products can be fully cleaned and decontaminated, making them trust their safety less. .

4.1.2 Social barriers

The social barriers to choosing reusable medical products mainly come from perceptions, habits, and a lack of awareness. Some staff believe that reprocessing equipment is worse for the environment than throwing disposables away. A lack of education and misinformation play a role, as staff may not fully understand the benefits of reusable products or the principles of a circular economy. Many healthcare workers and patients prefer single-use devices because they seem more convenient, easier to use, and safer.

There is also public mistrust: patients may be uncomfortable with reusable items. Workplace culture and decision-making structures also contribute to the issue, product users often don't have control over which devices are used, and sustainability is not seen as a priority in their roles. Finally, resistance to change is a big barrier. Staff are often overwhelmed by frequent policy changes and may worry that switching to reusables will add extra steps to their workflow, increasing stress and burden to them or their colleagues.

4.1.3 Systemic barriers
A systemic issue is the lack of knowledge or training on how to properly clean and sterilize reusable devices, which increases the risk of mistakes. This connects to the possibility of human error in reprocessing, as improper cleaning can lead to safety concerns. Additionally, practical challenges in collecting and separating reusable products make the process inefficient, especially when healthcare workers already face time constraints in their daily tasks.

4.1.4 Technological barriers
A common technological barrier is the risk of mechanical failure and material alteration, as reusable devices may wear down over time affecting safety and effectiveness. Healthcare providers also prioritize high quality and functionality, and there is a fear that reusable devices might not always meet the same performance levels as disposable ones. There is a perception that reusable devices have a decreased functionality, even if it is not always the case. These concerns make healthcare providers unsure if reusable medical products are practical and reliable, making adoption more difficult.

4.1.5 Conclusion
Multiple barriers make healthcare workers hesitant to choose reusable medical products over disposable alternatives. Misinformation and perceptions need to be tackled to improve trust in the safety and reliability of reusable products. Moreover, a reusable design should address the logistical challenges of reusables, such as improving collection, sterilization, and redistribution processes to decrease the feeling of healthcare providers that reusables are an extra burden for themselves or others. The reusable products need to be just as convenient and time-efficient as disposables, design improvements should focus on making reusable products simpler and more user-friendly. More evidence is needed on how well reusable products perform over time. Design improvements are needed to help reusable devices match or exceed the quality of disposables.

4.2 Barriers of reusing pediatric pulse oximeters at RdGG

Next, the findings of the literature review are validated through interviews with healthcare workers. During this research, the focus is on the specific case of pediatric pulse oximeters at Reinier de Graaf Gasthuis. This is done by conducting short interviews with nurses, department managers, doctors, and assistants, resulting in a total of 10 participants.

The most mentioned barrier is that reusables fall off too easily, mostly because they are not sticky. There is also less choice in sizes and types of reusables, compared to disposables. The combination of reusables having no adhesives and limited sizes, lead to concerns that reusables may shift or move. Moving of the products will lead to inaccurate measurements, false alarms and maybe falling off completely. This problem is a big barrier for measurements on children as they move much more than adults. According to nurses, children between a few months and 2 years move the most, especially in the days leading up to discharge, when their condition is improving. Newborns move less, but their skin is greasy and sometimes still moist from amniotic fluid. These patients need a strong adhesive to be able to keep the sensor in place.

A reusable is often larger and heavier, which leads to the problem of pressure points, something which babies are very sensitive for.
In order to tackle this barrier, a new fully reusable sensor needs to be designed that is better suitable for the smallest patients. Until this time it is more likely that a partly reusable sensor, including a disposable adhesive sticker, will be successfully implemented for infants.

The reusable is also seen as less child-friendly, caregivers think they are less comfortable, and that children may be less likely to accept such a big device on their finger or foot. If children do not like the sensor, they will try to take it off. If the reusable is not stuck to the finger, it will be relatively easy for children to shake the device off, leading to alarms. This argument also suggests that a much smaller, lighter, partly reusable sensor has a greater chance of success.

Moreover, concerns about reusables being less accurate and having a higher chance of infections are mentioned multiple times. Literature says that there is little difference in accuracy between disposable and reusable sensors on children (Bell et al., 1999) and a literature review found that reusables are also comparable in terms of comfort and safety (Kane et al., 2018). Also, there are already other reusable products used on children, like the thermometers, which are accepted by staff. A challenge will be to inform healthcare providers with correct information and gain their trust in the working and safety of reusables.

Apart from most staff members being unaware of the scientific evidence for reusables, there is also a high unawareness of the available products. They are used to the current product and have no idea what is available on the market, most of the interviewee did not know that there were even reusable options available for children. Even if they did know, two people mentioned that they were not able to make this change themselves. The current available reusables do not fit on their equipment and they do not have the power to change this.

4.3 Comparison of literature with practice

All barriers mentioned by staff of RdGG and the amount of times mentioned are shown in figure 4.1. The corresponding barriers found in the literature study are added to the figure.

Many barriers found in the literature are also reflected in those found at RdGG, but in more specific terms. So instead of a general barrier of 'perception of decreased functionality', staff members mentioned that reusable alternatives fall off too easily because they are not sticky. This clearly validates that the barriers found in litarature are also present at the specific use case of RdGG.

Barriers of caregivers in Reinier	Times mentioned (out of 10)	Comparable barriers found in literature
Reusables are not as sticky and fall off too easily	5	Perception of decreased functionality Ease of use of single-use devices Unsuitable device/material characteristics for circular strategy
There is more choice in sizes and types in disposables	4	Focus on and need for high quality and function of the device
The reusable sensor is not child-friendly	4	Focus on and need for high quality and function of the device Consumers prefer the single-use option over the reusable
Reusables are less accurate	3	Perception of decreased functionality Safety, efficacy, reliability is more important in the design process Focus on use and clinical outcomes, opposing circularity
Disposables have a lower chance of infections	3	Perception that single-use disposables are safer Potential for cross-infection
They do not have the power to make the change	2	Product users are separated from device decisions Lack of support from the hospital
There is no reusable option	2	Staff misconceptions
Reusable options do not fit on current equipment	2	-
Disposables are cheaper	1	Reusables cost more Financial constraints of different stakeholders.
Reusables are not convenient for children in isolation	1	Disposables are better for some specific uses
The more steps, the bigger the chance of mistakes	1	Possibility of human error in reprocessing
They are used to using disposables	1	Staff is resistant to change

Figure 4.1: Comparison of barriers of caregivers at Reinier with barriers found in literature

4.4 Conclusion

To answer the first research question, the main barriers to switching from disposable to reusable pulse oximeters for pediatric caregivers at Reinier de Graaf Gasthuis are both practical and perceptual. The most frequently mentioned concern is that reusable sensors are more likely to fall off, mostly due to a lack of adhesive and limited size options. This makes them particularly unsuitable for children under the age of two, who move frequently or have sensitive skin, resulting in inaccurate readings, false alarms, or sensor detachment. Additionally, the larger and heavier form of many reusable sensors raises concerns about pressure points and overall comfort, further reducing acceptance among caregivers.

Beyond physical design issues, there are also strong perceptual barriers. Many caregivers perceive reusables as less child-friendly, less hygienic, and less accurate, despite literature showing comparable safety and performance between reusable and disposable sensors. A lack of awareness about available reusable options and uncertainty about who holds the decision-making power also hinder adoption.

To overcome these barriers, design improvements must focus on making reusable pulse oximeters smaller, lighter, and more adaptable. In the meantime, the implementation of a partly reusable pulse oximeter for children under 2 years is more likely than a completely reusable option, looking at the current availability of completely reusable sensors.

Moreover, there should be a focus on gaining the trust of healthcare providers in the working and safety of reusables. It is important to include staff members in the transition to reusables to make them aware of the possibilities and give them control in the process.

Exploration of the design direction

Chapter 5 - Analysis of the Reinier de Graaf Gasthuis

In this chapter, the second research question is answered: What does the current system for pulse oximeter use look like, and what are its pain points?

5.1 Stakeholder mapping

First, all stakeholders involved in the process of pediatric pulse oximetry are mapped in a stakeholder map, shown in figure 5.1. The whole map is needed to answer the question of how the current system looks like, as pain-points can not only occur in the use phase, but also the logistics around the sensor. It is also important to know what the differences are between the logistics of disposables and reusables, to know what is needed in order to make this transition.

In order to successfully implement a reusable alternative, many stakeholders need to be on board. Nurse managers have influence on what products will be purchased for their department, but primarily consider criteria such as cost and quality. Most nurse managers are not well informed about more sustainable options and see this as extra work.

However, the hospital signed the Green Deal sustainable care 3.0, meaning that the hospital should transition to at least three reusables instead of disposables. Greenteams are often the ones who spend time on making sustainable changes, convincing the nurse managers. A more elaborated list of stakeholders can be found in Appendix B.

The main differences between disposable and reusable pulse oximeters is the way of distribution to the departments and the extra steps needed for reusables. Disposables are distributed to the correct storage rooms by the 'kastscanners' (closet scanners). These closet scanners also inform back to procurement how much and which new disposables should be ordered.
In order to implement a reusable medical device, other stakeholders are involved. Clinical physics do the testing and guarantee a certain quality. Infection prevention is involved to determine safe (cleaning)protocols. Medical instrumentation will test the quality of the reusable products and repair or replace broken products.

The full detailled life cycles of both reusable and disposable pulse oximeters can be found in appendix C.

5.1.1 Conclusion

To successfully implement a reusable medical product, it is important to involve a greenteam in order to convince nurse managers and department heads. Also, clinical physics, infection prevention and medical instrumentation should be involved in the process of transitioning to reusables.

Disposable pulse oximeters require frequent ordering, packaging, transport, and disposal. In contrast, reusable sensors involve a more complex initial procurement process but then last significantly longer. While reusables do require cleaning, their overall footprint is after a few uses lower than the footprint of disposables, making them a more sustainable option over time (Duffy et al., 2023).

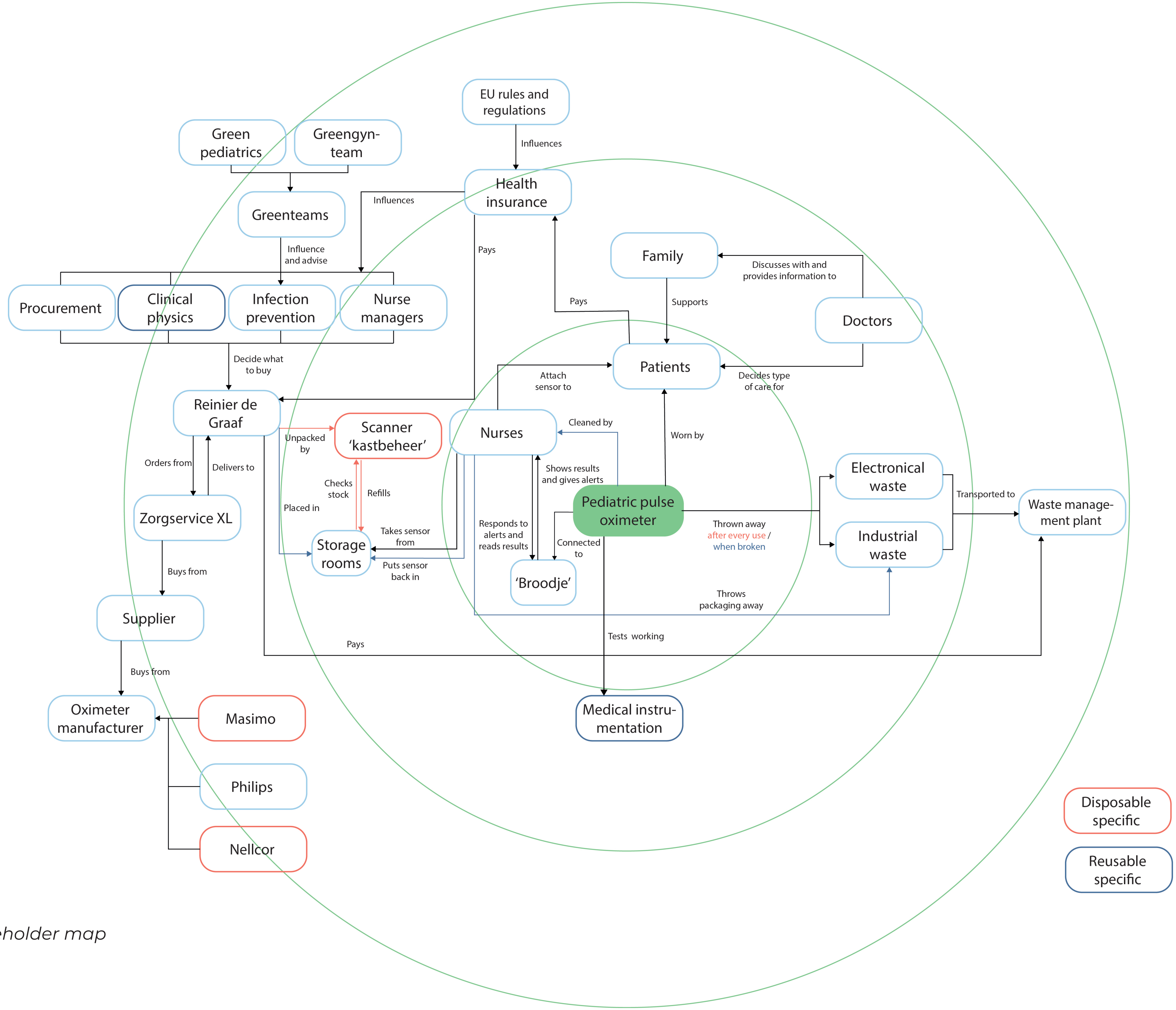


Figure 5.1: Stakeholder map

5.2 Usage of adult pulse oximeters

Even though the adult departments are structured in their own way and adults need to be treated very differently from children, it is still valuable to look at how the use of reusable and disposable pulse oximeters is organised.

By looking at how reusable sensors are used there, useful things can be learned about how the sensors are put into practice, how they are stored and cleaned, and how staff feel about using them. This can help us spot possible problems early and avoid the same issues when reusables are introduced in the children's departments.

Figure 5.2: Supply of disposable products

5.2.1 Disposables

In the case of disposable pulse oximeters, big carts with boxes full of different disposables are brought to the storage rooms in the department that ordered the products. The name and an illustration of the disposable is shown on the box for clarity. On each door in the storage room is a list with all the products stored in that specific closet. Inside the closet are drawers with the individual names and product numbers of each disposable. In the door of this closet, cards are placed by nurses and assistants for the products that need a refil, see figure 5.2. The 'kast-scanners' (closet-scanners) will scan these cards, informing procurement on the needed products. This process is the same for the children's departments.

5.2.2 Reusables

Reusable pulse oximeters are only ordered when they have a shortage of sensors, for example when one breaks or gets lost.

Figure 5.3: storage of reusable glove sensors

After use, the sensor should be cleaned with microfiber or 70% alcohol, as it is a non-critical product used on intact skin (SRI, 2024).Most reusable glove sensors are already connected to the "broodje" and available in each room, stored in the baskets or hung up on hooks, shown in figure 5.3.

Departments also have the ear-clip and sometimes a finger clip sensor available. Both the pulmonary department and OK mentioned they often did not know where these reusable devices were located. Storage is found to be less organised than in the case of disposables, as many different users of the sensor place them back where they think they are supposed to go. The packaging the sensors are supposed to be stored in sometimes also gets lost, resulting in creative solutions like writing the correct name on different packaging, shown in figure 5.4.

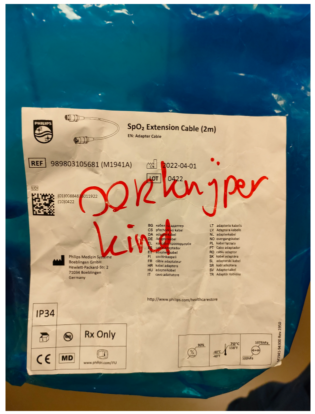


Figure 5.4: Wrong packaging usage

5.2.3 Pain points of use

Apart from sensors being lost and stored in the wrong packaging, some disadvantages during use were mentioned. The glove oximeter for adults only comes in one size, resulting in the sensor being too tight for people with thick fingers, while being too loose for people with small fingers. Additionally, the material is found to not be breathable, leading to sweaty and smelly fingers when used for a longer period of time. The sensor is also quite big and located at the inside of the finger, making it harder to grab stuff like a glass of water.

5.2.4 Conclusion

The most important take-aways for the children's department are the importance of always knowing where your reusable sensors are located and organized storage. The way of storing the product should be clear to avoid confusing situations like relabeled packaging.

5.3 Product journey maps of pediatric pulse oximeters

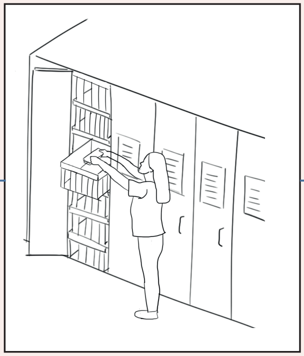
By visiting the four departments, insights into the current process and usage of the sensors have been gained. To be able to easily compare the departments, similar posters are made for each department showing the process, things that go well and pain points. When implementing a (partly) reusable sensor, inspiration can be taken from the things that currently go well and pitfalls can be avoided by looking at the pain points. The posters are made simple and clear, so they can function as a conversation starter for the co-creation session explained in the next chapter. The poster are also made in Dutch, as this is the language spoken by all of the staff of Reinier.

The posters are shown on the next pages.

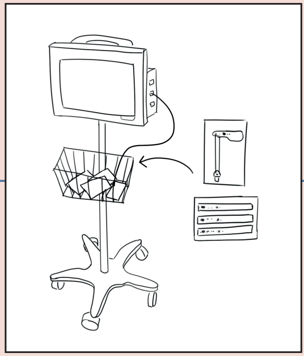
Kinder- en jeugdafdeling - 2FG

Scenario productgebruik

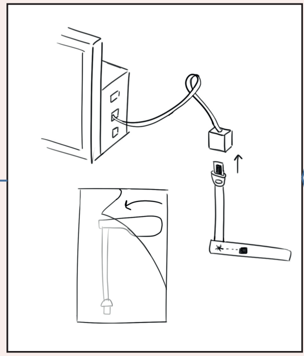
Sensoren pakken

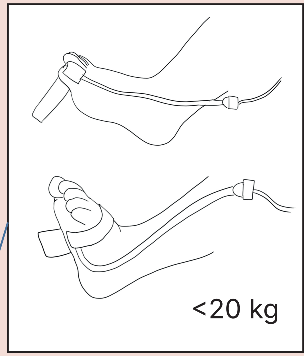


Mandje bijvullen

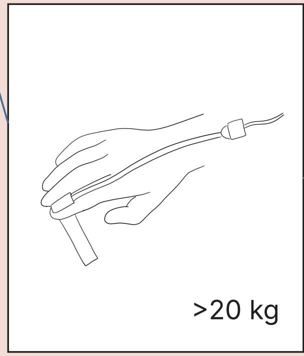


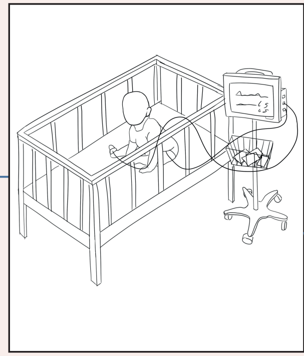
Uitpakken en aansluiten



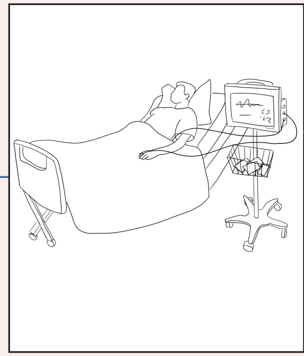


Sensor bevestigen

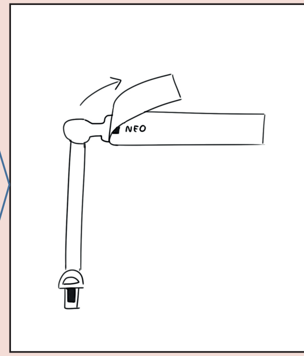




Continue monitoring



Herplakken van de sticker



2320
stuks

Gaat goed

- Een voorgevulde mand bespaart tijd, omdat alles in de kamer aanwezig is.
- Vaak wordt er een sok om de sensor heen gedaan om het te beschermen en de voet warm te houden.
- Door een nieuwe sticker op een nog werkende sensor te plakken, wordt de levensduur verlengd.

Pijnpunten

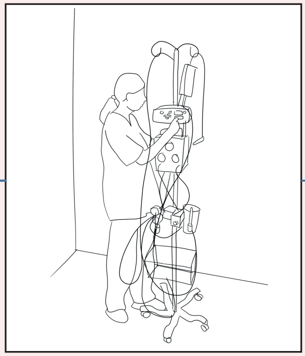
- Soms wordt het gewenste formaat sensor niet bijgevuld.
- Soms blijft de tape aan een handschoen plakken, waardoor de sensor scheurt.
- Er zijn veel valse alarmen wanneer kinderen bewegen.
- De kabel breekt soms bij het lostrekken van de sticker.

Belevenis productgebruik

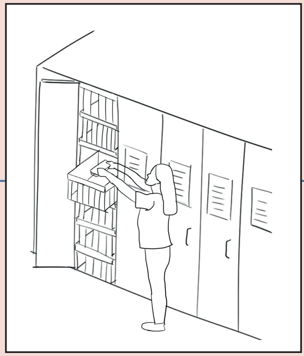
Kraamafdeling- 2A

Scenario productgebruik

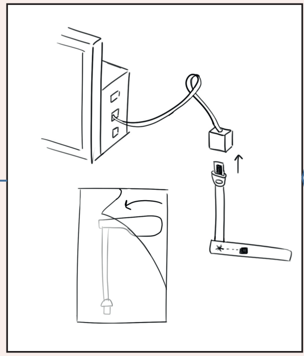
Paal pakken

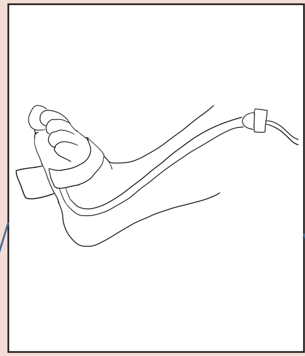


Sensoren pakken

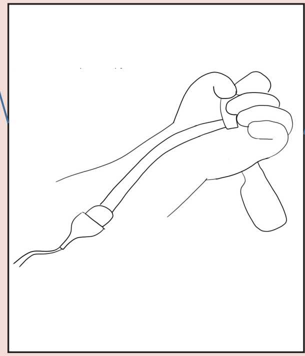


Uitpakken en aansluiten

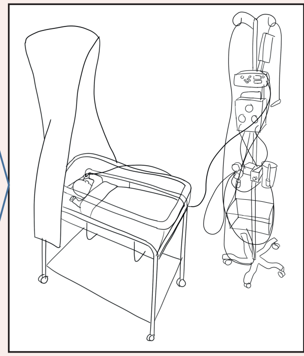




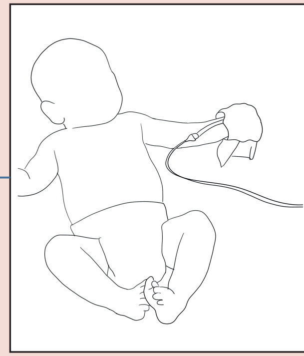
Sensor bevestigen



Controle meting



Handdoek om de sensor



110
stuks

Gaat goed

- Eerst de monitor aanzetten en dan pas de sensor aansluiten, voorkomt een lang alarm.
- De verplaatsbare paal maakt het mogelijk om de baby snel naar de moeder te brengen.
- Een handdoek gebruiken om de sensor af te schermen van licht leidt tot betere metingen.

Pijnpunt

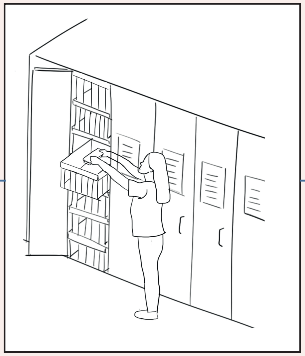
- Er is slechts één paal beschikbaar voor de hele afdeling.
- De verpleegster moet naar twee kamers om de apparatuur voor één meting te halen.
- Het blijkt lastig om de twee zijden van de sensor precies boven elkaar te plaatsen.

Belevenis productgebruik

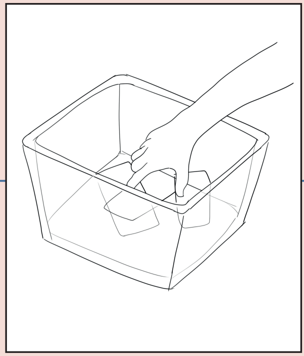
Verloskunde - 2C

Scenario productgebruik

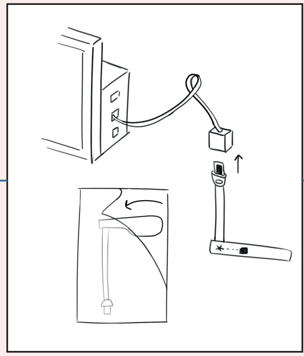
Sensoren pakken



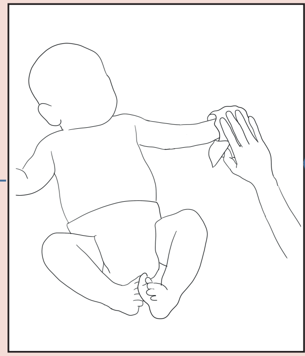
Bak hervullen

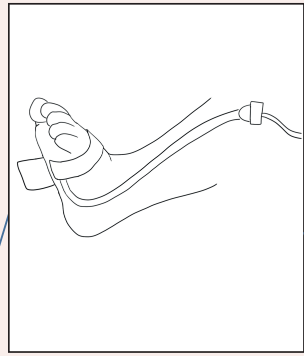


Uitpakken en aansluiten

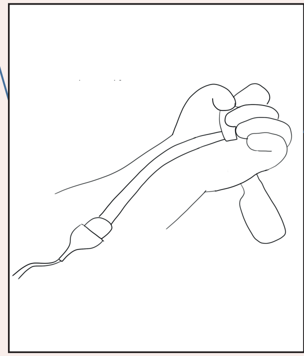


Hand of voet afdrogen

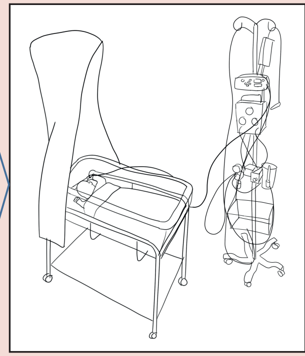




Sensor bevestigen



Controle meting



940 stuks

Gaat goed

Zorgassistenten vullen de bak bij, waardoor verpleegkundigen tijd besparen.

De sensor blijft beter plakken op een droge huid, waardoor er minder sensoren nodig zijn.

Pijnpunten

Als er geen sensor in de bak zit, kan de verpleegkundige de baby niet alleen laten en is er hulp nodig.

Veel wegwerp producten zitten door elkaar, waardoor het lastig is om de sensor en de stickers te vinden.

Het blijkt lastig om de twee zijden van de sensor precies boven elkaar te plaatsen.

Bij metingen aan de hand én de voet worden twee sensoren gebruikt, wat leidt tot extra verspilling.

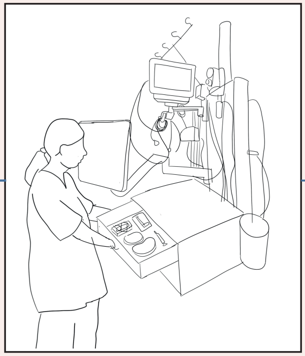
De vaak slechte meting direct na geboorte leidt tot het gebruik van een extra sensor.

Belevenis productgebruik

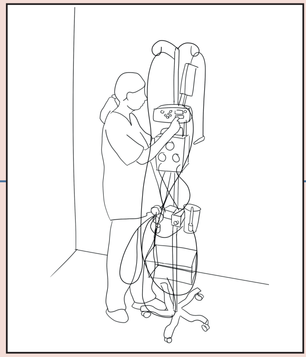
Neonatologie - 2D

Scenario productgebruik

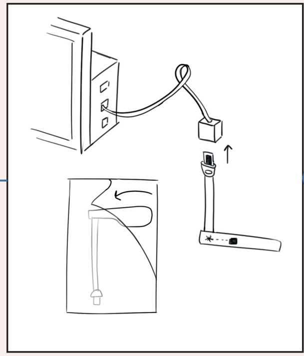
Sensoren in lade bijvullen

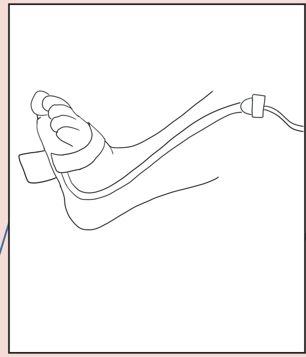


Eventueel paal pakken

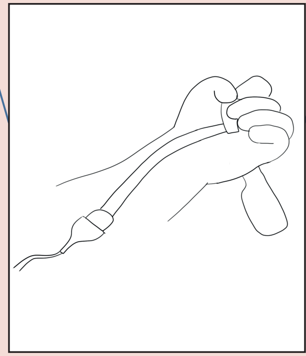


Uitpakken en aansluiten

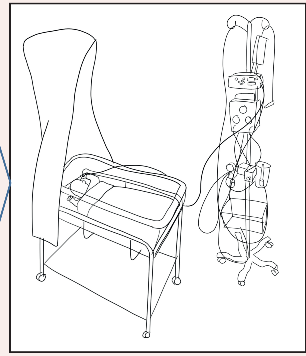




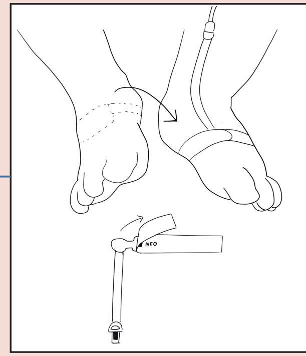
Sensor bevestigen



Continue monitoring



Wisselen van voet en sticker



765
stuks

Gaat goed

- Er ligt een foto in de lade met de correcte inhoud als hulp tijdens het bijvullen.
- Er is sinds kort een tweede paal beschikbaar.
- Het naambandje wordt gebruikt om de sensor te beschermen tegen licht.
- Ouders kunnen zelf het bandje van voet wisselen, dit scheelt tijd voor de verpleegkundige.

Pijnpunten

- Er moet zoveel in liggen dat de inhoud vaak niet helemaal klopt.
- Soms wordt er een sensor uit een andere kamer gehaald, waardoor het daar niet meer klopt.
- Soms blijft de sensor met klitteband niet goed zitten waardoor er nieuwe sensoren worden gepakt.
- Er is vaak een storing zonder bekende reden, dan wordt het bandje weggegooid.
- De sticker vervangen is vaak te lastig voor ouders.
- Er is maar één maat beschikbaar van de extra stickers.

Belevenis productgebruik

5.3.1 Main takeaways

Hard application
Nurses find it difficult to place the two sides of the sensor straight above each other. It is even more difficult on newborns as they have greasy wet skin, making the sticker harder to stay in place. Some sensors are already thrown away after failed application due to the sticker ripping or not sticking anymore. When two measurements are needed, both at the hand and foot, an extra sensor is used. Nurses do not want to undo the sticker on the foot, replace it on the hand and then place the sensor back on the foot again, as the application is difficult. Once the sensor is placed correctly on the foot, they want to keep it there and just take an extra sensor for the hand. This leads to an unnecessary usage of sensors.

Broken or not working sensors
Sensors break often when children move a lot. Especially for younger children with the sensor placed on their foot, the sensor breaks often when bent around the sock. Sometimes the sticker also sticks to the glove, leading to a ripped sensor.
At obstetrics a second sensor is sometimes used when the first one does not give a correct measurement fast enough, as measuring is harder for newborns who still have a very low saturation level. Nurses assume it is not the sensor is not working but the baby needing more time to increase their saturation, but doctors often demand the use of a new sensor to be sure.
Also other unknown errors lead to the disposal of the sensor, even though the problem could also be somewhere else. This also leads to an unnecessary usage of sensors.

Sticker changing
The changing of the sticker expands the lifetime of the sensor. However, the connection of the sensor and cable often breaks when the sticker is pulled off. Moreover, only the small type of sticker is available, even though nurses often prefer the wider sticker.

Inefficient storage
Every department has a different way of storing the sensors, stickers and monitor needed for saturation measurements, but each has their own storage issues.

The maternity ward only has one separate pole, which is also stored in a different room than the sensors, which makes the nurse go to two different rooms for just one measurement, see figure 5.6.

At obstetrics, everything is available in the same room, but they use one big box with all reusables mixed together. This is found a bit chaotic and can lead to not having the correct sensor available, see figure 5.8.

In neonatology, everything is stored in a drawer, see figure 5.5. A picture with the needed content is included in the drawer, but as so many things need to be in there, the content is not always correct. If they miss something, nurses take it from a different room, which only shifts the problem.

At the child and youth department they store the sensors, extra stickers and other disposables in the basket of the pole, having the same problem of the needed sensor size not always being refilled, see figure 5.7.

Figure 5.5: drawer with example picture at neotatology

Figure 5.6: storage of sensors and the pole at the maternity ward

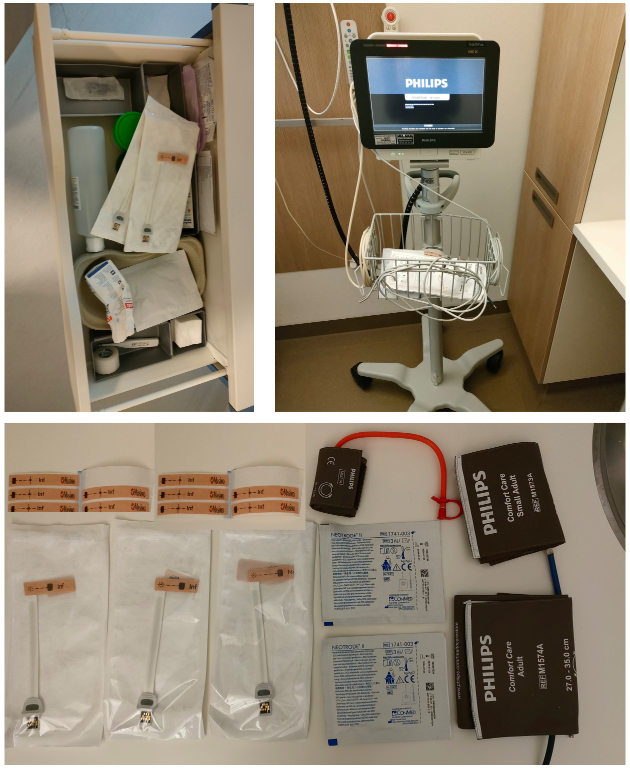


Figure 5.7: sensors and other disposabels stored in the drawer and basket at the Child en Youth department

Figure 5.8: sensors stored in the box at obstetrics

5.4 Conclusion

The research question was: What does the current system for pulse oximeter use look like, and what are its pain points?

The current system for pulse oximeter use in the pediatric departments at Reinier de Graaf Gasthuis is different in each department and in some ways inefficient. Storage methods differ by department and often lead to confusion, missing items, or extra work for nurses. Applying sensors can be difficult, especially on newborns, and broken sensors often result in unnecessary waste.

Sensors are sometimes thrown away not because they're broken, but due to unclear errors or time pressure. Although sticker replacement could extend sensor life, fragile connections and limited sticker options hinder this.

The system for reusable pulse oximeters at the adult departments show different pain-points, like unbreathable materials and lost sensors. To successfully implement reusable sensors at pediatric departments, clear storage organization and involvement of key stakeholders like clinical physics and infection prevention are essential.

Chapter 6 - Co-creation

To explore desired design possibilities, a co-creation session with important stakeholders was organized.

Co-creation is a term that covers a philosophy, method, and mindset of collective creativity (Coddington et al., 2016). The value of co-creation is to identify potential flaws early and create better adapted products with greater acceptance. It also creates a shared understanding and creative solution due to the combined knowledge and multiple disciplines.

In this project, co-creation is used as a method to achieve an understanding of the problem and suitable solutions and to achieve co-understanding among the relevant stakeholders. To successfully implement a reusable pulse oximeter, all relevant stakeholders should be involved in the process.
Each stakeholder has different values and priorities, and they need to get on the same page to start the transition.

6.1 Method

The goal of the session was to validate the outcomes of my research while getting to know more about the different interests and potential conflicts. By discussing this together, a co-understanding could be created among the attendees. After getting to know the current process, the goal was to collect their wishes and ideas for improvements for the current scenario and a possible reusable pulse oximeter.

The session was held on site at RdGG and lasted for one hour. There were 8 people present, all at some point, involved in the process of the current disposable and/ or the possible future reusable pulse oximeter.

The present stakeholders were:

- Pediatric nurse
- Infection prevention
- Medical instrumentation
- Sustainability coordinator
- Clinical physicist

In addition to these RdGG staff members, another student working on the transition to reusables participated and a researcher was observing the session.

Figure 6.1: The set-up of the co-creation session

The materials used for the session were post-its in different colours, pens to write and user journey maps printed on A2. All participants were Dutch speaking, so the session was held in Dutch. The post-its created during the session were also written in Dutch, but translated for this report.

6.2 Process

After a short introduction, the session began with an icebreaker. Each participant was asked to think of what would be most important to the person sitting next to them in the transition to reusable pulse oximeters. This perspective shift was intended to encourage them to think about the bigger picture and the different interests of those involved. Participants then shared what they thought mattered most to the other person, followed by that person revealing what was actually most important to them. Besides being an icebreaker, this activity was a first step in building co-understanding. The ice-breaker took about 10 minutes.

Next, the poster from the Child & Youth Department was presented, and participants were asked to respond to its findings. For the first exercise, each participant wrote on an orange post-it what they believed could be made more efficient, and on a green post-it what could be made more sustainable. The main goal was to gain a deeper understanding of the problem and explore suitable solutions.

This exercise took about 15 minutes.

Then, I showed the participants the current options for reusable pediatric pulse oximeters and asked them to write on blue post-its what they saw as specific barriers to implementing these options at present.

We then reviewed and discussed the post-its together, focusing on how those barriers might be addressed. This activity took approximately 10 minutes.

As a final 10-minute exercise, participants compared the different departments by reviewing the other three posters. They discussed differences and considered what they could learn from one another. This activity helped generate ideas that could apply across departments and created an opportunity for shared understanding between them.

6.3 Findings

Figure 6.2 shows all the post-its created during the session, categorized by theme: orange for ideas to improve efficiency, green for ideas to improve sustainability, and blue for perceived barriers to implementing reusables. Multiple reusables options were shown in the session, and some post-its refer to a specific option, indicated with the dotted line.

During the session the different values and priorities of the stakeholders were visible. An overview of the values of the stakeholders can be found in figure 6.3.

Most discussions and ideas were about storage, sensor-specific improvements, the packaging, cleaning and the whole procedure. A summary is shown in figure 6.4.

	Option 1		Option 2		Option 3		Option 4	
Types of (partly) reusable pulse oximeters shown in the session								
Mentioned **barriers** for reusables	Hard to yearly check stock	Adhesive of sticker looks hard to remove (1&2)	Looks hard to stay in place (2)	Looks hard to attach and prone to error (2)	Has to measure correctly, stay in place and easy cleanable	Does not fit and is not comfortable (3)	Does not look comfortable and able to stay in place (4)	Can lead to pinching when applying (4)
	Sensor should be well secured for good measurements	Sensor should be comfortable	Should be washable material	Cable should not pull at the sensor	Maintenance should be arranged	Extra time is needed for cleaning	What is the process, costs and environmental impact of cleaning?	
Proposed solutions for **efficiency** of pulse oximetry	One type of sensor in the whole hospital (3x)	Improve their quality	Clear color coding for each type of sensor	Refill stock the moment a patient is discharged with checklist	Better storage in the room: always a sensor and clear how many there are in stock	Make it easier to apply the sensor and change the sticker	More options for stickers, different sizes	Already applying the sensor at SEH
Proposed solutions for **sustainability** of pulse oximetry	Reusable sensor (2x)	Buying in bulk	Using the sensor longer with a new sticker	Reducing packaging (3x)	Look at the whole procedure, like reducing the number of gloves used	Replace the weakest spot of the sensor with something like a sock	Delivery without stickers and packaging, using color coding	Using less sensors per patient, make sure they don't break

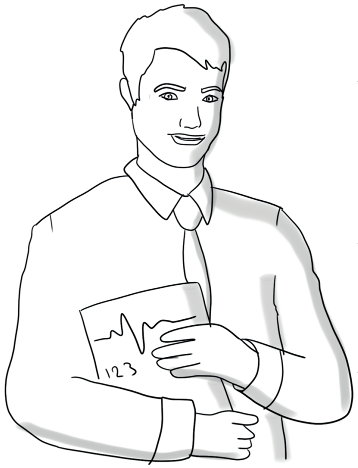
Figure 6.2: The post-its created during the session

"I want longer or no cables to reduce false alarms."

Pediatric Nurse

- We only get one product, we don't know what is available
- Should be easy cleanable, assistants don't have a connection with the child
- Comfort of the child is important, removing the sensor right after application is painful.
- Stock should be well organised and no sensors sticking to eachother.

"I think it is crazy how often these things break."



Clinical Physicist

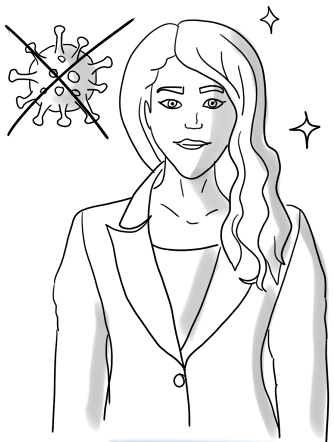
- The sensor should give reliable results and have a CE certificate
- I want cleaning with alcohol, microfibre damages the material
- Cheaper if we reduce the use of oximeters

"We should look at the whole procedure."

Sustainability coordinator

- Are there any unnecesarry actions in the process?
- Reduce the size of the packaging, add a QR-code for product information.
- Find a way to motivate staff to clean the product.

"It does not have to be sterile, why is it in this packaging?"



Infection Prevention

- Some things you can't clean 100%, make sure they do not put it in their mouth.
- Should be dust-free if stored without packaging
- I want staff to clean it with microfibre
- The adhesive makes the sensor dirty and uncleanable

"Quality is key: to measure is to know."

Medical Instrumentation

- We want unity in the whole hospital
- The two sides of the sensor should be right above each other for good measurements.
- Ideally, there should be no separate parts
- We can test reusables when they doubt the working, disposables are thrown away 'just in case'.

Figure 6.3: An overview of the values of the stakeholders

Sensor-specific

- Make it less painful for the child to detach the sensor

- Make sure the cable breaks less often to reduce usage per patient.

Procedure

- Reduce unnecessary use of towels and gloves. Towels are used to block the light for better measurements, even though clinical physics mentioned this has no effect as IR light is used in the sensor.

- Create unity by using the same type of sensor everywhere, look at the type of sensor in ambulances

Storage

- Better organising to keep the available products clear

- Color coding the sensors to recognize the different sizes and types faster

- Buying in bulk and storing the sensors without individual packaging

Packaging

- Make the packaging smaller. Use QR-codes if the information on the packaging does not fit anymore.

-Not using packaging at all as it is a non-sterile product. Maybe show the needed information somewhere else.

Cleaning

- Make the sensor an extension of the cable to make cleaning easy.

- Make it clear to nurses when a sensor is cleaned by assistants.

Figure 6.4: a summary of the generated ideas, divided in five categories

6.4 Conclusion

The co-creation session led to the first step toward a shared understanding among the involved stakeholders. For example, the infection prevention learned from the nurse about the number of sensor changes per patient, while the clinical physicisist was shocked about the quick breaking of the sensors. Meanwhile, the nurse learned about the myth of using a towel to block the sensor from light for a better measurement.

Valuable input was collected regarding improvements to the current scenario. Most ideas focused on improving storage systems, sensor durability, packaging, cleaning processes, and the overall workflow. Suggestions such as color coding, clearer organization, minimizing unnecessary packaging, and standardizing sensor types were mentioned.

The values of the stakeholders differ slightly. The medical instrumentation values unity and the ability to test the sensor, while clinical physicists are more focussed on a good combination of reliability and cost. Infection prevention wishes the sensor to be dust-free and easy cleanable, the nurse also values fast access and organized storage.

Chapter 7 - Design direction

Based on the results of the co-creation session from chapter 6, along with the analysis from chapter 5, circular design opportunities were identified. The chosen design direction for this project is then defined, answering the third research question: What intervention is needed to overcome the most significant barriers and ensure a seamless transition?

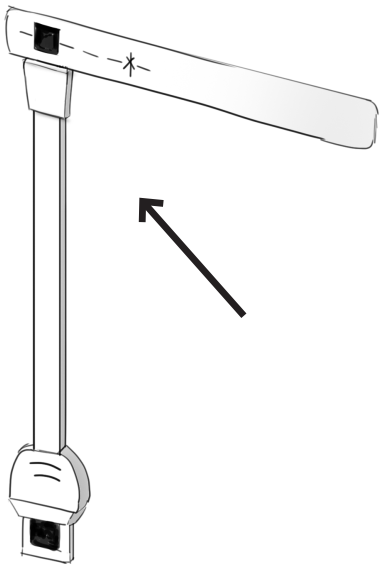
7.1 Opportunities to reduce

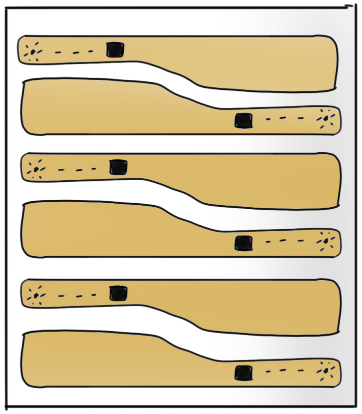
1. Reducing the amount of broken sensors.

By fixing the cable and making it more robust, the cable will be less likely to break. This can for example be done with a strain relief, a more round shaped cable or a less heavy coupling piece. A more robust design will also prevent the sensor ripping when the sticker is changed.

2. Increasing the usage of extra stickers.

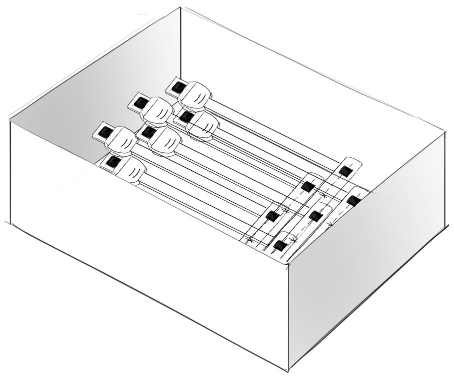
Introducing an extra size sticker makes it more attractive to use the stickers instead of extra sensors. Using the theory of nudging can increase the usage of stickers as well, for example by placing the sticker more upfront then the new sensors.

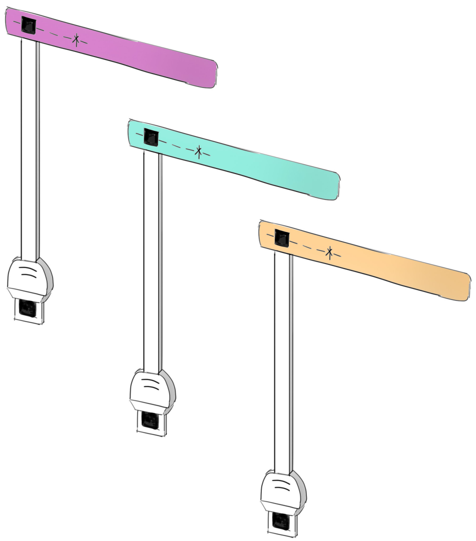




3. Reducing packaging

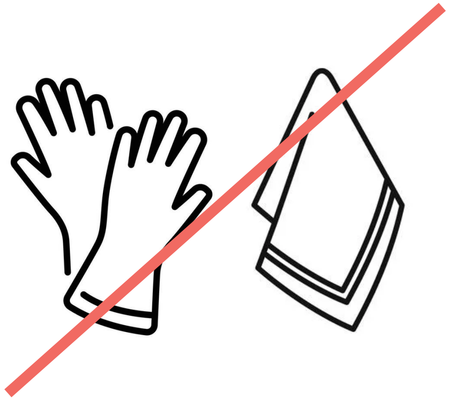
This can be done by placing more sensors in one packaging as it does not need to be sterile. Buying and delivering the sensors in bulk makes it also cheaper. Clear color coding is needed to see the differences between the sensors. This could be done by making the whole sticker in a different color, which also makes it more cheerful for the children.

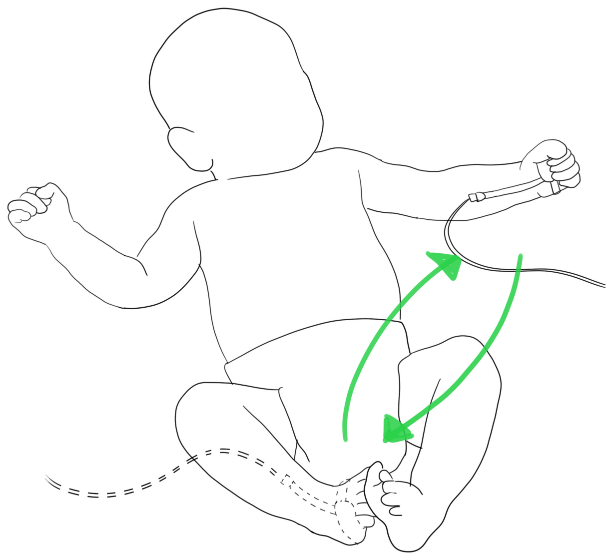




4. Informing nurses on unnecessary use of towels, gloves and extra sensors.

Informing nurses on unnecessary use of towels, gloves and extra sensors. The changing of the sensor does not need to be done with gloves on, while especially at neonatology this is standard done with gloves. Towels are used to protect the sensor from light, while this is not helpful as the sensor only uses red and infrared light. This is an old habit that is still part of their workflow. Resticking the sensor if a different placement is needed, like going from foot to hand, can also reduce the amount of sensors used.

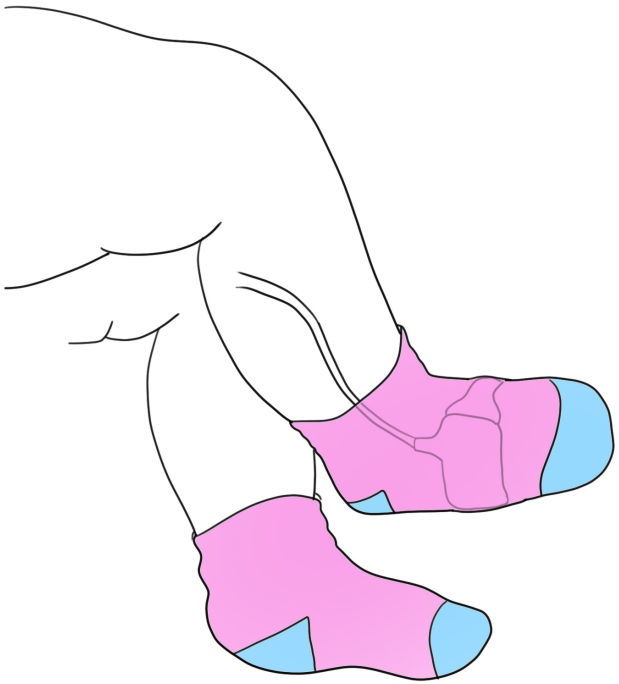




7.2 Opportunities to reuse

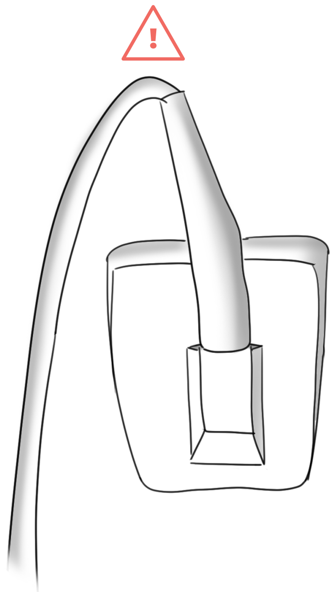
1. Redesigning the reusable pulse oximeter to be more child friendly

The probes for the finger should be adjustable in size, as the size of children's fingers differ a lot. A more breathable material is also preferred. The probes for the foot of an infant should be made more comfortable and smaller to be able to place it under a sock. When the oximeters are designed to be more child friendly, nurses are more likely to choose a reusable option.



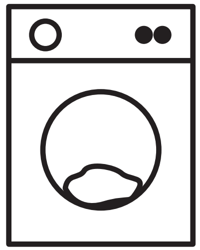
2. Increasing the lifetime of the reusable pulse oximeter

More than 50% of the fully and partly oximeters break at the cable (Crede et al., 2013), just like the disposables. By strengthening this weakest point, reusables can last longer. The lifetime can also be extended by avoiding pulling the cable at the probe and by improving storage conditions (Crede et al., 2013). The reusable could even be redesigned to be modular with the option to replace the wires. Cable clutter should also be avoided to reduce entanglement between different cables, which also creates a safety risk (Poncette et al., 2019).



3. Using reusable microfiber cloths with water for cleaning

Reusable microfiber cloths could be a step for the future to decrease the impact of saturation measurements even further. It is already proven that reusable microfiber cloths clean no less than disposables (Smith et al., 2011).



4. Designing a suitable context for a (partly) reusable sensor

The partly reusable sensor should be implemented at the obstetric, maternity and neonatology department as the current fully reusable designs will not fulfill the wishes of nurses. The context should be made suitable for both the partly reusable sensor and the disposables, as it is expected that in some cases a disposable is still needed. The storage should be designed to protect the sensors to last as long as possible, while nudging nurses towards using the greener option when possible. The barriers of caregivers towards reusables should be taken into account, like making it clear when a sensor is cleaned.

7.3 Conclusion

Redesigning the disposable or reusable sensor will not be feasible for this project. The client Reinier de Graaf Gasthuis wants to reduce their waste and impact as soon as possible to reach the green deal 3.0, while it takes several years before a redesigned medical product can be implemented in a hospital. Moreover, a collaboration with Nellcor would be needed in order to go further than just concepts of redesigns. Therefore, to answer reasearch question 3, a solution that can have immediate impact is best. The identified opportunities for improvements of the disposable sensor, redesigns of a fully reusable sensor and changes in packagings are recommendations for the manufacturers, but will not be further elaborated on. The focus for this project, will be on designing a suitable context for a partly reusable pulse oximeter in order to accomplish a seamless transition towards a more sustainable way of saturation measurements at the children's departments.

7.4 Design goal

“To design an intervention for safe and efficient storage conditions for a partly reusable pulse oximeter, with a focus on encouraging sustainable behaviour of healthcare workers, in order to accomplish a seamless transition towards a more sustainable way of saturation measurements at the children's departments at Reinier de Graaf Gasthuis.”

Concept development

Chapter 8 - Choosing the most suitable sensor

For a suitable storage solution, the specific characteristics of the sensor must be taken into account. In this project, the focus is on implementing the hybrid Oximax Dura-Y D-YS sensor by Nellcor. This chapter explores attitudes toward the sensor, highlights specific challenges associated with its use, and provides recommendations for improving the sensor to increase its chances of adoption.

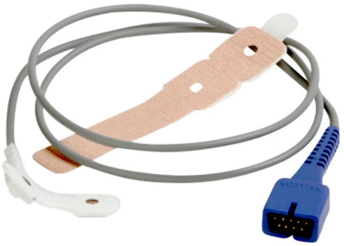
8.1 Why this sensor?

As explained in chapter X, a fully reusable sensor for children under 2 years seems to be hard to realise with the currently available products.

8.1.1 A hybrid sensor
The most impactful part of a pulse oximeter is the electronics: the wire, the connector, the light emitting diode and the photodetector. With a hybrid sensor, these electronic parts are reusable.

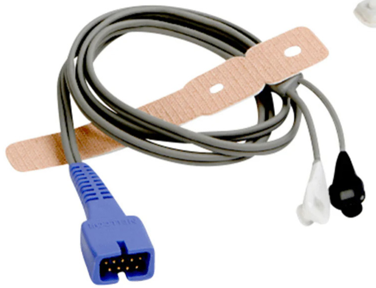
The disposable sticker has a relatively low environmental impact, while largely improving the usability of the sensor. The sticker has the same advantages as the current disposable sensor: it ensures comfort for the child and prevents pressure points, while making sure that the sensor stays in place, limiting the amount of false alarms.

8.1.2 The D-YS sensor
As all children departments will switch to Nellcor, a matching sensor is chosen. Nellcor has three options for hybrid pediatric pulse oximeters, shown below.



OxiMax SpO2
sensor A/N

OxiMax SpO2
sensor P/I



OxiMax SpO2
Dura-Y D-YS

The choice for the dura-Y D-YS has been made as this is a multi-site sensor, suitable for all patients weighing more than 1 kg. The A/N is only for <3 or >40 kg patients and the P/I for 3-40 kg. As all children aging 0 to 17 are treated at the Child and Youth department, switching between the different sizes would be necessary. To avoid this hassle, the dura-Y D-YS has been chosen.

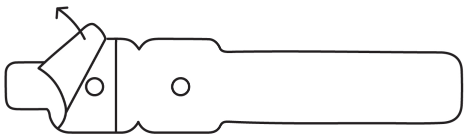
8.2 Working of the D-YS sensor

The sensor needs to be attached to the cable of the 'broodje'. No extra adapter is needed once the departments are transferred to Nellcor. There are four different stickers available for this sensor, shown in figure 8.1. Depending on the patient's weight, one of the two sizes of stickers should be used. For children weighing less than 3 kg or more than 40 kg, the wider sticker is best suitable. For children weighing between 3 and 40 kg, the thinner stickers can be used. Both sizes of stickers are available in a plaster-like material and in a softer foam material. The ladder is designed for sensitive skin. After use, the sticker can be removed from the sensor and thrown away. The sensor itself can be cleaned with 70% alcohol and be reused on other patients.

Figure 8.1: types of available stickers

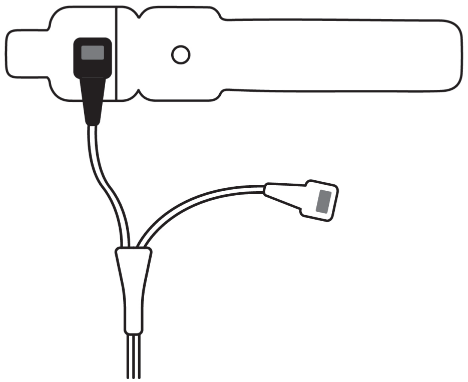
The small piece of paper at the back of the sticker can then be removed first (1).

1



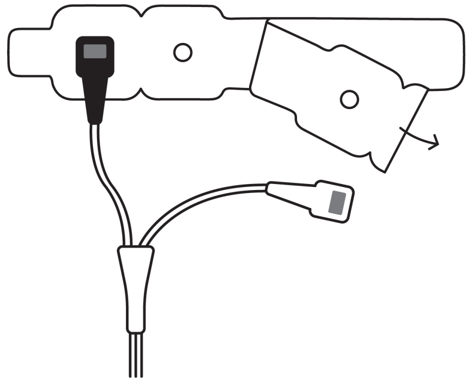
The black sensor pad should be pushed through the hole in the sticker first (2).

2



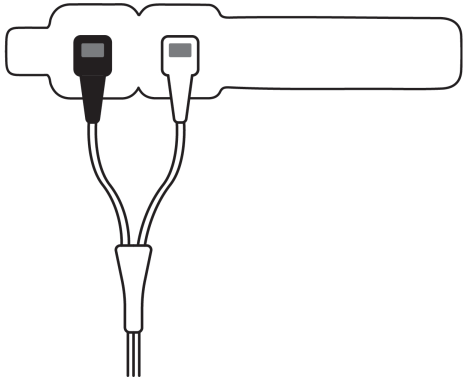
Then the remaining of the paper can be removed (3).

3



The white sensor pad can then be pushed through the second hole (4).

4



The sensor is now ready to attach to the patient. When placing the sensor on a finger or toe, the white end should be on the nail side. The black end should be positioned directly opposite of the white end. The cable should be positioned along the side of the foot, toe, hand or finger.

When the sensor pads are positioned correctly, the rest of the sticker can then be wrapped around to secure the sensor properly, shown in figure 8.2.

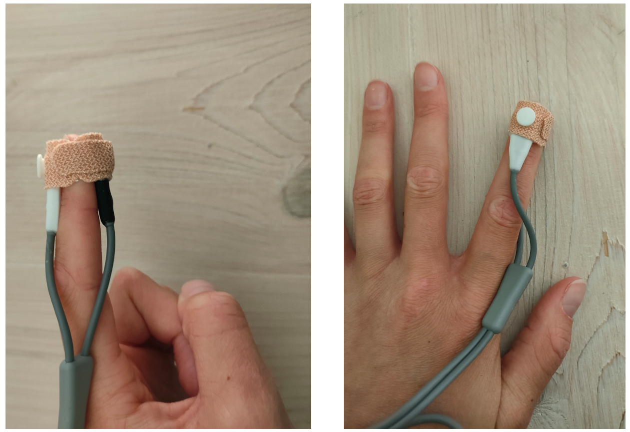
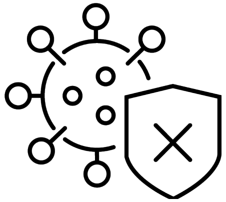


Figure 8.2: correct placement of the sensor

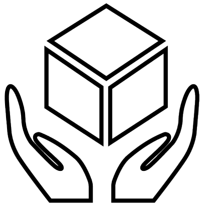
8.3 Challenges

Apart from the already existing challenges in the usage of pulse oximeters, this sensor has its own specific challenges:



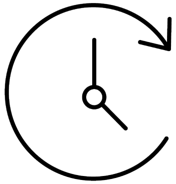
Sticker hygiene

The sensor is delivered with extra stickers, but these are placed together in one plastic bag. A challenge will be to make the stickers easy to grab, without infecting the other stickers.



Material protection

The reusable pads are made out of a soft silicone, to not harm the patient. However, once the sensor is severely damaged, it can become uncleanable and thus unusable. A challenge will be to protect the material from scratches to ensure a long lifetime.



Time of assembly

Lastly, a few steps are needed to assemble the sensor before use, unlike the ready-to-go disposable. A challenge will be to, despite the extra time needed, make the reusable sensor more desirable than the disposable.

8.4 Attitude of healthcare workers towards the sensor

In order to make the staff members of Reinier de Graaf Gasthuis familiar with this hybrid option, I showed multiple stakeholders this pulse oximeter and let them interact with is, shown in figure 8.3. Apart from creating awareness, the likeliness of adoption has been investigated and some design improvements are suggested.

Figure 8.3: Testing the user-friendliness of the sensor with nurses

An often mentioned barrier in the earlier interviews was the hygiene of reusable sensors. Attitudes toward the cleanability of this hybrid sensor were generally positive. Although the sensor includes some small components, the flexible material makes it easier to clean around the edges.

"The ends are so flexible that it will be very easy to clean"

Some concerns were raised about the cable, which consists of two cylindrical parts, as dirt could accumulate in the groove between them. One stakeholder even considered the hybrid sensor safer, as the less adhesive stickers are less likely to damage the skin, reducing infection risk.

"I think it will lead to less infections, as this sticker is less likely to damage the skin."

Views on how easy the sensor is to use were mixed. Everyone agreed it's harder to apply than the current disposable version.

"We often work in the dark, it will be fiddly to apply the sticker."

For some, this was a big problem, especially in emergency situations. Others were open to using it, as long as it stays in place once applied.

"It is a little more work, but I would do it if it would stay in place."

Patient comfort was also a point of discussion. Some didn't believe the sensor would be suitable for very small babies.

"The sensor is too thick and long for the smallest babies, it will be a bigger burden for them."

Others thought the soft material made it more comfortable and child-friendly.

"It feels even softer than the disposables"

8.5 Conclusion

Staff involved in the process around but not working with the oximeter are positive and willing to try. These people working in the office of Reinier see the environmental advantages and the practical possibility of implementation.

The opinions of nurses working closely with the pulse oximeter are divided. A big difference in attitude is seen between nurses who joined the green team and those who did not. When implementing the D-YS sensor, nurses should be nudged towards reusable when intern motivation to switch is low.

The department managers have the final say in which sensors are ordered for their department. As the manager of the Child and Youth department is currently not willing to get involved with this hybrid sensor, further testing should be done to provide her with positive outcomes.

When designing for the storage of the sensor, the challenges of contaminating other stickers, damaging the soft material and the extra assembly time should be taken into account.

8.6 Recommendations

As attaching the sticker to the sensor takes time and nurses sometimes have busy hours, it would be ideal if the sensor was pre-installed. Care assistants are already making the room ready for a new patient and do have time to pre-assemble the sensor. With the current sticker design, the paper can not be removed after assembly. I would recommend making a small cut in the paper to make pre-installation possible, shown with the dotted line in figure 8.4.

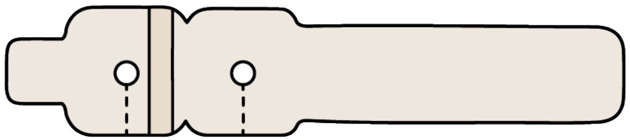


Figure 8.4: Design recommendation for the sticker to make pre-assemble possible

Since nurses are very carefull to prevent cross-contamination, it is important to design the sensor for easy cleaning. Currently, the cable consists of two round wires placed side by side, creating a slit where dirt can accumulate. To improve hygiene and simplify cleaning, a smoother cable would be preferable, shown in figure 8.5.

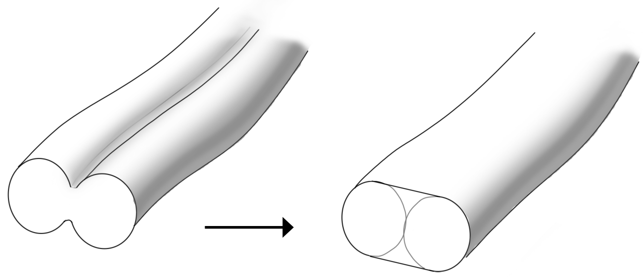


Figure 8.5: Design recommendation for the cable to improve cleanability

Chapter 9 - The design process

To achieve a well-fitted solution aligned with the design goal, an iterative design process was carried out. This began with making a list of requirements, followed by repeated cycles of ideation, prototyping, and testing, which gradually shaped the final design.

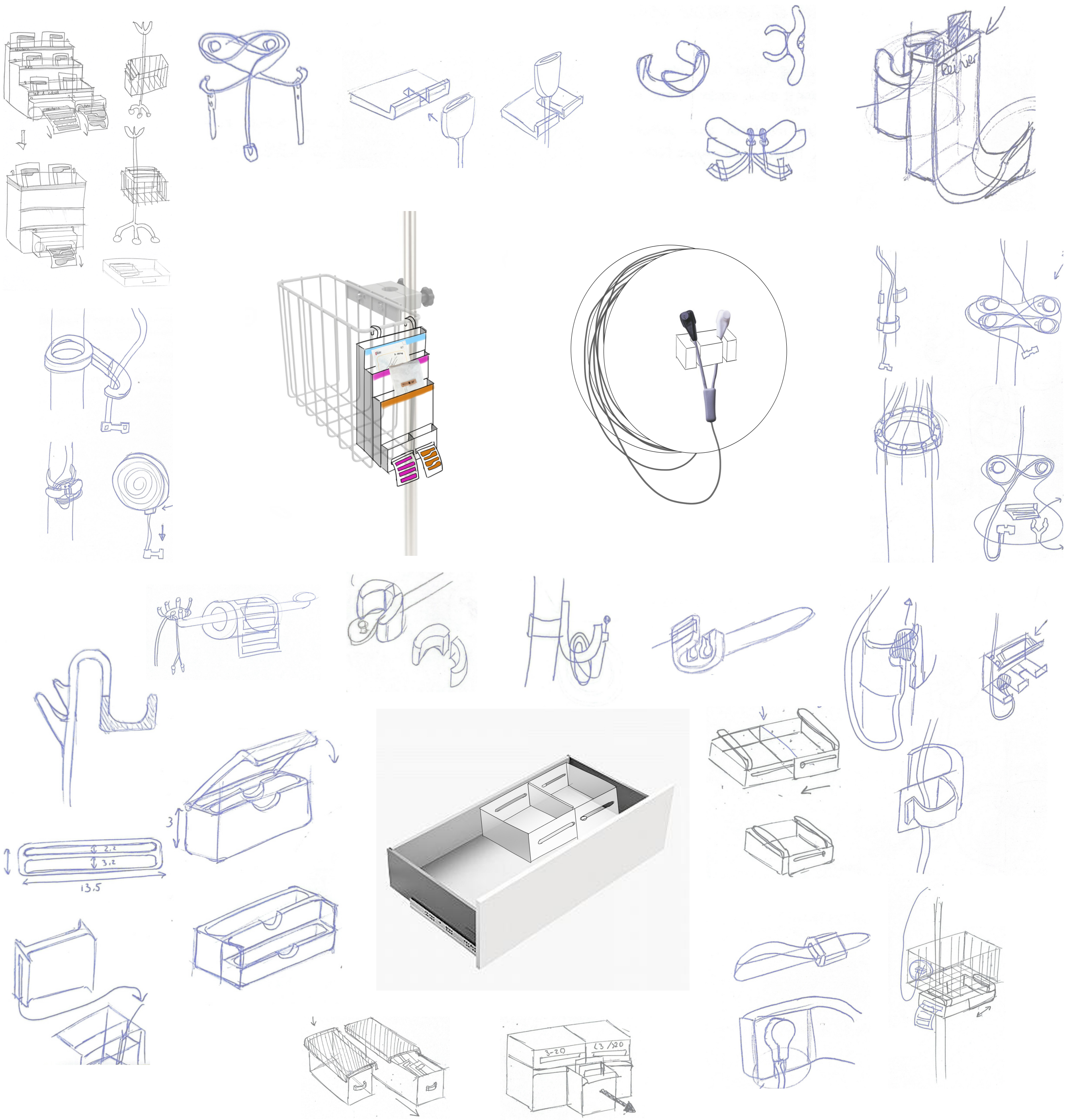
9.1 List of requirements

To guide a focused ideation process, a list of requirements and wishes was first created from the insights of the previous chapters

1. It should be possible to store the hybrid sensor in every room of all four pediatric departments
2. The storage method should not damage existing equipment in the rooms.
3. Disposable sensors should always be available in the patient room as a backup
4. The different sizes of stickers should be clearly recognizable in 2 seconds
5. It should be clear in 5 seconds which stickers and sensors need to be refilled
6. Storage design should clearly encourage the use of extra adhesive stickers over opening a new disposable sensor by making stickers more visible or faster to reach.
7. The soft silicone ends should be protected so that no visual damage is present after 50 uses.
8. The hybrid sensors should be stored in a way that avoids mechanical stress on the cable, ensuring that 90% still function after 5 years.
9. Cable clutter from the hybrid pulse oximeter should not occur more than once every 10 uses.
10. Cable entanglement of the pulse oximeter with other cables should not occur more than once every 50 uses.
11. When stored, used and clean parts should not be able to touch each other
12. It should be possible to grab a sticker without touching more than one other sticker
13. The stickers should not be stored in the open air for more than 24 hours.
14. The reusable part of the sensor should be cleanable with microfibre or 70% alcohol.

Wishes

1. It should preferably not take more time to get the needed equipment for saturation measurements than it does currently, so less than 30 seconds (excluding maternity ward).
2. Staff should be encouraged to use the hybrid sensor through environmental design based on nudging principles.



9.2 Concept development

9.2.1 Ideation

In the first design phase, several directions were explored, such as keeping the cable in place to reduce the number of broken sensors, reorganizing the entire basket that holds ECG and blood pressure materials, or making different sensor sizes easier to find. Low-fi prototypes were made to interact with ideas and easier discuss it with other students.

Later on, the ideation became more focused. The main areas of exploration were: storing the stickers, protecting the probe end, guiding the cable, and attaching the sensor within the room. A morphological chart was created based on these themes, which led to a combination of selected ideas. Another co-creation session, but this time with other students, was done to explore more ideas. The prototypes of this session can be found in appendix D.

The sketches on the left show the ideation process and the different directions explored. The bigger images in the middle were the most promising ideas and functioned as the starting point of further iterations.

9.2.2 Testing in the workplace

A big advantage of doing this project for the hospital, is being able to easily go in the field. Prototypes from an early stage were already tested with the end users in the correct context. This led to valuable insights which could be fastly implemented into a next prototype, which could then be tested again. Testing in the actual use place gave more insights into the workflow of nurses and how this product can and can not fit in.

The first prototype was tested at the Child- and Youth Department. Due to the manager of this department not wanting to cooporate in this project, the later tests have been done with staff at neonatology, the maternity ward and obstetrics.

Figure 9.1 shows some pictures of the inbetween tests. The top left shows a nurse placing the product ment for a pole on her desired place of use: at the front of the basket. The bottom right picture shows have a nurse had rolled up the cable on the prototype, which was way faster and less precise than expected.

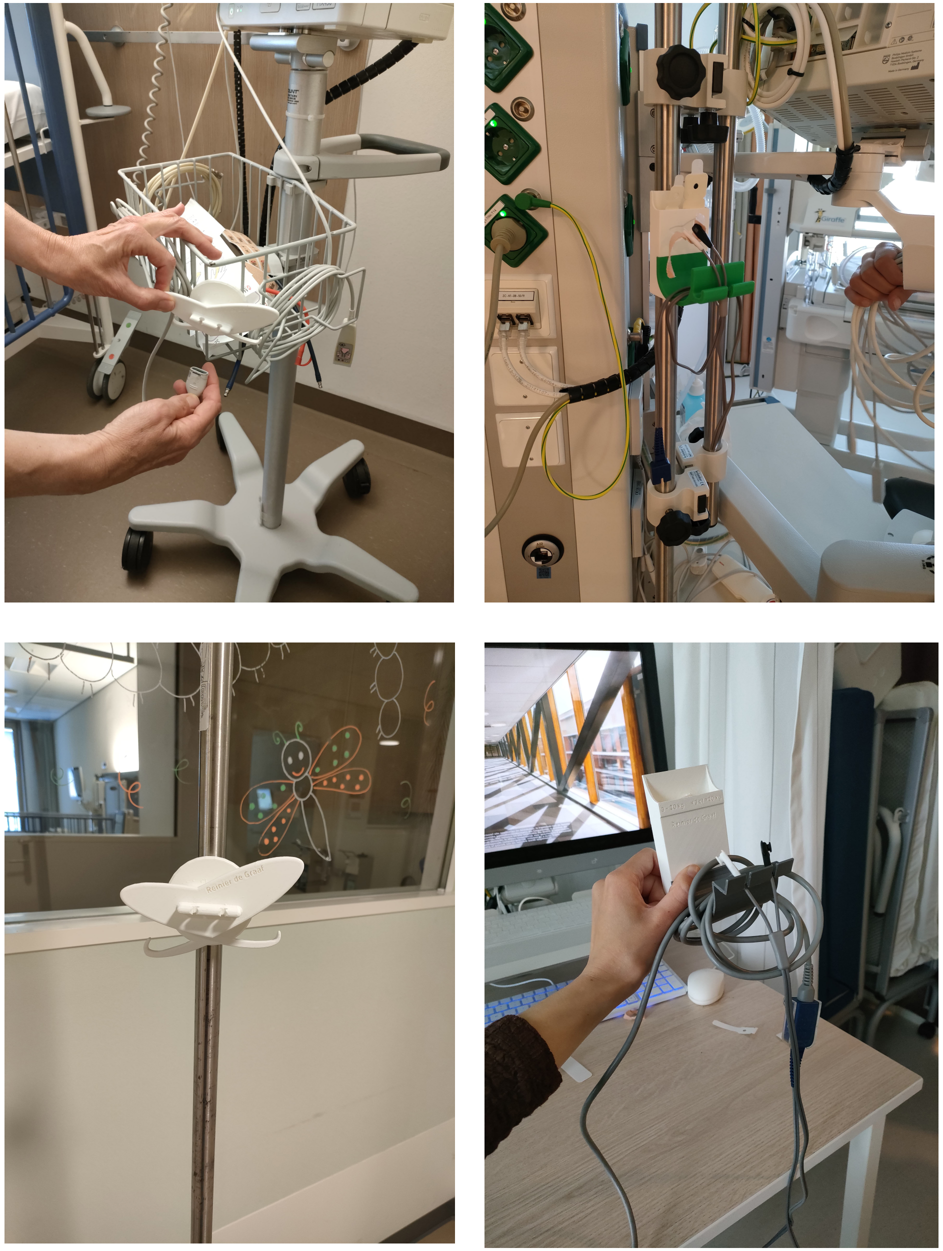


Figure 9.1: Testing different prototypes with nurses

9.2.3 Prototype evolution

Here, the biggest iterations of the different prototypes made for on a **pole** are shown. The negative and positive feedback is given by a combination of hospital workers and other design students.

The stickers are separated from the mess in the basket, so they are easier to find.

The cord needs to be wrapped around the product too many times.

They prefer to wrap the cable around the hand first, which is now not possible.

It does not fit well on the monitor and it is preferred to place it at the front of the basket, using the existing hook.

Hanging the sensor ends looks neat and care assistents will always to it correclty once they see it hang like this.

Very easy to refill and to take one sticker out.

Dirt can accumulate in the engraved letters, which is hard to clean

It takes too much time to securely hang both sensor ends

The sensor hanging looks neat, and once it is seen like this, it is very understandable how to use it correctly.

Very easy to hang the end of the sensor with the big advantage of it never touching the ground or drawer anymore

The container for the stickers is hard to clean, while it does easily gather dust

The clamp on the pole holds the product but it is not tight enough to restrict any movement

The hanging of the sensor is not intuitive enough and it falls out when hung sideways

On this page, some iterations of the different prototypes made for on a **basket** are shown.

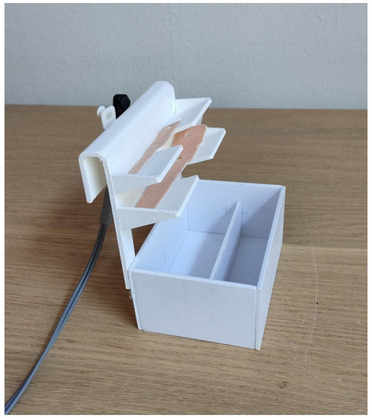
The stickers on the shelves are very easy to grab, this works nicely

The stickers are very well protected and can not fall off

The sensor hanging is done in one movement and matches the other SatuSaver nicely

The opening in the divider of the container reaches all the way to the ground, making the grabbing easier

The shelves and container have very big rounding in the inside, making it possible to easily clean all sides



Stickers on the shelves can fall off too easily, for example when another cable touches it

Stickers in the container are too hard to grab

The shelves are too steep, making them hard to clean

Stickers in the container are easier to grab, but the smaller ones are still too difficult

Sticker on the bottom shelve is hard to see when standing in front of the basket and looking down

The legs connecting the shelves with the container are too fragile

The direction of opening the storage container is not ergonomic

9.3 Choice for the design with the most potential

One product was initially chosen for further development. Once the product with the most potential is finalized, it can be used and tested in part of the pediatric care unit. Later, the other products can be finalized and adjusted based on feedback from the product already in use. This approach allows for a step-by-step transition, reducing initial costs and enabling implementation to begin with the easiest transition. It also helps to gain early support before implementing it across all departments.

The decision was made to continue with the pole-mounted product for multiple reasons:

1. This prototype was found to be more pleasant to work with during tests with nurses, meaning fewer design adjustments are needed before final production.

2. The product for on the basket was mainly designed for the Child and Youth department. However, the manager of this department was currently unwilling to cooperate with testing. As the other departments were more enthusiastic, a bigger potential is seen there. The clinical physics also assumed that especially the Neonatology and Obstetrics would be most willing to cooporate, as in these departments there have not yet been pilots with new pulse oximeters. If departments are more open to trying it, the chances of the product being successfully adopted, and actually making an impact, are higher.

3. The pole-mounted product can be used in three departments. Their combined use of disposable pulse oximeters last year was slightly lower (1,925 sensors) than that of the Child and Youth department (2,320 sensors). However, usage in the Obstetrics department is expected to increase largely due to a new protocol requiring the saturation of every newborn to be measured. This will lead to an increase of approximately 3,000 additional sensors per year, resulting in a much higher usage and thus environmental impact.

By choosing the pole-mounted design, the time required to finalize the product is shorter, the likelihood of adoption is higher, and the potential reduction in disposable pulse oximeter use is higher.

9.4 Design refinement

After choosing the pole-mounted design, another iteration was done to optimise the product. The main pain points to address were: the difficulty of cleaning the sticker storage, slight movement of the product on very smooth pole surfaces, and the unintuitive way of hanging the sensor end. For these three issues, different solutions were prototyped and tested with other students.

9.4.1 Cleanability

To improve the cleanability of the sticker container, all corners should be reachable with a finger. Stickers could also be stored differently, for example in another orientation or location. However, placing them behind the hook remains the safest option, considering the action of hanging the rolled-up cable. Additionally, a vertical orientation feels more intuitive and takes up less space.

Therefore, three small adjustments were made, as shown in Figure 9.2. In the left prototype, the front of the container is made very low to allow better access to the bottom. In the middle prototype, the container is deeper, and the sticker separator is only placed at the top. In the right prototype, the container is also deeper and includes a cut-out at the bottom front to improve access to the container's bottom.

The right prototype was still found difficult to clean. The middle prototype was chosen, as it was found to be the easiest to clean while also keeping the stickers better in place than the left prototype.

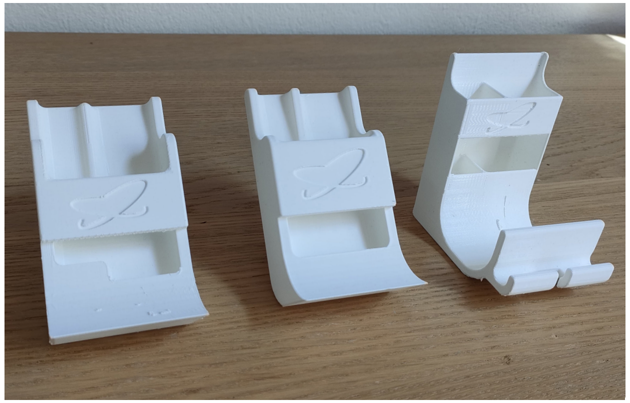


Figure 9.2: Prototypes for better cleanability

9.4.2 Attachment to the pole

To securely attach the product to the pole, three suitable options were prototyped. The first option was to simply make the clamp tighter, but with a flared opening to allow easier placement, shown on the left in figure 9.3. The second option was to insert a rubber part on the inside of the clamp to increase friction. Lastly, a nut and bolt could be used to further tighten the clamp, shown on the right in figure 9.3.

With the first option, the clamp could still move slightly. The second option, using a rubber insert, would improve grip but reduce recyclability. Therefore, the final choice was the third option, using a nut and bolt for secure attachment.

9.4.3 Intuitive sensor hanging

To make it more intuitive to hang the sensor in the correct position and orientation, visual user cues were introduced.

Figure 9.4 shows three prototypes. The one on the left was found to be the clearest in terms of user guidance. However, it reduced cleanability and negatively affected the shape of the hook. The right prototype included a grey inside to indicate where the grey part of the sensor should be placed. In practice, this was not noticeable enough and would complicate the production process.

The middle prototype also has a subtle guide for the thicker part of the sensor, but in a smaller form. This maintained cleanability while still hinting the correct usage. Therefore, this prototype was selected as the most suitable. Additionally, the hole was made tighter, ensuring that the sensor can only be hung in one specific orientation.

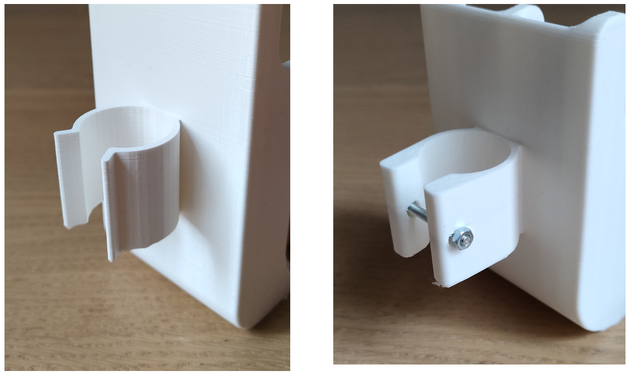


Figure 9.3: Prototypes for better attachment on a pole

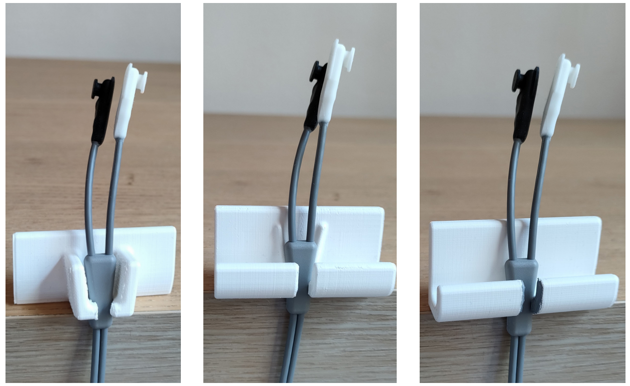


Figure 9.4: Prototypes for a more intuitive way of sensor hanging

9.5 Form study

The final form of the products was developed through an iterative process. First, the practical requirements were implemented. Then, ideation focused on finding the most suitable shapes for the products. The goal was to create a design that feels like one complete product, instead of separate functions combined into a single item. The design should also look safe and child-friendly, while fitting in a clinical environment
The form study began with the SatuSaver for the pole.

Later, the designs for the basket and drawer versions were developed to match the same look and feel, creating a sense of unity across all versions.

9.5.1 Form variations

First, a form study focused on one of the SatuSavers. The aim was to find a balance between clinical and child-friendly, by looking safe, approachable, and professional. It was also important for the design to look visually appealing, showing that sustainable solutions can also be attractive.

The products should not feel like an obligation, but rather something departments are proud to display in their rooms.

An 2D study was first done to find a silhouette, see figure 9.5. A larger material thickness was chosen for the hook, staying consistent in its entire form. This thicker material in combination with the large roundings show a friendlier and more approachable appearance. However, the hook no longer visually matches the back of the product. Moreover, the cleanability of the design is not optimal.

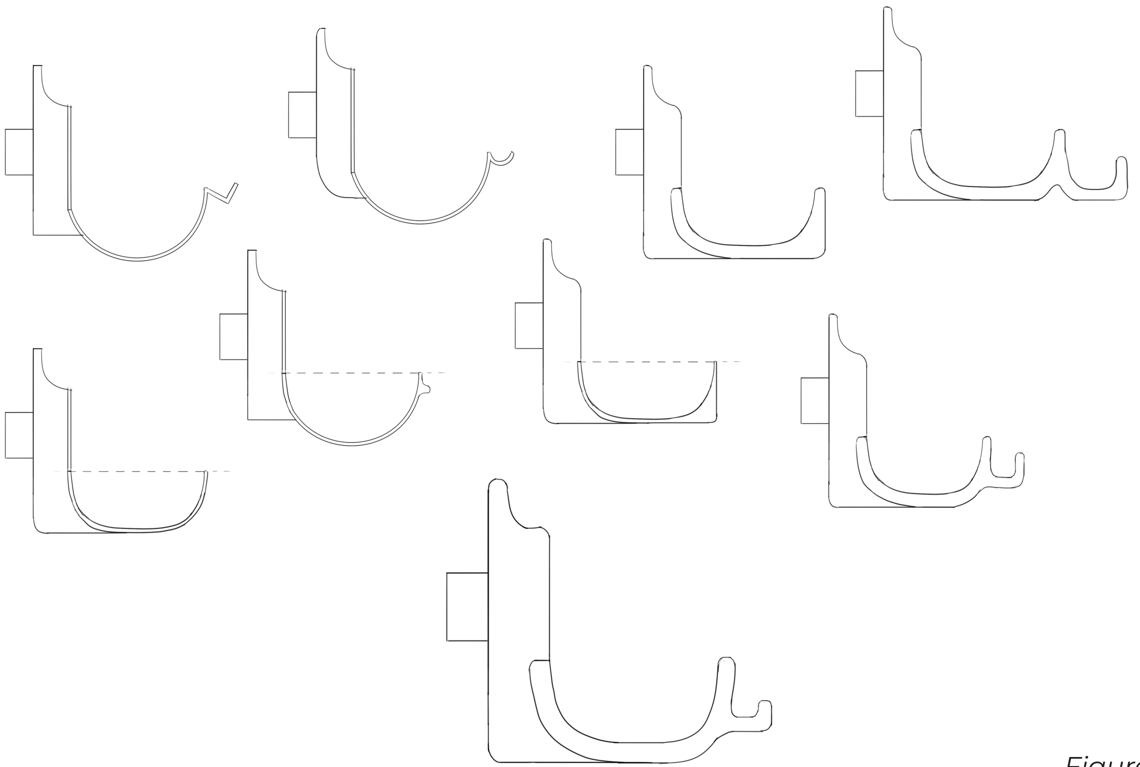


Figure 9.5: A 2D form study on the silhouette

To find a more suitable form, different variations in 3D were explored, shown in figure 9.6. The stickers are still placed vertically, as this orientation feels more natural when grabbing a sticker from the product. The thickness used in the hook is now consistently used in the back part as well. Large roundings are used on every corner of the front side of the product, while only small roundings for safety are used on the left and right sides.

A balance between aesthetics and cleanability was achieved by making the back part deeper, allowing easier access to the interior and better aligning with the robust feel of the hook.

The sticker separation is placed only at the top, aligning with the side of the product to create a calm look, while making cleaning of the bottom easier.

The stickers are slightly tilted to help them stay in place, while the outer form of the product stays straight, for a cleaner and more visually pleasant form. The height is similar to the length of the product for a balanced feeling. The white colour and rounded edges make the product still look clinical, and the logo creates a professional feel.

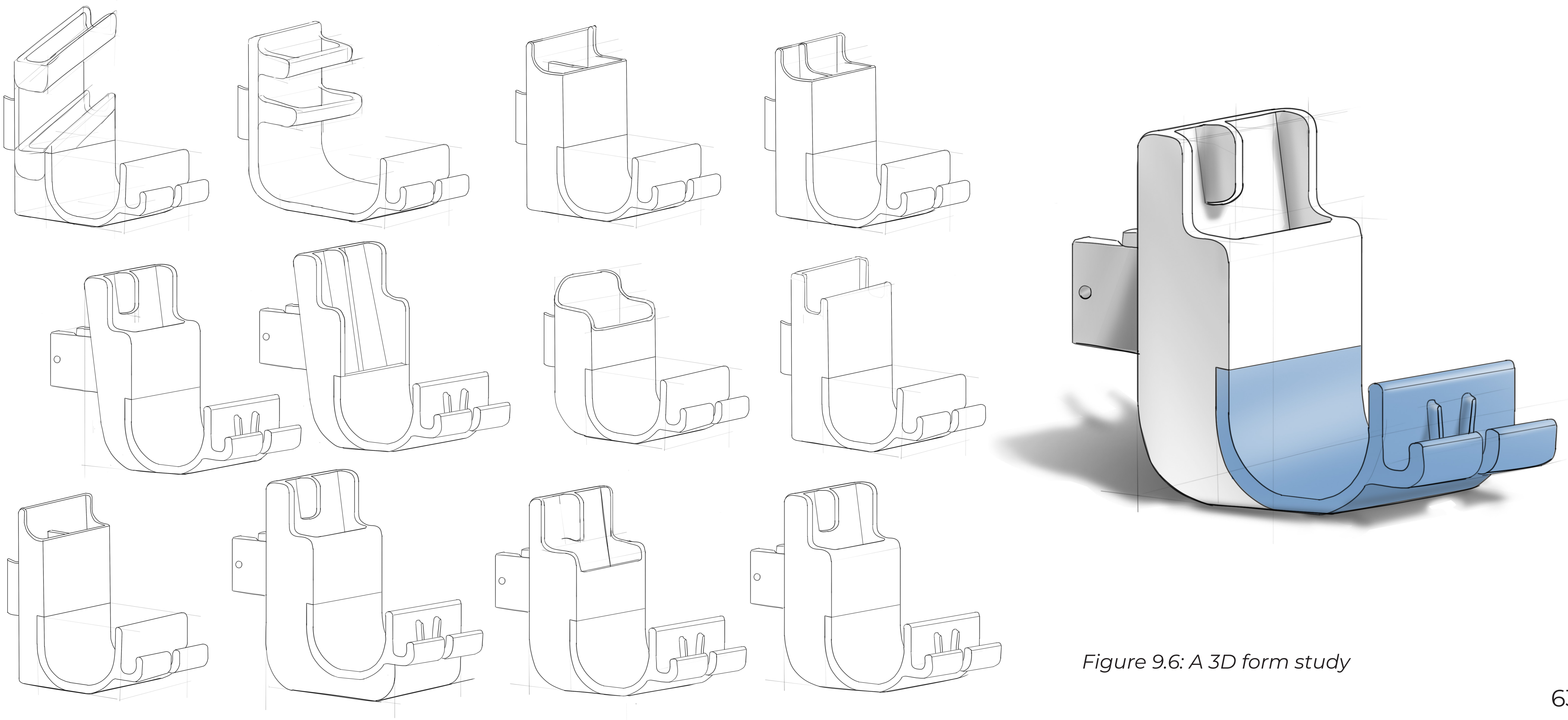


Figure 9.6: A 3D form study

9.5.2 Product family

The products need to feel like a cohesive family, visually showing that they belong together. Since they serve the same function, it's important for staff across different departments to recognize the similarities. A mood board was created (see Appendix E), using examples from other product families to explore how different items can still belong together by creating a shared design language. Key insights from this moodboard on what elements make products feel like they belong together include:

- General shapes. Base shapes, like rounded or angular forms, are repeated to create a similar silhouette.

- Proportions. Products in different sizes often only scale consistently in one direction while keeping the others the same, or are fully scaled with the same height-width ratio. The material thickness typically remains the same.

- Detailing. Similar edges, cut-outs, surface transitions and handles are used in the different products. A unified design language is created through shared curves, thicknesses and alignment.

- Color and material. A consistent material, finish, and color palette makes products instantly recognizable as part of the same family. Brands often stick to a few signature colors with the same finish. Each brand has its own characteristics, resulting in a different feel. Hema, for instance, uses playful transparent colors with extra detailing, focusing on affordability and accessibility. In contrast, Mepal products feel more high-quality using neutral, soft colours and a smooth, simple design.

To make the other products look like they belong to the Satusaver on the previous page, the elements learned from the moodboard are implemented.

General shape & proportions.
Due to the different contexts of the products, the base shapes are not identical. To still create unity, the noticible blue part of SatuSaver 1 is implemented again. The same dimentions of the small part of the hook are used for SatuSaver, including the identical hole for the sensor. Now, this small hook is extented to another hook of the same dimentions but upside down, to fit the purpose of this specific product, see figure 9.7. The hight, width and thickness is the same, but the length is twice as long. This is inline with the results of the moodboard to scale consistently in one direction while keeping the others the same.

The base shape of the white part of SatuSaver 1 is partly used again for the sticker container on SatuSaver 2. The depth of the conainer is the same as the height of SatuSaver 1, while the height of the container is the same as the depth of SatuSaver 1. Again, the lenth of the SatuSaver 2 is twice as long to fit the size of the stickers, see figure 9.8.

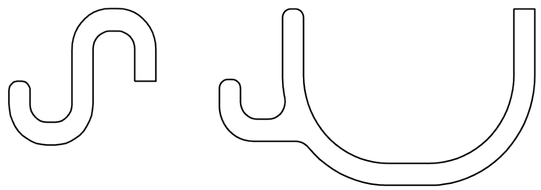


Figure 9.7: Consistency in the blue hook

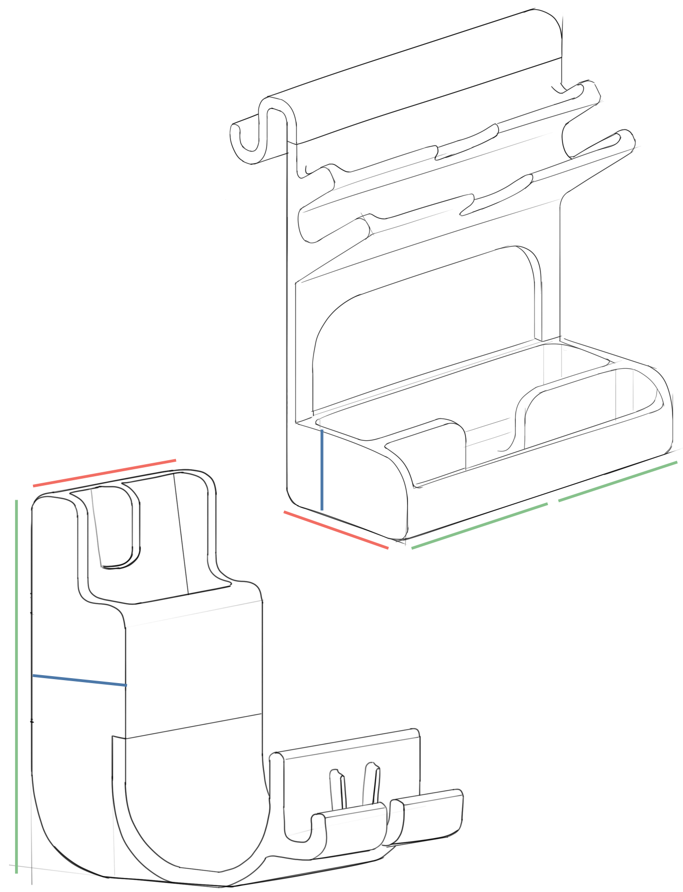


Figure 9.8: Dimensions of the base shape

Detailling, color and material

All three SatuSavers include a combination of blue and white, a bold contrast which will stand out in the room. This color choice toghether with using the same material, lead to immediate recognizability.
Another key design feature is the material thickness of 5 mm together with large roundings. This material tickness is implemented everywhere on all three products. All edges are either rounded with a 1 mm fillet, or with much larger fillet. Figure 9.9 shows how these roudings are brought back in each design.

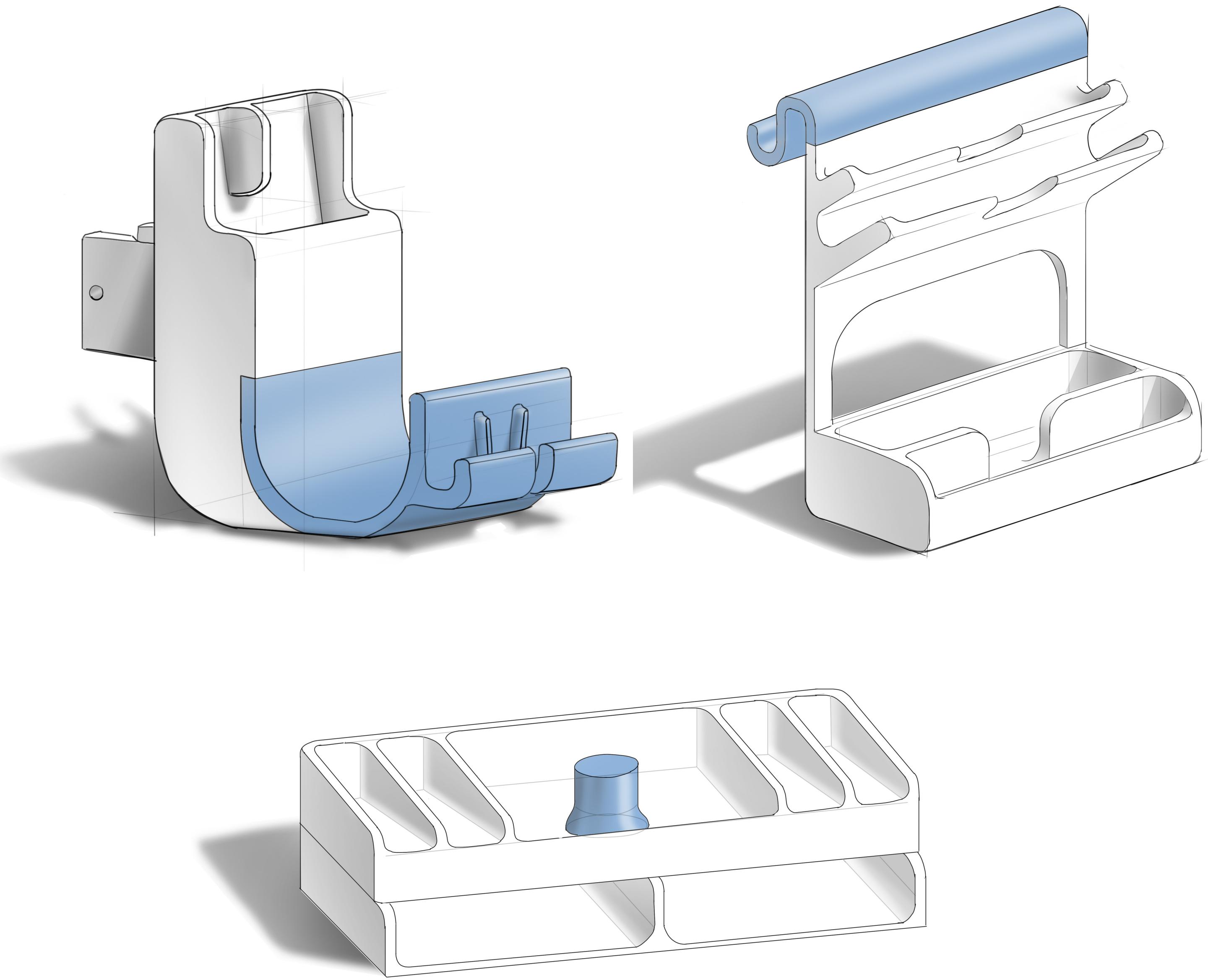
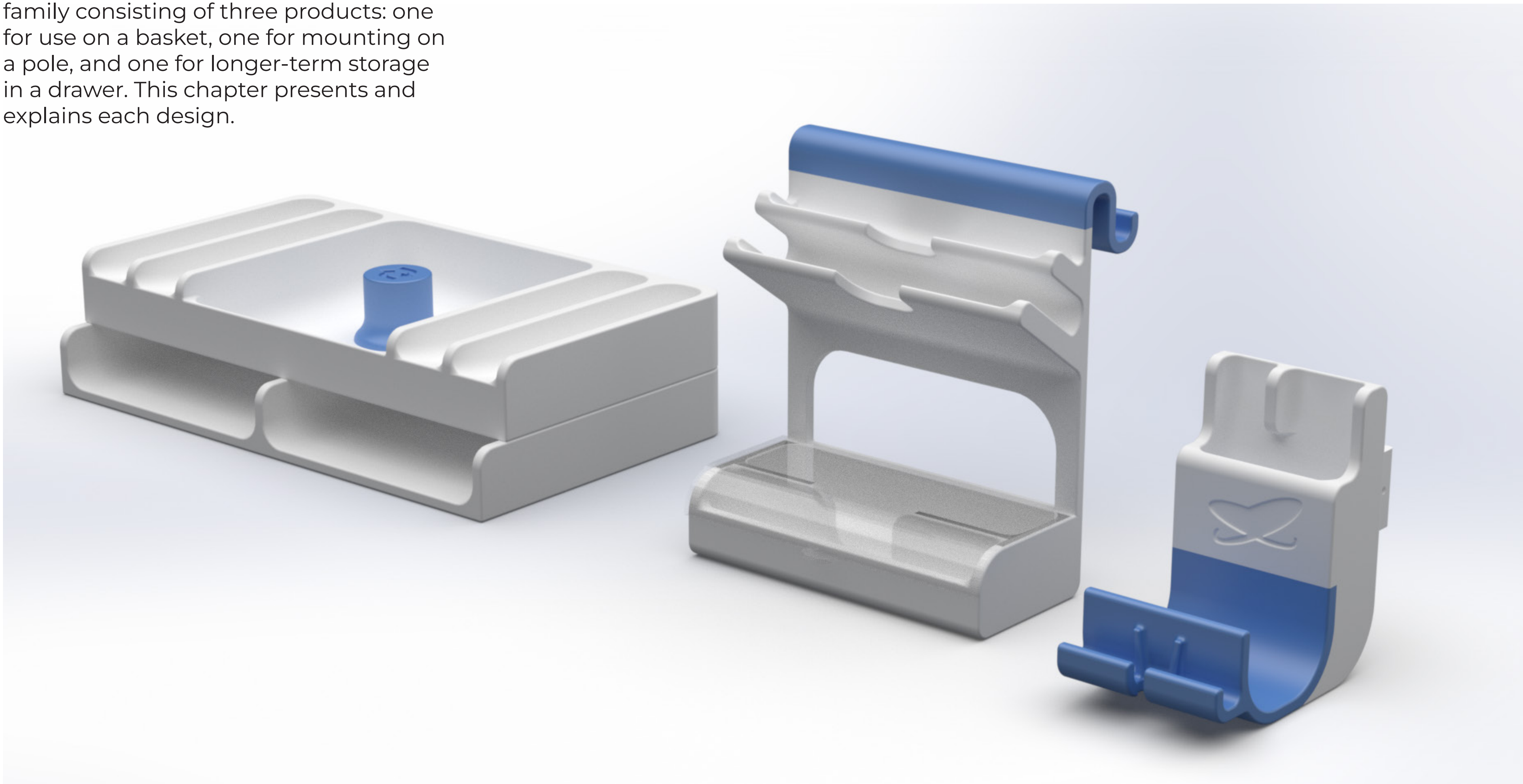


Figure 9.9: All SatuSavers with a similar design language

Final product design

Chapter 10 - The SatuSavers

To ensure safe and efficient storage conditions for a partly reusable pulse oximeter, the SatuSavers have been designed. The SatuSavers are a product family consisting of three products: one for use on a basket, one for mounting on a pole, and one for longer-term storage in a drawer. This chapter presents and explains each design.



10.1 Placement on a pole

At the neonatology department, in every room there is a ceiling pendant which contains both the drawers and the monitor. The SatuSaver is here placed on the pole close by the monitor. A prototype at the intended place of use is shown in figure 10.3.

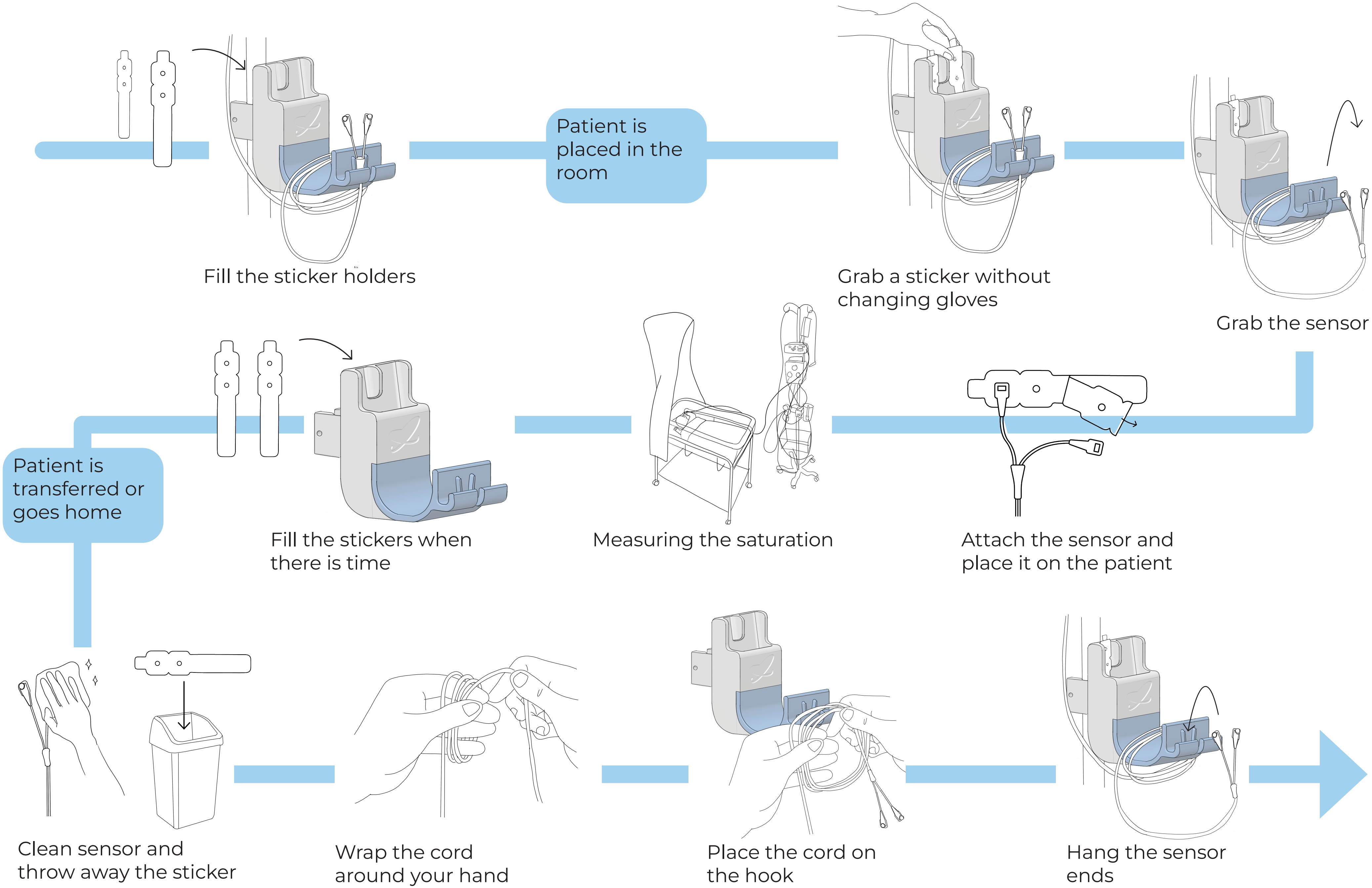
At the Maternity ward and Obstetrics, a separate pole with the monitor attached is used for saturation measurements. This pole does not contain a basket. So also in this case, the SatuSaver can be placed on the pole just below the monitor.

Figure 10.1: The ceiling pendant at Neonatology

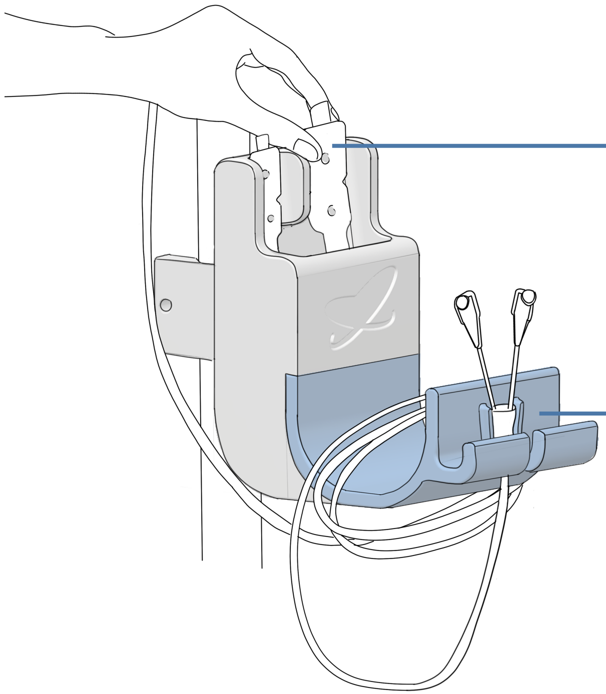
Figure 10.2: The separate pole for the Maternity ward and Obstetrics

Figure 10.3: Placement of the SatuSaver on a pole

10.1.1 Use scenario



10.1.2 Product functionality



Holders for two stickers

Designed to hold two different sticker sizes, allowing easy access while preventing the stickers from being hit by other cables.

Sensor end support

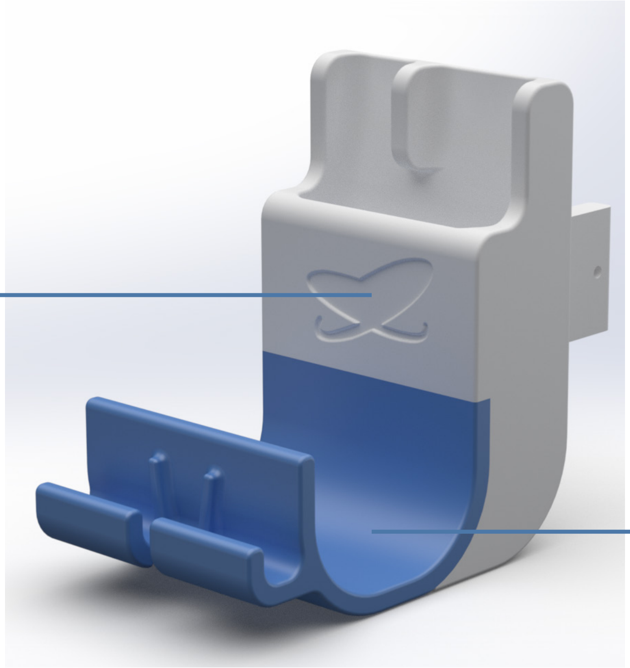
The soft silicone ends of the sensor are protected by a hanging spot at the front of the hook. The design allows only one placement orientation, ensuring consistent and uniform use.

Integration on the pendant

The sensor is placed on a pole of the pendant with a clamp at eye-level and close to the old oximeter, nudging nurses towards the new sensor.

Reinier de Graaf Gasthuis look

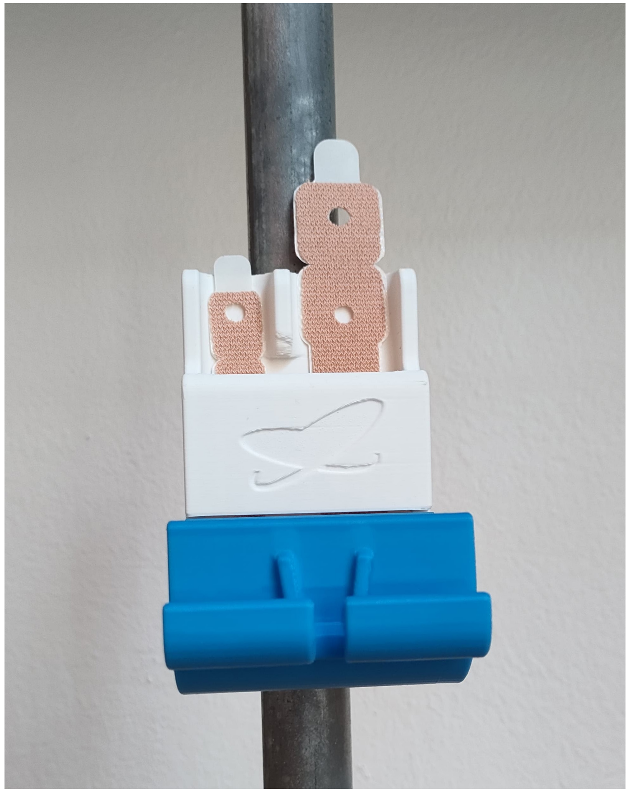
The engraved logo creates a sense of pride and trust among staff. The blue also matches the hospital color scheme, while clearly indicating that the product is not disposable.



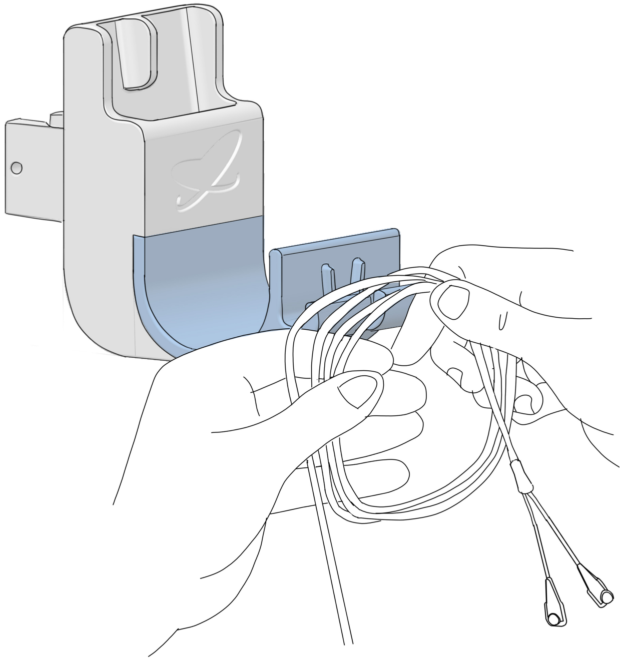
Cable hook

The hook allows the cable to be rolled in the hand and then hung up, similar to the current workflow and supporting an intuitive transition.

10.1.3 Design choices



Wrapping the cable
The hook was chosen because it is the fastest and easiest way to hang up the cable. At first, a spool was tested, but wrapping the cable around it took too long. In a busy hospital environment, other items could also get hit by the cable while wrapping it around by accident. It worked better to calmly wrap the cable by hand at a place with enough space and then hang it on the hook.



Sticker placement
The stickers are placed in a way that they are clearly visible, but still protected. The different sizes are easy to recognize because the stickers stick out. By having two clear places to insert a sticker, assistents are more likely to always place both sizes when refilling.

Way of hanging the sensor
The sensor is hanging at the thicker and stronger part of the cable. This is a safe and easy way of hanging, as it can be hung of in one movement without damaging the softer part of the sensor.

10.2 Placement on a basket

At the Child and Youth department, in every room there is a portable monitor present which contains a basket at the front. The only place on the pole available for a SatuSaver is under the basket, which is of course not convenient.

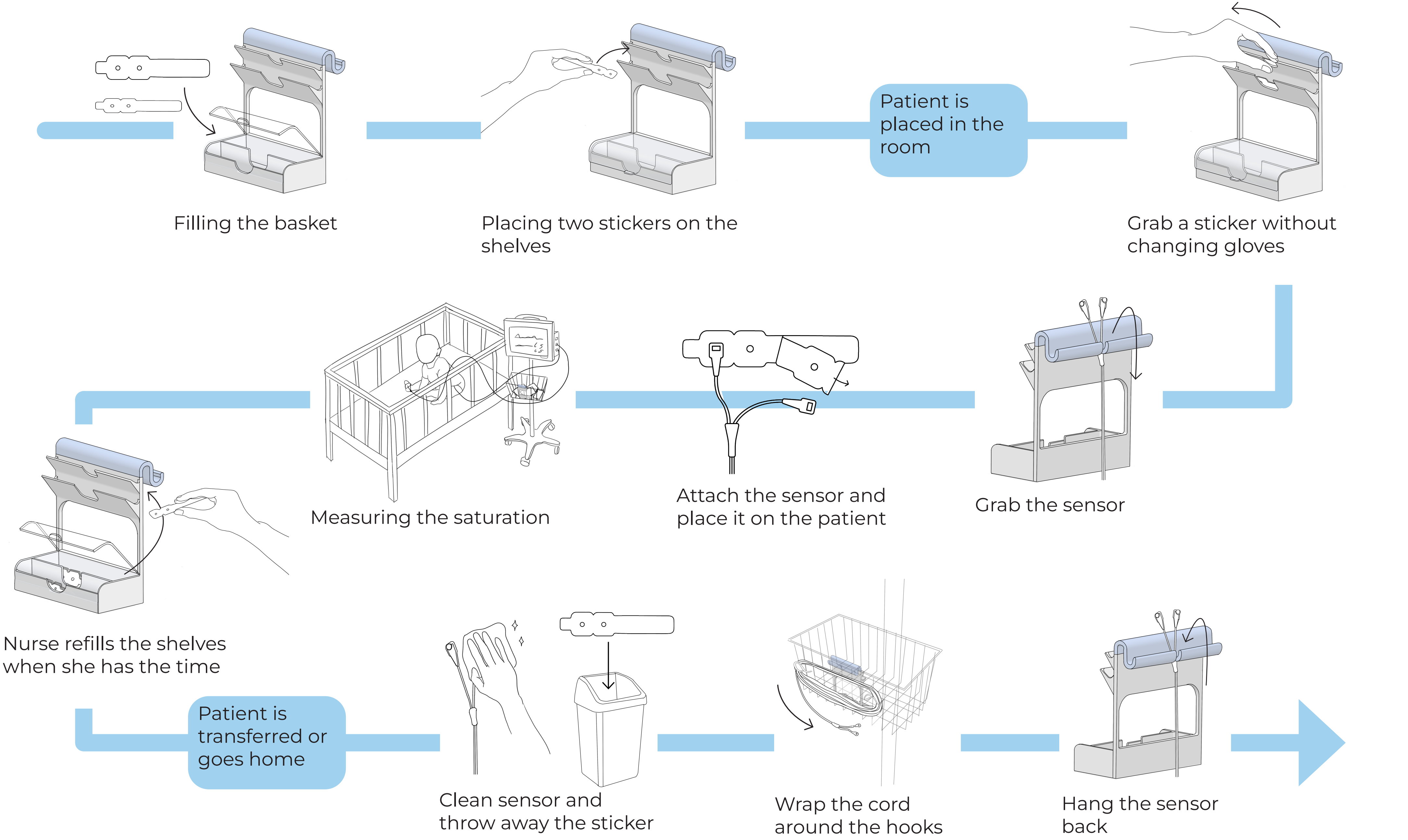
Therefor, the SatuSaver is placed in the basket, hanging over the front of the basket. The drawer is at the other side of the room, making it even more convienent to always have a sticker ready in the SatuSaver.

The basket contains at the left, right and front side hooks to wrap the cables for pulse oximetry, ECG and blood pressure. The SatuSaver is placed at the front, in such a way that the existing hooks can still be used to wrap the cable, see figure 10.5.

Figure 10.4: A room in the child department

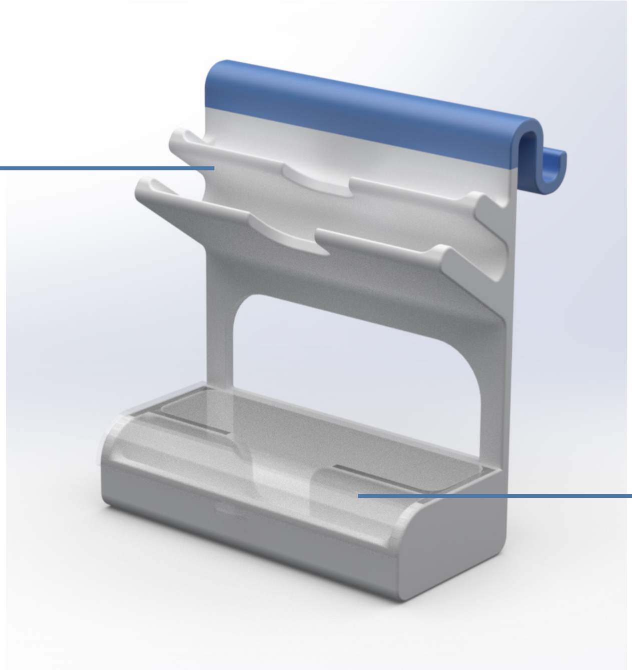
Figure 10.5: Placement of the SatuSaver in the basket

10.2.1 Use scenario



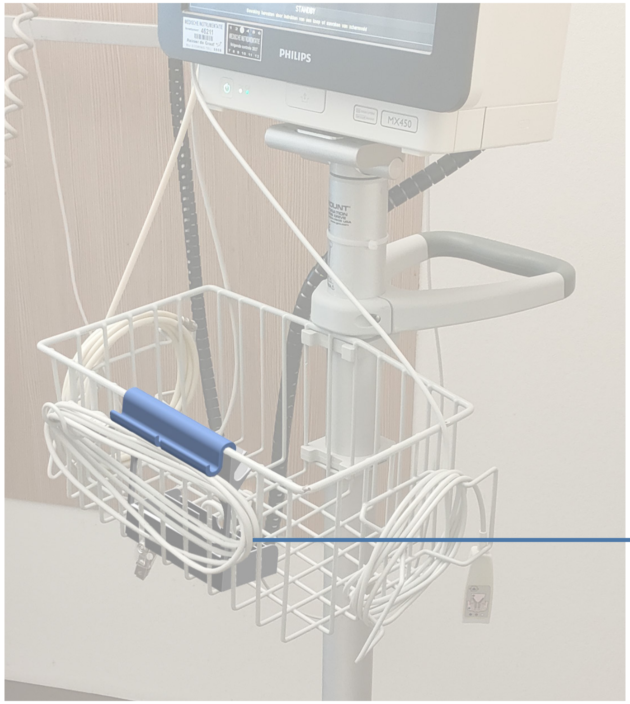
10.2.2 Product functionality

Dual sticker holders
Always keep two different sticker sizes within reach. The holders are made to prevent the stickers from falling out, while remaining open enough to easily grab without touching anything else.



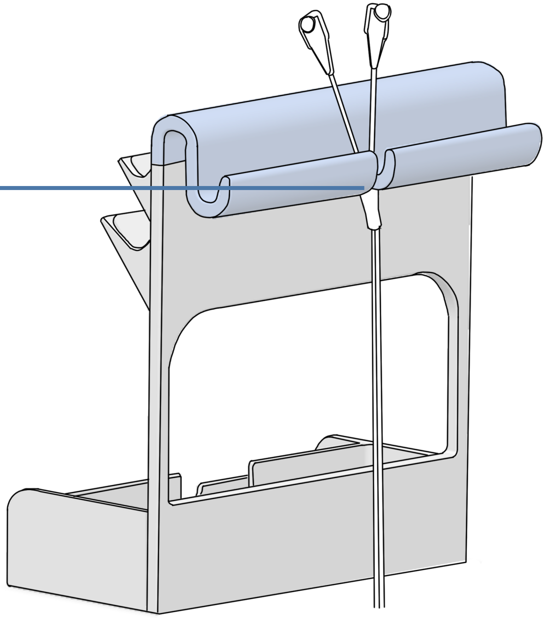
Uniform design language
The similar designs communicate that they serve the same function, ensuring consistency across departments.

Closed sticker storage
Extra stickers are stored in a closed compartment to keep them clean and protected, while still being close by to be easily accessible when needed.



Sensor end support
The silicone ends of the sensor are again protected by a hanging spot. This time it is placed at the front of the basket to separate it from the content of the basket.

Integration with existing basket
The sensor is placed at the front of the existing baskets, in the same location as the old oximeter. The hooks on the basket can be used in the same way to wrap the cable around. This familiar placement subtly nudges nurses to adopt the new sensor.



10.3 Placement in a drawer

The reusable D-YS sensor is not always the most suitable choice in every situation. There will always be exceptions where a disposable pulse oximeter is preferred. Nurses have mentioned examples such as patients who are highly infectious or have extremely low oxygen saturation levels. For these cases, disposable Nellcor sensors must also be available in the room. The base cable remains the same for both options, but the sensor end can be switched between the reusable and disposable versions.

When the disposable sensor is used, the reusable D-YS sensor needs to be temporary stored somewhere else. All rooms contain drawers that can be used as additional storage space. In here the sensor can be stored, shown in figure 10.8.

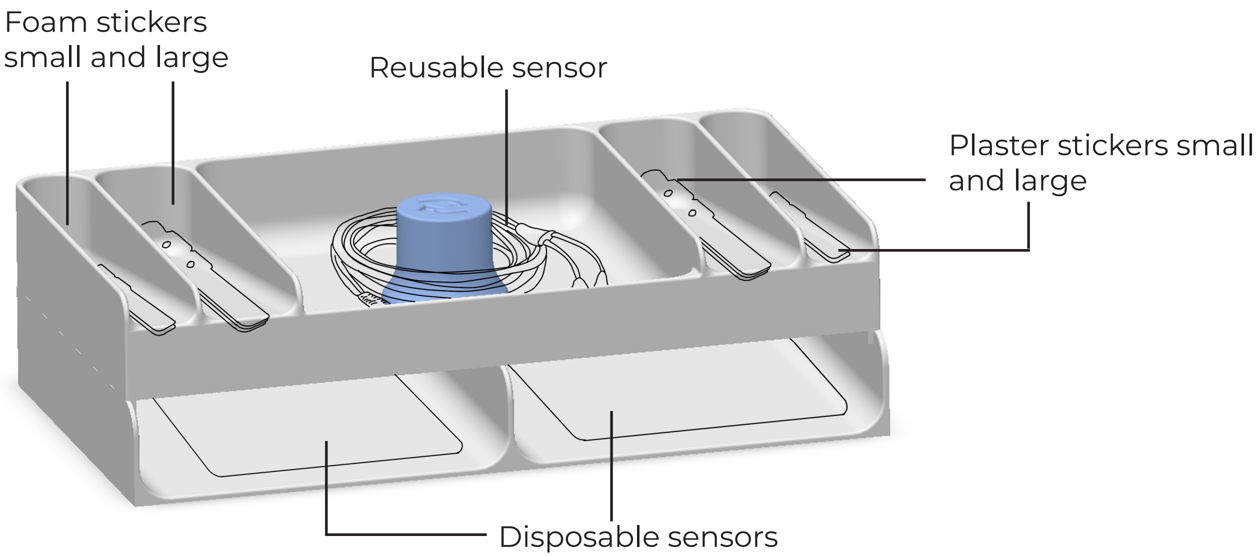


Figure 10.7: Placement of the needed equipment for saturation measurements in the SatuSaver

Figure 10.6: A filled drawer at Neonatology

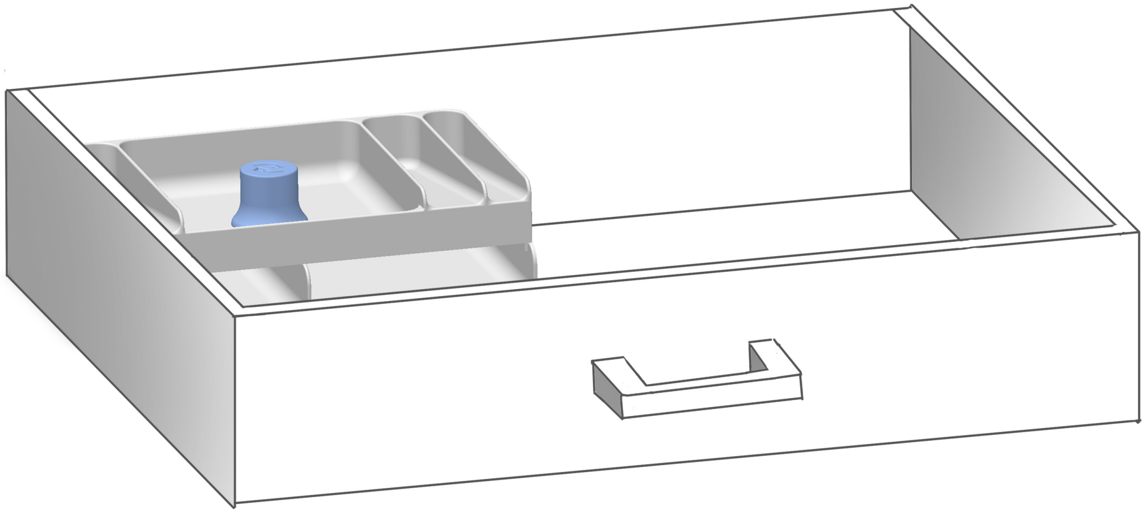
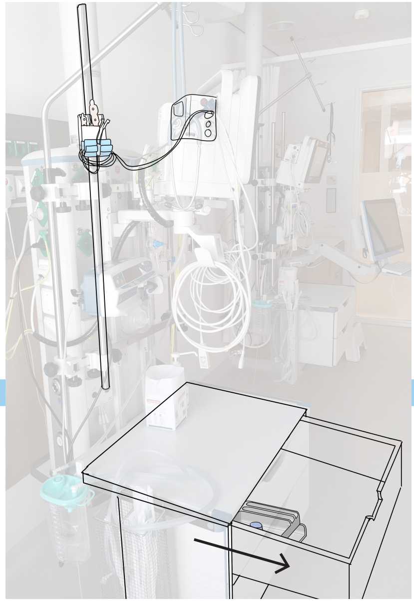


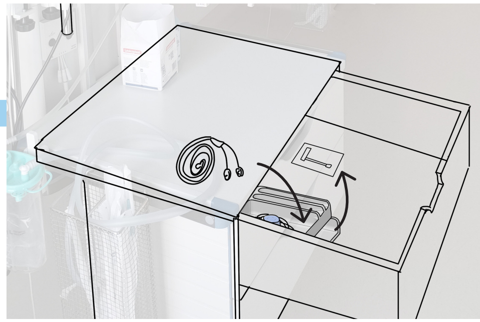
Figure 10.8: SatuSaver in a drawer

10.3.1 Use scenario

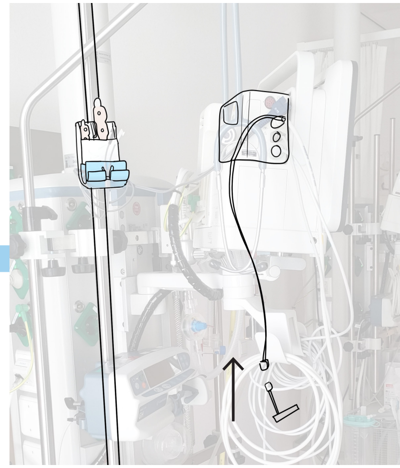
The following use scenario shows the steps taken to switch from the hybrid sensor as the default option, to the use of the disposble sensor. This will only be the case for specific situation in which a hybrid sensor is not ideal or does not give the right values.



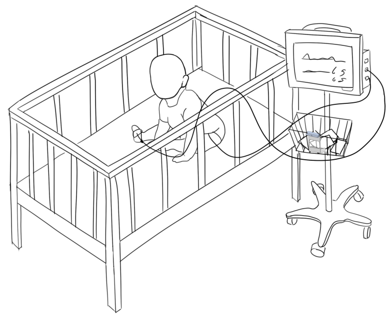
Open the drawer and unplug the hybrid sensor from the base cable



Place the hybrid sensor in the SatuSaver and take out the disposable sensor

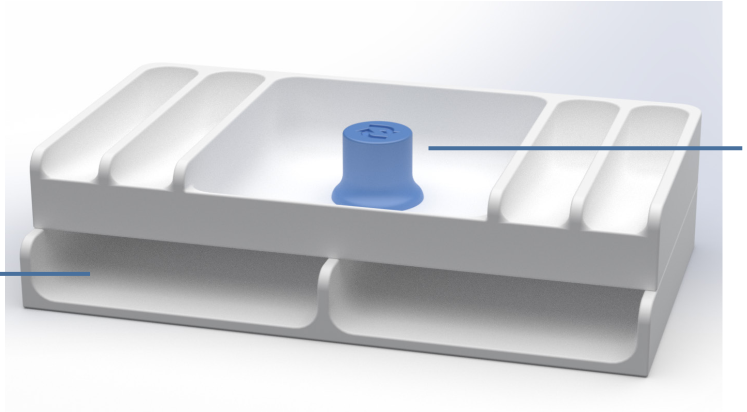


Plug the disposable sensor in the base cable



Measure the saturation while the hybrid sensor is safely stored in the drawer

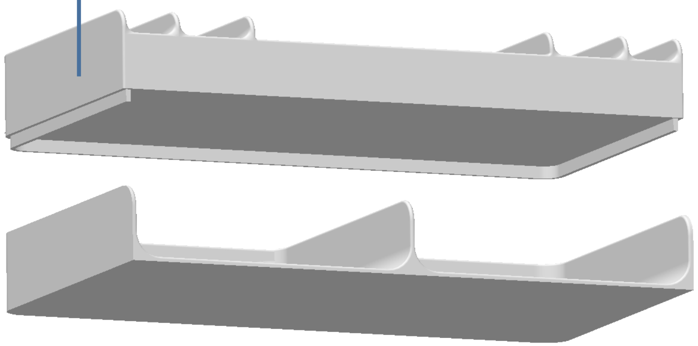
10.3.2 Product functionality



Reuse icon
In the center, there is space for the reusable cable, which can be wrapped around a central blue cylinder to help maintain its round shape. This cylinder has a reuse icon on top, indicating that this area is meant for the reusable sensor.

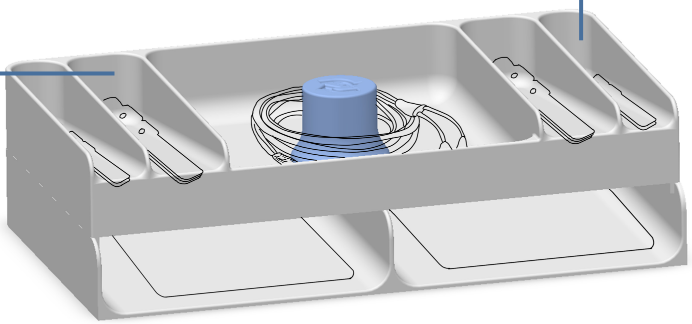
Disposable stickers
At the bottom there are two compartments for two sizes of disposable sensors. These compartments are intentionally placed beneath the reusable sensor to make them slightly less convenient to reach, encouraging the use of the more sustainable option.

Separatable compartments
To support easy maintenance, the compartment that holds the disposable sensors can be separated from the rest of the unit. This allows for simple cleaning and easy replacement if any part becomes damaged.



Tilted stickers
The areas for sticker storage are tilted, making the front of the sticker placed higher. This lead to easy grabbing of the stickers.

Sticker storage
Foam stickers in two sizes can be placed on one side of the storage unit, while plaster stickers are stored on the opposite side.



10.4 Behavioural change

Nurses are used to working with disposable sensors, which will still be available even after the reusable version is introduced. To ensure a successful transition, a change in behaviour is needed. As discussed in chapter 8.4, some nurses lack the internal motivation to adopt the more sustainable hybrid sensor. That's why the theory of nudging has been applied in the design of the SatuSavers.

Nudging means organizing the environment in a way that subtly steers people toward a desired behaviour (Ölander & Thøgersen, 2014). Since people often choose the easiest option, the reusable sensor is made the default. It's already connected to the cable and placed visibly on the pole, while the disposable sensors are kept in a closed drawer. This makes nurses more likely to grab the reusable one.

The SatuSaver is placed at eye level on the pole, making it easier to reach than the drawer, which requires bending down and opening it. On the basket, the SatuSaver is placed in the same spot where the disposable cable used to be, right where nurses instinctively reach when they need a pulse oximeter. The stickers are also easy to grab, without having to search, open drawers, or switch gloves, keeping the barrier to using the hybrid sensor as low as possible.

10.5 SatuSaver without the D-YS sensor

The products are designed for the scenario of switching to the D-YS Nellcor sensor. Untill this switch to Nellcor or in the case of not using this specific D-YS sensor, the product can still be functional and adaptable. It can be used with other partially reusable sensors, possibly with small adjustments to the part that holds the sensor tip.

The products can also be used in the current workflow with disposable sensors, by encouraging the use of new stickers on a used sensor for the same patient. The currently used stickers fit both the neonatal and pediatric versions of the product, allowing for quick retrieval. This makes the use of stickers more attractive as they are always available and no extra time is needed to search for one.

The existing cable can also be hung on the same hook used in the neonatal design, and even disposable sensor bands can be temporarily stored there. Nurses sometimes leave a used band next to the bed in case it is needed again later for the same patient. By hanging it up instead, it's more likely to remain usable and not stick to itself.

10.6 Systemic changes

With the introduction of the SatuSavers, a few small system changes are made. Instead of only delivering disposable sensors, the logistics staff (kastscanners) now also bring the sealed bags of stickers to the storage rooms. The care assistants open these bags and sort the stickers into the four compartments in the drawer. At the Child and Youth department, they also refill the container in the basket.

When nurses receive a call that a patient is on their way, they now place two stickers in the SatuSaver in the room, instead of taking a disposable sensor from the drawer and placing it on the bedside as they currently do. Placing the stickers on the shelves only when the patient arrives helps prevent dust buildup.

When a patient is discharged, the care assistant cleans not just the cable, but also the sensor and the SatuSaver itself. After cleaning, they roll up the cable and hang the ends neatly. This makes it visually clear that the sensor is cleaned.

10.7 Product qualities

10.7.1 Ease of use

The designs are made for fast and intuitive use. Two stickers are always available on top of the product, removing the need to open drawers or packaging during use. The reusable part of the saturation sensor is stored visibly and consistently in the same place, making it easy to grab without searching. The sensor ends can be hung up in a single motion. As a result, the cable never touches the floor or drawer, and the setup remains easily neat.

Cable management remains familiar. In the Child and Youth department, the cord can still be wrapped using the existing hooks on the monitor basket. In the other departments, the cable can still be rolled up around the hand and then hung up on the hook.

10.7.2 Ergonomics

The products are designed with the daily workflow of nurses in mind.

For the Child and Youth department the product is placed on the basket. By positioning the stickers and the sensor directly on the front of the monitor basket, both components stay within arm's reach, reducing unnecessary movement and bending. A cut-out in the center of the platform holding the stickers allows users to effortlessly grasp the sensor with two fingers. The cable can be wrapped and unwrapped in a familiar motion.

For the Neonatology department, the hook allows the cable to be hung up in the same way nurses already do: by wrapping it around their hand and placing it on the hook. This makes it feel natural and avoids extra steps. Behind the hook, the stickers stick out far enough so you can grab one easily without having to reach into a box. The product is placed at eye level, so everything is clearly visible and within reach. If needed, it can be adjusted a little to match the right height.

10.7.3 Acceptance

Adoption of the product is encouraged through both aesthetics and meaning. Its clean, rounded forms give it a friendly, hygienic, and safe appearance. These qualities were mentioned by pediatric nurses to be important. The blue component highlights its reusablility to make sure they do not mistake it for single use, which is often coloured white. The Reinier de Graaf Gasthuis logo creates a sense of ownership and pride, reminding staff that this solution was created by and for their hospital.

10.7.4 Consistency

The product designed for on the basket in the Child and Youth department closely resemble those for on a pole in Neonatology, Obstetrics and Maternity ward. They share the same material thickness, corner radius, surface finish, and the characteristic blue color. This visual consistency makes it immediately clear that the products serve the same function, even across different departments. The method for hanging the sensor is also identical, which ensures a uniform look and handling experience throughout the hospital. This consistency aligns with Reinier de Graaf Gasthuis's emphasis on unity and recognizability within their clinical environment. For doctors and staff who move between departments, this shared design language helps create predictability and ease of use.

Chapter 11 - Design detailing

11.1 Sticker placement

The stickers are positioned to be clearly visible while still being protected. A balance has also been achieved between keeping the stickers securely in place and ensuring the product remains easy to clean.

For use on the pole, different sticker sizes are separated by a divider placed only at the top of the product. This design choice allows for easier cleaning at the bottom. All edges are largly rounded to avoid hard-to-reach corners during the cleaning process. The container holding the stickers is relatively deep, allowing fingers to reach inside with a microfiber cloth. To keep the stickers in place, the back surface is tilted at a 10-degree angle, shown in figure 11.1.

For use on a basket, the holes in the shelves are large enough for nurses to easily grab a sticker, yet small enough to prevent them from falling through (figure 11.2). The shelves are sloped to protect the stickers while still allowing access to the back for cleaning.

Since nurses typically retrieve the stickers while standing in front of the basket, the bottom shelf has been made longer with an extra-large rounding at the back.

This places the sticker closer to the front, making it easier to see and grab from above, see figure 11.3.

To improve accessibility in the closed compartment, the base has also been tilted so the stickers angle upward and are easier to reach from the same standing position, see figure 11.4.

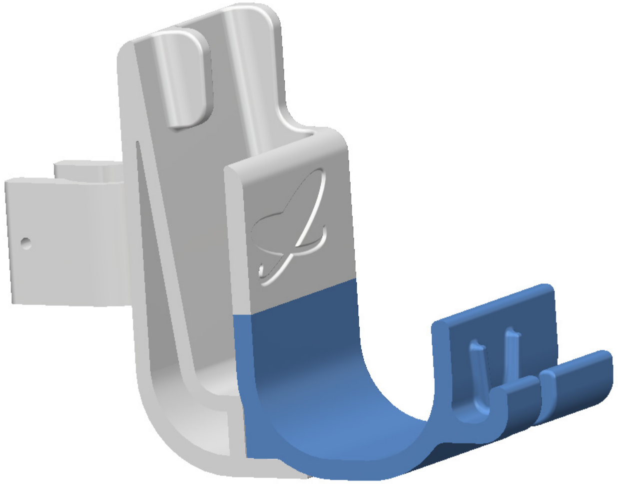


Figure 11.1: A section view showing the tilted back

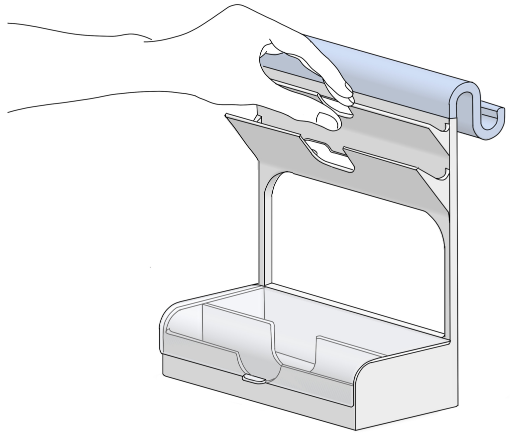


Figure 11.2 Holes on the shelves for easy access

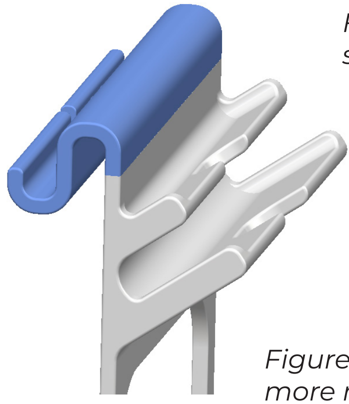


Figure 11.3 The longer and more rounded bottom shelve

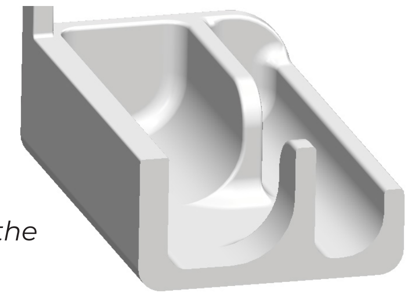


Figure 11.4: A section view showing the tilted ground of the closed sticker compartment

11.2 Probe hanging

In the final design, small guiding beams have been added to ensure correct placement of the sensor, see figure 11.5.

These beams match the angle of the thicker part of the sensor. The hole for the sensor has the same shape as the cross-section of the inserted part. This both communicates how the product should be used and prevents incorrect insertion.

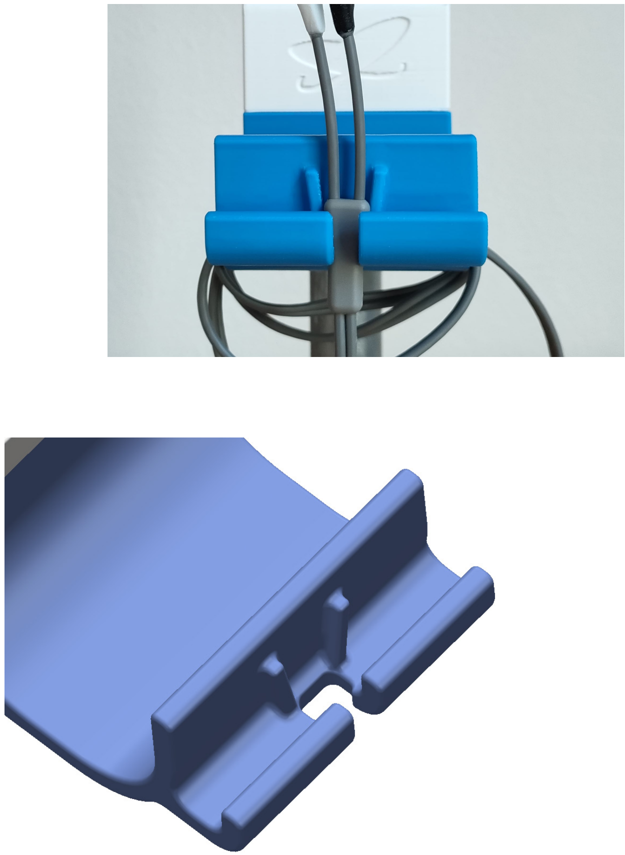


Figure 11.5: Guiding beams for probe support

11.3 Attachment on a pole

To attach the product, it must first be pushed firmly around the pole. The inner diameter of the clamp is 27 mm, which is 1 mm smaller than the diameter of the pole on the pendant, ensuring a tight fit.

Next, a bolt with a diameter of 3 mm should be inserted through the holes (figure 11.6). By tightening a nut onto the bolt, the clamp is secured around the pole to hold the product in place. This attachment only needs to be done once per SatuSaver. A nylon-insert lock nut is used to provide extra resistance to prevent loosening o

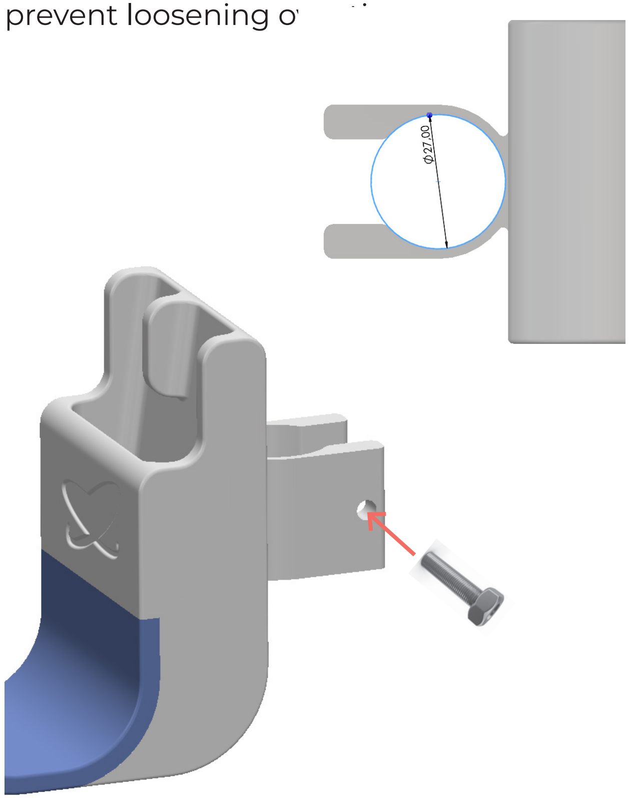


Figure 11.6: Attatchment on a pole

11.4 Assembly

The blue and white parts of the product are printed separately and assembled afterward. It is important to prevent unintended separation of the parts. Two screws with a diameter of 3 mm are used to ensure that disassembly can only be done intentionally with the correct tools.

To provide enough material for the screws to hold securely, the blue part has been made locally thicker. For proper alignment, additional ridges have been added that fit into the cut-outs of the white part, see figure 11.7.

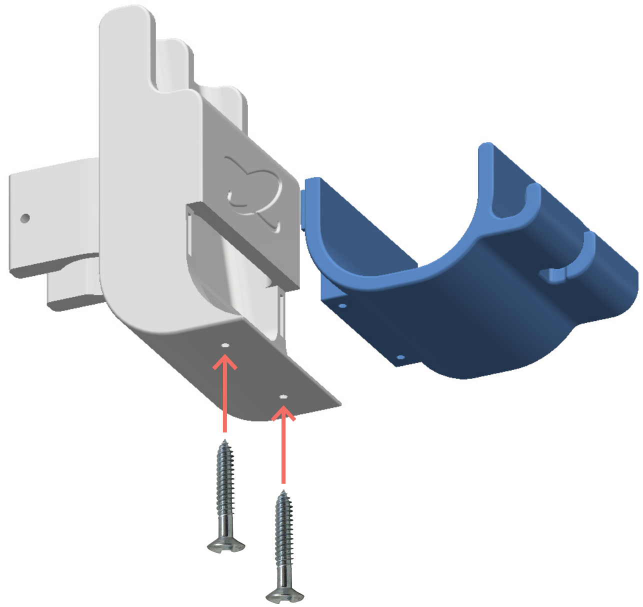


Figure 11.7: Assembly of the two parts

11.5 Implemented R-strategies

The main focus of the SatuSavers is on reuse. They enable and encourage the use of the hybrid pulse oximeter, replacing single-use sensors. By making the reusable sensor the default option, SatuSavers help healthcare workers choose reuse over disposal.

Although in-house repairs of the hybrid pulse oximeter are still challenging, testing the reusable part of the sensor is possible. This avoids unnecessary disposal of functional sensors due to uncertainty. At the Medical Instrumentation department, testing devices for adult pulse oximeters are already in use (see figure 11.8). These monitors can also be set to test child and neonatal sensors, making them compatible with the D-YS sensor.

The 'reduce' strategy is also addressed. By encouraging the use of stickers, one sensor can be used for a longer period. This means fewer sensors are needed per patient, reducing overall consumption.

The recyclability of the SatuSavers has also been considered. PLA was chosen because it is highly recyclable. However, the hospital does not yet have a suitable recycling stream. If there will be one in the future, the designs are already suitable.

Despite all strategies, some incineration will still occur. Both the D-YS sensor and the SatuSavers reach end-of-life when they are too damaged to clean safely. For example, if there are deep scratches where dirt can build up, they become unsafe to use. The D-YS sensor must also pass accuracy tests, if the measurements are no longer reliable, the sensor must be discarded. Figure 11.9 shows the lifecycle streams of the different elements.

Figure 11.8: Test measurement of a pulse oximeter

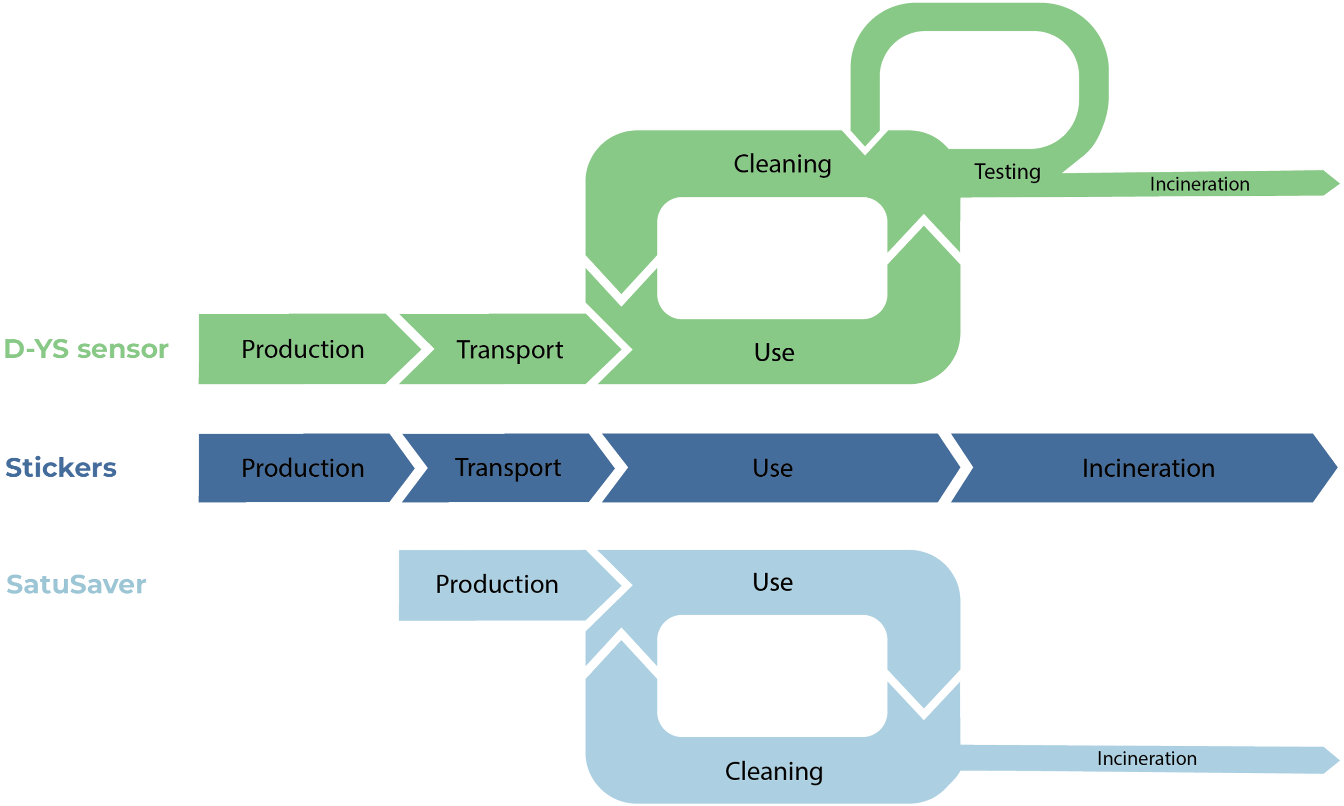


Figure 11.9: Lifecycle streams of the different parts of the new system

11.6 Materials and manufacturing

The number of products that need to be manufactured is relatively low. To cover all rooms in the four departments, around 23 SatuSavers for baskets and 47 for poles are needed. If the scope is extended, additional units may be required for the pediatric clinic and daycare. For now, with such low quantities, 3D printing using material extrusion is the most viable and accessible manufacturing method. This technique offers a high degree of design freedom. Different filament colours can be used; however, the blue parts need to be printed separately from the white parts. The hospital owns two 3D printers already, giving the opportunity to do inhouse printing, see figure 11.10.

The required material for material extrusion is a thermoplastic. Since the product does not come into direct contact with patients, it does not need to be made from medical-grade plastic. PLA is chosen as the most suitable material. It is easy to print, delivers high detail, and does not require an enclosed printer. PLA is also a bioplastic, and it can be recycled into new filament from leftover or discarded parts. Currently, there is no recycling stream in the hospital, but if one is established in the future, PLA will only be suitable if it is separated from other plastics.

The SatuSavers contain rounded forms. To achieve a smooth 3D print of these shapes, it is important to place the parts on the print bed in a way that allows the X-axis to accurately form the curves. Therefore, the blue parts are positioned on their side, see figure 11.11. The cylinder at the back of the white part, used to attach it to a pole, is oriented vertically and placed upright on the print bed. The correct positions of the parts on the print bed are shown in figure 11.12, with the green areas indicating support structures.

To produce one SatuSaver for a pole, 74 grams of plastic and 2 hours and 20 minutes of print time are required.

To produce one SatuSaver for a basket, 143 grams of plastic and 4 hours of print time are required.

Figure 11.10: 3D printers at RdGG

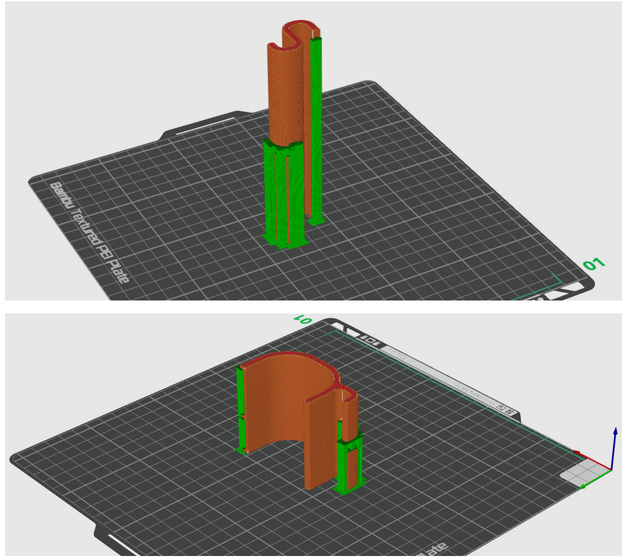


Figure 11.11: The blue parts in the correct possition on the printbed

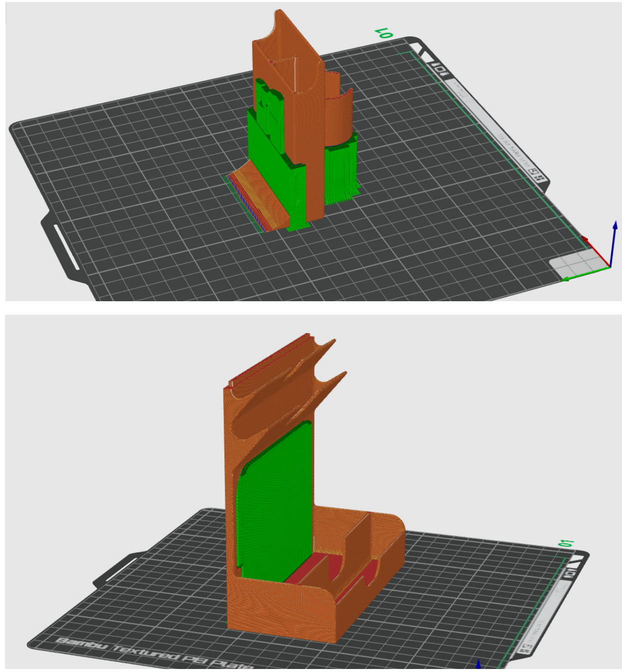


Figure 11.12: The white parts in the correct possition on the printbed

11.7 Environmental impact

A calculation has been done to evaluate the environmental impact of possible future scenarios with the adoption of the SatuSavers.

Currently, no Life Cycle Assessments (LCAs) exist for the specific types of disposable and hybrid sensors. Additionally, no detailed information is available regarding the materials and production processes of the hybrid sensor components. Therefore, the results of the only available environmental impact study on pulse oximeters, conducted by Duffy et al. (2023), are used as the basis for this comparison.

According to this study, one disposable pulse oximeter has an environmental impact of 0.15605849 kg CO_2-eq, while one reusable sensor has an impact of 0.35437821 kg CO_2-eq, including transport and material emissions. The number of sensors used in the current scenario is based on 2024 purchase data.

11.7.1 Different scenarios

Different possible scenarios have been developed to compare the environmental impact with the current situation. In all scenarios, the impact over one full year is calculated.

The first step in implementation is to introduce the hybrid sensor in the Neonatology, Obstetrics, and Maternity wards.

Afterward, the hybrid sensor will also be implemented in the Child and Youth department. Both steps are evaluated in two possible scenarios: one with a 50% adoption rate and one with a 99% adoption rate.

The 99% adoption scenario is based on the current usage of reusable versus disposable pulse oximeters in the adult departments. In 2024, 140 disposable sensors were used across all adult departments that had transitioned to reusables. RdGG has a total capacity of 481 beds, 70 of which are in the pediatric departments. Based on the ratio of beds, it is assumed that in the most successful scenario, where the product is implemented in all departments, 24 disposable sensors per year would still be used in specific cases where a hybrid sensor is not ideal.

The 50% adoption scenario is based on the application of nudge theory. Rearranging the choice architecture can increase the likelihood of individuals choosing the nudged option (Sunstein & Thaler, 2009).
For example, one hospital made seasonal flu vaccination the default for healthcare workers, requiring them to sign a form to opt out. This opt-out policy increased vaccination rates among staff from the national average of 40% to 98% (Schnirring, 2007).

However, healthcare workers can be resistant to change. A study offering reusable gowns alongside disposable ones showed that adoption plateaued at 25%. Taking this resistance into account, combined with the increased adoption expected by making the hybrid sensor the default option, leads to an estimated short-term adoption rate of 50%.

Different scenarios

1. Implementation of only the pole mounted SatuSaver with an adoption rate of 50%
2. Implementation of only the pole mounted SatuSaver with an adoption rate of 99%
3. Implementation of all SatuSavers in all four departments with an adoption rate of 50%
4. Implementation of all SatuSavers in all four departments with an adoption rate of 99%

11.7.2 Impact of cleaning

It is estimated that, on average, 1.5 sensors are used per child receiving oxygen monitoring. Continuous monitoring over multiple days requires multiple sensors, while single-use measurements lower the average. Therefore, it is assumed that the hybrid sensor is cleaned once for every 1.5 disposable sensors avoided.

The environmental impact of using one cleaning wipe is 0.010233 kg CO_2-eq (Duffy et al., 2023). It is assumed that one full cleaning wipe is used to clean both the hybrid sensor and the SatuSaver.

11.7.3 Impact of separate stickers

Currently, in many cases, a new sensor is used when the adhesive sticker no longer sticks properly. It is estimated that in 10% of the used sensors a new sticker is used, based on conversations with multiple nurses.

The exact materials used in the stickers are unknown. However, the sticker closely resembles Leukoplast tape and is therefore assumed to be made of viscose, which has a carbon footprint of 14 kg CO_2-eq per kg. With an average weight of 0.585 grams per sticker, the impact is estimated at 0.00819 kg CO_2-eq per sticker.

The adhesive is assumed to be the same as that used in disposable sensors, a polyurethane-based adhesive, with an estimated impact of 0.00365626 kg CO_2-eq per sticker (Duffy et al., 2023).

11.7.4 Lifetime of the hybrid sensor

The actual average lifetime of the hybrid sensor in clinical use is not yet known. A fully reusable clip-style pulse oximeter was estimated by its manufacturer to have a lifetime of two years. However, since the hybrid sensor includes soft silicone components, a shorter lifespan is expected.

The product comes with a one-year warranty (Unimed Medical, n.d.), so for now, it is conservatively assumed that the hybrid sensor has a lifetime of one year.

11.7.5 Impact of the SatuSavers

The environmental impacts of 3D printing are largely dominated by energy consumption during the printing process, particularly for Fused Deposition Modeling (FDM), which generates minimal waste. During FDM printing with PLA, approximately 95.5% of total energy consumption occurs during the actual part-building phase. The functional unit energy consumption for FDM using PLA is estimated at 50.069 kWh per kilogram (Enemuoh et al., 2021).

In 2024, the grid emission factor in the Netherlands was 0.328 kg CO_2-eq per kWh (CO_2 Emissiefactoren, n.d.).

PLA itself has a production impact of 1.19 kg CO_2-eq per kilogram (Seile et al., 2022).

The environmental impact of an in-house produced SatuSaver can therefore be calculated as follows:

((50.069 × kg of SatuSaver) × 0.328) + (1.19 × kg of SatuSaver)

This formula includes both the emissions from energy use during printing and the material-related emissions from PLA production.

11.7.6 Results

A comprehensive Life Cycle Assessment (LCA) is required to calculate more specific and reliable data on the environmental impact. However, based on the current assumptions, every implementation scenario results in a lower impact compared to the current situation, see figure 11.13. Scenario 1 has a 0.76% reduction of kg CO2 eq, scenario 2 a 26.3% reduction, scenario 3 a 14.2% reduction and scenario 4 a 57.6% reduction. The more in detail data can be found in appendix F.

The first scenario, implementing only the pole-mounted design with a 50% adoption rate, shows only a slightly lower impact than the current scenario. The solution will have a bigger positive effect on the environment if the adoption rate is higher or if it is implemented in all pediatric departments.

The total environmental impact could be even lower than currently estimated, as the calculations assume the same impact for the hybrid sensor as for a fully reusable sensor. Since the hybrid sensor is smaller, its actual impact is likely to be lower. Additionally, it is estimated to last for approximately one year. Given that the warranty covers one year, the actual average lifespan may turn out to be longer.

Lastly, the SatuSavers are currently produced in small batches. If production is scaled up, alternative manufacturing methods that are less energy-intensive may become more viable, further reducing the overall environmental footprint.

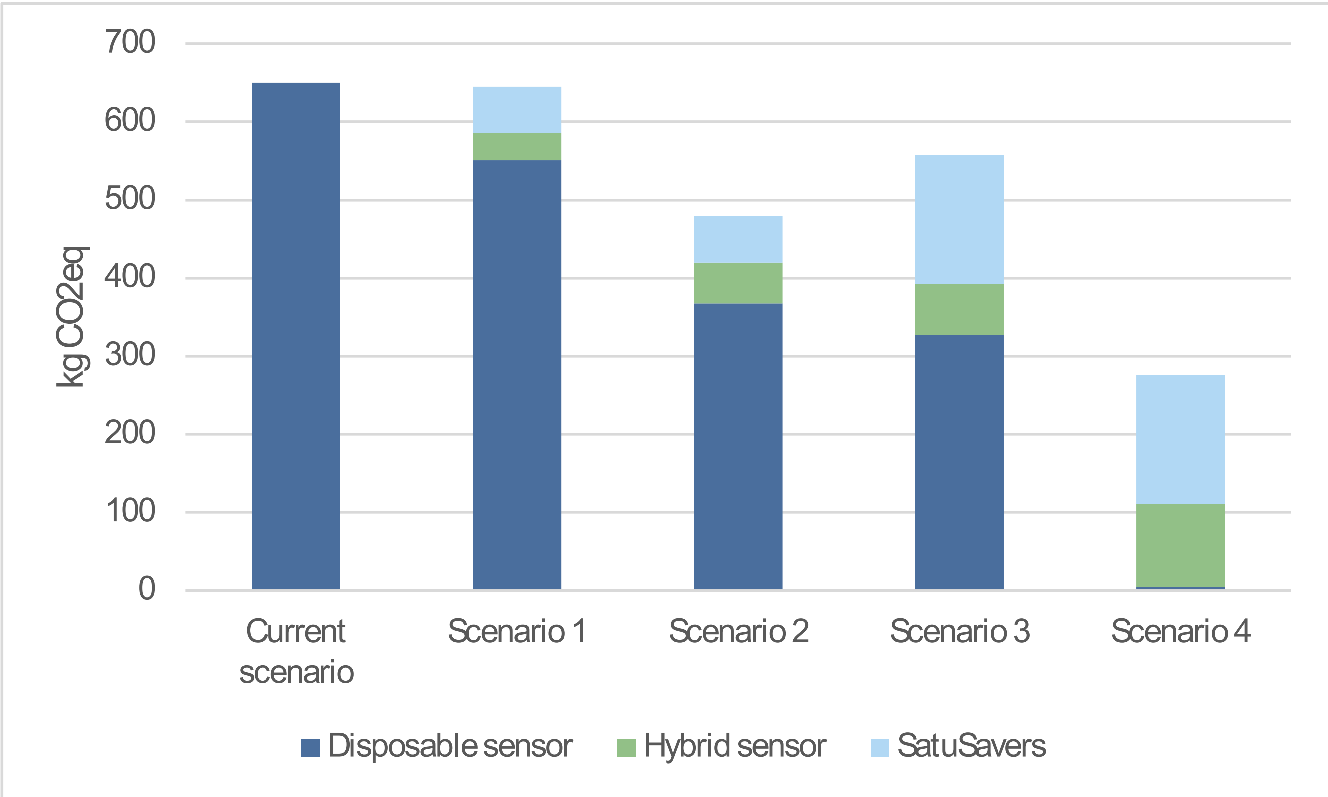


Figure 11.13: An estimation of the impact in kg CO2 eq of pulse oximetry in the different scenarios

11.8 Costs

To produce one SatuSaver for a pole, the material cost is approximately €1.85 per unit. The required energy to print the product is 3.7 kWh. With the average price per kWh being €0.27 (Pure Energie, 2025), the energy cost is €1.00.

There are two printers available at the hospital. It takes some time to upload the file, start the printer, and remove support material afterward. Since multiple prints can be placed at the same time, the estimated average time per unit is 10 minutes. Assuming an hourly wage of €25 for medical instrumentation staff, the labor cost per unit is €4.17.
The total cost per pole-mounted SatuSaver, including materials, energy, and labor, is therefore €7.02.

To produce a SatuSaver for a basket, the cost is approximately €9.70 per unit, and €15.97 for the SatuSaver placed in a drawer.

On a yearly basis, the hospital currently spends €48,113 on disposable pediatric pulse oximeters. Waste processing costs are negligible (less than one euro), due to the light weight of the sensors.

The cost of a hybrid sensor differs per supplier, but is on average around €156 per sensor, including 40 stickers. Additional stickers cost €0.64 each. In the case of a full switch to hybrid sensors with SatuSavers, the annual cost for pediatric saturation measurements is estimated at €14,350, based on material needs calculated in [X].

Thus, fully switching to hybrid sensors with the SatuSavers would result in a 70.2% cost reduction, saving the hospital approximately €33,763 per year.

Conclusion

Chapter 12 - Evaluation and discussion

12.1 Looking back at the list of requirements

To evaluate the final design, tests were carried out to check which requirements are met.

These final tests focused on the pole-mounted SatuSaver and were done with six students and one nurse. Requirements that were met are marked in green; those that are not yet met or can't be confirmed yet are marked in orange.

1. It should be possible to store the hybrid sensor in every room of all four pediatric departments
2. The storage method should not damage existing equipment in the rooms.
3. Disposable sensors should always be available in the patient room as a backup
4. The different sizes of stickers should be clearly recognizable in 2 seconds
5. It should be clear in 5 seconds which stickers and sensors need to be refilled
6. Storage design should clearly encourage the use of extra adhesive stickers over opening a new disposable sensor by making stickers more visible or faster to reach.
7. The soft silicone ends should be protected so that no visual damage is present after 50 uses.
8. The hybrid sensors should be stored in a way that avoids mechanical stress on the cable, ensuring that 90% still function after 5 years.
9. Cable clutter from the hybrid pulse oximeter should not occur more than once every 10 uses.
10. Cable entanglement of the pulse oximeter with other cables should not occur more than once every 50 uses.
11. When stored, used and clean parts should not be able to touch each other
12. It should be possible to grab a sticker without touching more than one other sticker
13. The stickers should not be stored in the open air for more than 24 hours.
14. The reusable part of the sensor should be cleanable with microfibre or 70% alcohol.

Wishes

1. It should preferably not take more time to get the needed equipment for saturation measurements than it does currently, so less than 30 seconds (excluding maternity ward).
2. Staff should be encouraged to use the hybrid sensor through environmental design based on nudging principles.

One of the requirements was that the different sticker sizes should be clearly recognizable within 2 seconds. This varied depending on the situation. When the stickers were placed correctly, everyone could identify them within the time. However, during testing, the small stickers sometimes tipped to the side, which made it harder to see them clearly.

The requirements of no visible damage to the silicone ends after 50 uses, working cables after 5 years, and no more cable entanglement than once in 50 uses, can't really be tested right now and need time to evaluate during actual use. The silicone ends are currently protected in the design so that nothing touches them when stored, so damage during storage is not expected. Also, when the cable is rolled up and hung on the hook as intended, it should not be under much stress. Still, it will depend on whether nurses actually use the SatuSaver in the way it was designed.

The requirement that stickers should not be left out in open air for more than 24 hours is also hard to measure at this stage. If stickers are only placed when a patient is expected and replaced after each use, they would be exposed for less than 8 hours, so they would meet this requirement.

12.2 Limitations

Three concepts have been developed, of which one has been fully worked out and is ready for implementation. The other two SatuSavers still require further development. The SatuSaver for in the drawer has not yet been tested, while the one designed for use on the basket has only been tested in an early stage with one nurse and later with non-healthcare professionals. Extensive testing is still needed to ensure optimal usability, cleanability, and manufacturability. To test within the Child and Youth department, the department manager first needs to be convinced with positive results of an extensive clinical study comparing the hybrid sensor with the disposable alternative.

A co-creation session was held, which generated many valuable insights. However, due to the busy and unpredictable schedules of nurses, only one nurse was able to participate. As a result, the input gathered was somewhat one-sided, and comparing perspectives between departments was challenging.

Interviews and usability tests were conducted throughout the project with healthcare workers. The pediatric GreenTeam was the most accessible and most willing to collaborate. However, their opinions are not representative of the average healthcare worker, as GreenTeam members voluntarily joined the team due to their interest in sustainability. They may therefore be more open to adopting sustainable alternatives compared to other staff members. Although non-GreenTeam members were also consulted, the balance between both groups was not ideal.

While observations of saturation measurements on actual patients were conducted, no actual testing took place in rooms with patients. Even though the SatuSavers do not come into direct contact with patients, it would still be valuable to assess their impact on pediatric patients. The designs aim to appear child-friendly and unintimidating, especially for younger children, but this still needs to be validated through testing.

Importantly, the SatuSavers are only functional if the hospital actually transitions to hybrid sensors. Although the clinical physics team is leading the project to replace patient monitors and are positive about the hybrid sensor, they do not make the final decision on which sensors are purchased. That decision lies with the individual department managers, and it remains uncertain whether they will be open to trying the hybrid sensors or prefer to continue using the disposable pulse oximeters.

12.3 Recommendations

To continue developing this project, several recommendations are provided per SatuSaver concept. In general, it is advised to conduct a detailed Life Cycle Assessment (LCA) of both the disposable pulse oximeter and the hybrid sensor to validate the expected environmental impact reduction.

12.3.1 Pole-mounted SatuSaver
The first step for the pole-mounted SatuSaver would be to implement it in a few rooms as a pilot. This should happen simultaneously with the introduction of the hybrid sensor, meaning the pilot should wait until the installation of the new Nellcor patient monitors, which is expected around the end of 2025.

It is recommended to carry out observations during the initial use of the SatuSavers and conduct short interviews with the nurses who use them. A department-wide survey could also help collect broader feedback on usability and any experienced drawbacks.

During observations, focus should be on:
- How many stickers are placed on the product
- Whether the stickers remain upright or tend to fall over
- If the two sticker sizes are placed correctly and consistently refilled
- Whether the cord is properly wrapped and placed on the hook without tangling
-Whether the sensor ends are stored as intended
- Whether the SatuSaver stays clean

In addition, purchasing data of disposable pulse oximeters should be tracked to determine whether the SatuSavers have the intended effect of reducing use.

12.3.2 SatuSaver on the basket
Based on initial testing, several design improvements are recommended for the basket version. Although the shelves were adjusted to make it easier to grab the lower sticker, the movement is still not fully intuitive, and visibility of the sticker when standing in front of the basket is not optimal. A new design iteration should be made to improve this.

The same applies to the accessibility of the stickers in the closed compartment. The addition of a tilted base improved usability, but grabbing a sticker while holding the lid open remains suboptimal, especially with shelves positioned above.

Further, the production of the transparent lid has not yet been investigated. Research should be done to determine the most suitable material and possible manufacturers, along with a pricing comparison.

Additional testing should be conducted with nurses from the Child and Youth department. This testing should also examine how the design impacts access to other items in the basket.

It may be worth exploring whether the SatuSaver could be expanded to store other materials more efficiently as well.

12.3.3 SatuSaver in the drawer
For the drawer version, the ideal size needs to be determined: one that provides space for all compartments without taking up too much room for other products.

Optimizing the size also supports a broader recommendation: reducing the weight of the SatuSavers. A lighter design lowers the energy and environmental impact of 3D printing. While the pole-mounted version is already designed to be lightweight, the other two could be improved further. For example, walls with a 5 mm thickness could be redesigned as two thinner layers with a hollow section in between.

12.3.4 Longterm recommendations
In the future, the SatuSaver designs could be adapted to accommodate hybrid blood pressure or ECG equipment if such technologies become available.

After a successful implementation at RdGG and validation over time, the concept could be scaled up for use in other hospitals. The designs can be easily adapted in terms of color, logo, clamp diameter, and dimensions to fit different departments or equipment.

For large-scale production, investing in injection molding might become financially beneficial. Producing in large batches also reduces the environmental impact per SatuSaver (Faludi, 2019). In that case, collaboration with GreenCycle could be explored to use recycled medical waste for the blue component of the SatuSaver.

12.3.5 Conclusion

In short, the next step is to 3D print additional SatuSavers using the printers at RdGG. A pilot project using the pole-mounted SatuSaver in combination with the hybrid sensor should then be launched in the Neonatology department once the new monitors are in place.

Observations, interviews, and a survey should be carried out to gather feedback. In parallel, a clinical study should evaluate the performance and safety of the hybrid sensor.

If successful, the pole-mounted SatuSaver can be rolled out in the Obstetrics and Maternity wards. Based on pilot feedback, the other two SatuSaver versions can be further developed and adjusted. Eventually, all SatuSavers can be implemented across Neonatology, Maternity, Obstetrics, and the Child and Youth department.

Chapter 13 - Conclusion

Pulse oximetry is widely used in pediatric care, but its environmental impact is significant due to the use of disposable sensors. While reusable alternatives present clear sustainability benefits, the transition is challenging. This is especially challenging in pediatric settings, where patient comfort is critical and large ranges of weight and sizes of patient exists. This project explored these challenges at Reinier de Graaf Gasthuis and aimed to support a shift toward more sustainable pulse oximetry practices. Through interviews, observations, and a co-creation session with healthcare professionals, key barriers were identified and addressed with a practical design intervention tailored to the needs of pediatric caregivers.

1. What are the main barriers to switching to reusable instead of disposable pulse oximeters for pediatric caregivers at Reinier de Graaf Gasthuis?
The main barriers are both practical and perceptual. Caregivers raised concerns about the physical limitations of reusable sensors, especially for children under two years of age. These sensors often lack adhesive, come in limited sizes, and are heavier, resulting in discomfort, detachment, or inaccurate readings. These issues reduce trust in their reliability and suitability for pediatric use. Perceptions also play a strong role: reusable sensors are often viewed as less hygienic, less accurate, and less child-friendly, despite evidence supporting their safety and effectiveness. A lack of familiarity with available reusable options and unclear ownership of decision-making further delay adoption. Overcoming these barriers requires both design improvements and an inclusive implementation approach that builds caregiver confidence and ownership.

2. What does the current system for pulse oximeter use look like, and what are its pain points?
The current system is inconsistent across departments and often inefficient. Storage solutions vary, leading to misplaced items and extra work for staff. Nurses frequently struggle with sensor application, particularly on newborns, and fragile sensor connections can lead to extra disposal. In many cases, sensors are thrown away due to vague errors or simply because of time constraints.

In adult departments using reusables, additional issues were noted, such as unbreathable materials and misplaced sensors, highlighting the importance of not only improving the products themselves but also the supporting system around them. Consistent organization, stakeholder involvement including clinical physics and infection prevention, and clear protocols are necessary for a successful transition.

3. What intervention is needed to overcome the most important barriers, ensuring a seamless transition?
To address these challenges, a set of three context-specific solutions was developed: the SatuSavers. These products aim to support the introduction of a hybrid pulse oximeter sensor (partly reusable) by improving storage, ease of use, and durability. Each design supports a specific context: a pole-mounted version, a monitor-basket version tailored for the Child and Youth department, and a drawer version for long-term storage. All include dedicated spaces for sticker storage, sensor protection, and cable organization to prevent entanglement and damage.

Designed in collaboration with nurses and based on insights from their workflows, the SatuSavers include behavioral nudges to subtly encourage adoption. Their compatibility with in-house 3D printing makes them accessible and scalable within the hospital environment. By addressing both product and system-level pain points, these interventions offer a practical and sustainable step toward reducing single-use waste in pediatric pulse oximetry.

Chapter 14 - Personal reflection

As I complete this six-month graduation project, and with it, my entire studies, I will reflect on the journey and the personal goals I set for myself.

14.1 Personal Goals

One of my main personal goals was to design something that fits into a broader system, rather than just a nice-sounding concept. I wanted to create something realistic and feasible, taking into account all contextual factors and constraints. I conducted a lot of research into the system surrounding pulse oximetry and the workflow of nurses who use these sensors. I believe I succeeded in designing a product that is truly suited to the hospital context while considering the broader system in which it is used. I'm very grateful for the opportunity to work in and with the hospital, this made understanding and analyzing the environment much easier.

Another goal was to improve my skills in working with different stakeholders: learning to listen to diverse perspectives, navigate conflicting expectations, and make confident, informed decisions. In the beginning, this was quite challenging. I was unfamiliar with the hospital's structure, and there were many stakeholders involved with their own priorities. However, over time, I learned to better manage the stakeholders.

The co-creation session really helped in this process. I received a lot of positive feedback on how I facilitated and involved participants in the creative process. This was a big achievement for me as it was my first self organised co-creation session.

I also challenged myself to go beyond low-fidelity prototypes and deliver something functional that could be tested properly and be close to a finished product. I believe I really succeeded in this. While I had worked with 3D printing before, I had never done it to this extent. I learned a lot, through hands-on experimentation, support from the PMB department, and contact with Oceanz. I'm proud of the final design, which is well-tested and ready for implementation.

Throughout the project, I learned a lot about the hospital system itself. I gained insight into the complexity of internal processes, the importance of different stakeholders and specific design considerations for medical contexts. Togheter with the thesis lab exercions and sessions i learned a lot about sustainability in health care.

14.2 Being a designer in a hospital

Hospitals are not traditional design environments, which can be both interesting and challenging. Healthcare professionals aren't always used to working with designers, which sometimes led to a problem-focused approach or hesitancy in engaging creatively.

Planning meetings with care staff was difficult due to their unpredictable schedules. I learned that the best way to engage with them was simply to walk by and ask if someone had a moment, something that felt intimidating at first but turned out to be the most effective. I eventually conducted test sessions with two nurses at a time, which was very productive. They reflected together, asked new questions, and built on each other's feedback, something that really enriched the outcome.

Working with the hospital's Green Team was also a big advantage. They were proactive, open to solutions, and already familiar with tackling environmental challenges in healthcare. Attending their meetings taught me a lot about other areas of hospital-related pollution and how sustainability can be implemented in daily operations. Observing how the sustainability coordinator works also gave me insight into the balance between top-down strategies and bottom-up initiatives. For any designer entering a hospital setting working on sustainability, I would recommend reaching out to Green Teams.

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Appendix

Appendix A: Full literature review

Barriers for healthcare providers in choosing reusable medical products over disposable alternatives

Abstract
The healthcare industry is a large contributor to environmental pollution, with hospitals generating 4.6% of global greenhouse gas emissions. A big portion of this comes from the reliance on single-use medical devices, which create large amounts of waste and deplete natural resources. Reusable medical devices are a more sustainable alternative, but their adoption remains low due to various barriers. This paper explores the barriers that prevent healthcare providers from choosing reusable medical devices instead of disposable ones.

A systematic literature review was conducted, analyzing 15 papers and identifying 35 relevant barriers. These barriers were categorized into safety, social, systemic, and technological challenges. Social barriers were mentioned frequently and concerns about safety, lack of awareness, and resistance to change were key obstacles. The findings suggest that addressing these social barriers should be a priority. The study highlights the need for a combined approach, including improvements in product design, education, and system-level changes. Future research should validate these findings with healthcare providers and focus on specific cases, such as reusable oximeters, to develop targeted solutions.

Circular economy; Circular design; Medical devices; Reusable devices; Sustainable healthcare;

Introduction
The healthcare industry is facing a big environmental problem. Hospitals and medical centers produce 4.6% of global greenhouse gas emissions, with most of this coming from supply chains that depend on single-use medical devices (Watts et al., 2019). These devices are made to be used once and then thrown away. This “use-and-throw-away” system wastes natural resources and harms the environment while making the hospital reliant on those single-use medical devices (MacNeill et al., 2020). Yet, an increasing number of medical devices are designed for single use (Alkatout et al., 2021).
To address this environmental problem, the idea of a circular economy is gaining attention. A circular economy focuses on reducing waste by reusing, repairing, and recycling materials to make the most of resources (Moreno et al., 2016). Medical devices that can be reused or recycled help reduce waste, save valuable materials, and lower the carbon footprint of healthcare. For instance, studies show that switching to reusable medical devices can cut emissions by up to 63% compared to disposable ones, although reusable devices may use more water (Keil et al., 2022). This research only focuses on the strategy of reuse, as reuse is the most common circular strategy for medical devices. As stated by Hoveling et al. (2024), 95% of all medical devices that used a circular strategy, were reusable for more than one product life cycle.

Despite the benefits of reuse, healthcare has been slow to adopt reusable products. Challenges are among others strict regulations and concerns about contamination. The widespread use of single-use devices also shows worries about patient safety, supply chain issues, and limited awareness of the environmental harm caused by disposable products.
Frameworks to replace single-use devices and general barriers to achieving a circular economy have been examined in previous papers (Vanderwee et al., 2024)(Abreu et al., 2002), but there has been no specific focus on the barriers for healthcare providers like nurses and physicians for choosing a reusable option instead of a disposable one. Health care providers are end users of medical devices, they make clinical decisions that determine the necessity and volume of resource use. For many medical devices, there are already reusable alternatives available. Hospitals sometimes have both the reusable as well as the disposable option of a device available, healthcare providers can in this case select between the options, influencing procurement volumes (Hennein et al., 2022).

As disposables are still chosen a lot, insights into this choice are needed to improve reusable products and make them a better choice than disposables. The objective of this paper is to explore the barriers for healthcare providers for using reusable or circular medical products instead of disposable ones. Understanding these barriers can help the healthcare industry to decrease the use of disposable medical devices.

Method

A systematic review was conducted to identify barriers of using reusable medical devices compared to disposables. The database Scopus was used to find the selected papers. The following keywords were used to search the database:("Circular economy" OR "reusable devices" OR disposable OR single-use) AND "medical devices" AND (barriers OR challenges OR implications). The Scopus search was conducted in article title, abstract and keywords without restriction of time, in January 2025, and resulted in 81 papers. The articles (Jessica F Davies et al., 2024)(Tamara Hoveling, 2024)(Rumana Hossain, 2024)(Andrea J. MacNeill, 2020) were found as the basis of this analysis. Via snowballing 11 more articles have been found. A total of 15 articles have been analyzed for this review.

After the most insightful papers were selected, all barriers mentioned in the papers were listed in a table. The barriers were analysed by clustering the types of barriers into the categories made by Hoveling et al. (2024). Only the barriers that were both relevant to healthcare providers and could be influenced by industrial design were selected. These selection criteria are based on the objective of this study, which is to analyse the problem of disposables as a start for this industrial design project aimed at addressing the barriers healthcare providers face when choosing reusable alternatives. By focusing on barriers that can be addressed through design, it ensures that the results are useful for creating reusable medical products that healthcare providers are more likely to use instead of disposable alternatives. Selecting the barriers based on these two criteria led to a complete removal of all barriers from the categories regulatory and financial barriers as barriers listed in these categories are all not influenceable by design or not relevant for healthcare providers.

Results

In total, 94 barriers were identified in 15 papers. After selecting only the papers that comply with the criteria, 35 barriers remained. The most frequently identified barriers are the perception that single-use disposables are safer than reusable devices and patients having negative perceptions of reusable devices. The barriers are summarised into categories based on their topics and listed in table 1.

Safety barriers

Multiple safety barriers make healthcare providers hesitant to choose reusable medical products over disposable alternatives. A common barrier is the perception that single-use disposables are safer, as they come pre-sterilized. This reduces worries about contamination due to human error and cross-infection. Some papers found that some healthcare professionals doubt whether reusable products can be fully cleaned and decontaminated, making them trust their safety less.

Social barriers

The social barriers to choosing reusable medical products mainly come from perceptions, habits, and a lack of awareness. Some staff believe that reprocessing equipment is worse for the environment than throwing disposables away. A lack of education and misinformation play a role, as staff may not fully understand the benefits of reusable products or the principles of a circular economy. Many healthcare workers and patients prefer single-use devices because they seem more convenient, easier to use, and safer. There is also public mistrust—patients may be uncomfortable with reusable items. Workplace culture and decision-making structures also contribute to the issue—product users often don't have control over which devices are used, and sustainability is not seen as a priority in their roles. Finally, resistance to change is a big barrier.

Barrier	Category	Source
Perception that single-use disposables are safer than reusable devices	Safety barriers	(R. Hossain et al., 2024),(MacNeill et al., 2020), (Davies et al., 2024), (Hoveling et al., 2023)
Potential for cross-infection	Safety barriers	(Tsay & Sabharwal, 2024), (MHRA, 2021)
Inability to clean and decontaminate	Safety barriers	(MHRA, 2021), (Hoveling et al., 2024)
Careless adherence to decontamination method (human factor)	Safety barriers	(Hoveling et al., 2024)
Dangers of hazardous components such as batteries and toxins	Safety barriers	(Hoveling et al., 2024)
Focus on use and clinical outcomes, opposing circularity	Safety barriers	(Hoveling et al., 2024)
Public mistrust / Negative public perceptions of patients	Social barriers	(Tsay & Sabharwal, 2024), (Hoveling et al., 2024), (Kelly et al., 2022)
Consumers prefer the single-use option over the reusable or the doctor's preferred option (in case of the endoscope)	Social barriers	(Chuah et al., 2024)
Unawareness about and complexity of the circular economy	Social barriers	(Hoveling et al., 2024)
Failure of reprocessing is highly stressful	Social barriers	(Davies et al., 2024)
Attitudes, preferences (or differences between), and lack of support	Social barriers	(Hoveling et al., 2024), (Hennein et al., 2022)
(Expected) limited environmental benefits of actions	Social barriers	(Hoveling et al., 2024)
Product users are separated from device decisions	Social barriers	(Davies et al., 2024)
Belief that reprocessing reusable equipment is worse environmentally than using a disposable item and throwing it out	Social barriers	(Davies et al., 2024)
Belief that reusable equipment creates an extra step for nursing and support staff, and does not enable the most efficient workflows	Social barriers	(Davies et al., 2024)
Ease of use of single-use devices	Social barriers	(Milota, 2024)

Sustainability is not a priority and not part of staff roles	Social barriers	(Davies et al., 2024), (Hoveling et al., 2023)
Staff intend to make sustainable choices when possible, but might feel it is in conflict with other intentions, such as patient safety and reducing burden on colleagues	Social barriers	(Davies et al., 2024)
End users have power to make decisions but are usually isolated from the waste disposal and other implications beyond the use of the item, therefore might not weigh environmental impacts as heavily	Social barriers	(Davies et al., 2024)
Staff is resistant to change	Social barriers	(Sullivan et al., 2023)
Staff misconceptions	Social barriers	(Sullivan et al., 2023)
Lack of social acceptance leading to circular behavior	Social barriers	(Hoveling et al., 2023)
Worry for increasing waste streams	Social barriers	(Milota, 2024)
'Verander-moe': tired of change	Social barriers	(Milota, 2024)
Inadequate information or education	Social barriers	(Petre et al., 2018)
Lack of knowledge or training for reprocessing	Systemic barriers	(Tsay & Sabharwal, 2024)
Possibility of human error in reprocessing	Systemic barriers	(R. Hossain et al., 2024)
Practical difficulties related to collection and separation logistics	Systemic barriers	(Hoveling et al., 2024)
Time constraints of all stakeholders	Systemic barriers	(Hoveling et al., 2024)
Inability to collect and separate devices	Systemic barriers	(Hoveling et al., 2023)
Concerns for mechanical failure	Technological barriers	(Tsay & Sabharwal, 2024),(MHRA, 2021)
Focus on and need for high quality and function of the device	Technological barriers	(Hoveling et al., 2024)
Inability to perform device updates in circular devices	Technological barriers	(Hoveling et al., 2024)
Concerns for material alteration	Technological barriers	(MHRA, 2021)
Perception of decreased functionality	Technological barriers	(Hennein et al., 2022)

Figure A.1: all barriers found in the selected papers that are relevant for healthcare providers and influenceable by industrial design.

Staff are often overwhelmed by frequent policy changes and may worry that switching to reusables will add extra steps to their workflow, increasing stress and burden to them or their colleagues.

Systemic barriers
A systemic issue is the lack of knowledge or training on how to properly clean and sterilize reusable devices, which increases the risk of mistakes. This connects to the possibility of human error in reprocessing, as improper cleaning can lead to safety concerns. Additionally, practical challenges in collecting and separating reusable products make the process inefficient, especially when healthcare workers already face time constraints in their daily tasks.

Technological barriers
A common technological barrier is the risk of mechanical failure and material alteration, as reusable devices may wear down over time affecting safety and effectiveness. Healthcare providers also prioritize high quality and functionality, and there is a fear that reusable devices might not always meet the same performance levels as disposable ones. There is a perception that reusable devices have a decreased functionality, even if it is not always the case. These concerns make healthcare providers unsure if reusable medical products are practical and reliable, making adoption more difficult.

Discussion
All barriers listed in this article highlight the complexity of transitioning from disposable to reusable alternatives in hospital settings. Even though improvements in design are necessary, it should be combined with improvements in education, and system-level changes. Switching to reusables requires a holistic approach that considers both product design and the broader hospital environment.

Whether a barrier is of relevance for a healthcare worker is now based on assumptions and critical thinking. Further research with healthcare workers is needed to validate these assumptions. Moreover, barriers can differ a lot depending on the type of healthcare providers, hospital and country. Differences in rules and regulations per country can influence the barriers as well. These differentiations are not yet taken into account in this study. Future research should explore how these factors influence the adoption of reusable products in different healthcare systems.

Even with the added criteria, there are still a lot of barriers found. Among these, social barriers stand out as a big obstacle, as they prevent healthcare workers from even trying reusable products. Social barriers were also the largest category of all the barriers identified, making them a key focus. Addressing misunderstandings, resistance to change, and workplace culture should be a priority before focussing on product-specific challenges.

This study focuses only on the barriers in the medical field, but similar barriers may exist in other industries where single-use products are used. By including research in other sectors, additional insights could be found that also help in designing better strategies for switching to reusable alternatives in the healthcare sector.

As a next step, research should also focus on oximeters, as this will be the topic of the upcoming design project. Conducting interviews with healthcare workers will help verify which barriers are most relevant for this specific case.
Finally, frameworks for changing habits should be explored, as experienced healthcare workers most likely make the choice between using reusables and single-use products unconsciously.

Conclusion
Multiple barriers make healthcare workers hesitant to choose reusable medical products over disposable alternatives. Misinformation and perceptions need to be tackled to improve trust in the safety and reliability of reusable products. Moreover, a reusable design should address the logistical challenges of reusables, such as improving collection, sterilization, and redistribution processes to decrease the feeling of healthcare providers that reusables are an extra burden for themselves or others. The reusable products need to be just as convenient and time-efficient as

disposables, design improvements should focus on making reusable products simpler and more user-friendly. More evidence is needed on how well reusable products perform over time. Design improvements are needed to help reusable devices match or exceed the quality of disposables.

Next steps could be to validate assumptions with healthcare workers, focus on specific barriers for the oximeter and look into habit-changing frameworks.

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Appendix B: Stakeholders

Reinier de Graaf Gasthuis
Reinier de Graaf Gasthuis is the hospital for more than 500.000 people with over 3000 employees. Reinier de Graaf Gasthuis became an independent hospital in 2023 and offers specialized care in areas such as oncology, fertility, hematology, and pediatric allergy.
The hospital includes eight care units: Mother & child, oncology, chronic care and vulnerable elderly, acute care and planned care. Since 2015, Reinier de Graaf Gasthuis has been processing its waste and wastewater sustainably through the purification system and associated Tonto (grinders) from Pharmafilter. As of March 2024, Reinier is discharging its wastewater into the municipal sewer system again due the bankruptcy of the Pharmafilter.

Waste that was previously processed through the hospital's bio-purification system via the sewer will now be disposed of through the regular (specific hospital) waste streams. Currently Pharmafilter is processing wastewater again, but not solid waste. Because of this history of using the Pharmafilter, the hospital is used to disposing of disposables and throwing them all awaying in the same place. Now that the filter is not able to process these disposables anymore, they are in need of drastic changes in product use and waste separation. Reinier de Graaf Gasthuis has received bronze in the environmental thermometer (milieu thermometer). This year, they signed the Green Deal sustainable care 3.0, showing their willingness to become more sustainable. In this Green Deal, it is stated that the hospital should transition to at least three reusables instead of disposables.

GOUD
ZILVER
BRONS

Greenteams
To actively make sustainable steps, the green teams were founded. There are 12 green teams in Reinier de Graaf Gasthuis, all active in different departments. These green teams consist of enthusiastic employees who are willing to spend time before and after their working hours or in their breaks on making the hospital more sustainable. Alie Rozendal, the sustainability coordinator, manages and supports these green teams. Together they are trying to improve the waste separation and reduce waste overall. Examples of green initiatives are only doing a line change of the infusion sets at the IC once a week instead of every 48 hours and switching almost fully from sterile gloves to normal gloves in the obstetrics department.

Patients
The patients are all children aged 0 to 18. Most patients who are continuously monitored for oxygen saturation are lying in isolation and are staying at the hospital for multiple days. In most cases, at least one of the parents is present in the room with their child. For the child it is important that the sensor is not annoying, as some may try to remove it by pulling or shaking it off. Parents want their child to get better as soon as possible, meaning they want the best possible care and medical devices.

Nurses
Nurses work the most with the pulse oximeters. They will get the sensors from the storage place, unpack them and apply them to the appropriate location on the patient's body. During each shift they will also move the sensor to the other hand or foot of the patient to prevent pressure points. If there is an issue with the sensor or the readings, they will receive an alarm and fix the problem. In some cases this means resticking the sensor or taking a new one. For nurses, the ease of use and correct working of the oximeter are important criteria.

Nurse managers have an extra organizational function and also have influence on what products will be purchased for their department, primarily considering criteria such as cost and quality. Most nurse managers are not well informed about more sustainable options and see this as extra work.

Doctors
Doctors mostly do not work directly with the sensors, but read the measurements from the 'broodje'. They decide their treatment among others based on the results of saturation measurements, meaning they want accurate and reliable measurements. In critical situations, they also need results quickly.

Manufacturers
The manufacturers want to have the highest profit. By marking products as single-use, manufacturers create an unending demand for their product, making disposables particularly attractive to manufacturers. It also costs manufacturers money to label a product as reusable (Kamille, 2023). Knowing that most hospitals need to comply with sustainability rules and want to meet their green initiatives, manufacturers also offer reusables. Masimo has even produced a newer version of disposable pulse oximeters with the focus on sustainability. Among other changes, they have reduced the cable length and packaging, claiming to reduce waste by 84%. But ultimately, it is the decision of the manufacturer whether they want to label a device as 'reusable' or 'single-use' (Rutala & Weber, 2019).

Health insurances
Health insurance companies have a big influence on hospitals, as they fund hospitals using the insurance premiums paid by patients. Health insurances want to offer the cheapest possible insurance packaging to attract the most people. They generally require hospitals to comply with the Green Deal sustainable care 3.0.

Appendix C: Product life cycles

Disposables
Disposable pulse oximeters are ordered by procurement via ZXL (Zorgservice XL) who buys the sensors from a supplier, who in turn buys them from the manufacturer. A lot of transport is done here to get the sensors from the place of manufacturing to the hospital.

The 'kastscanners' of logistics deliver the boxes with the disposables to the correct storage rooms in the departments and throw these boxes away.
After using the sensor, the packaging, potential gloves and the sensor itself are thrown away as well. Reduction of the impact of disposables can be realised by reducing unnecessary glove usage, reducing or eliminating the packaging for each individual sensor or reducing the amount of sensors used per patient.

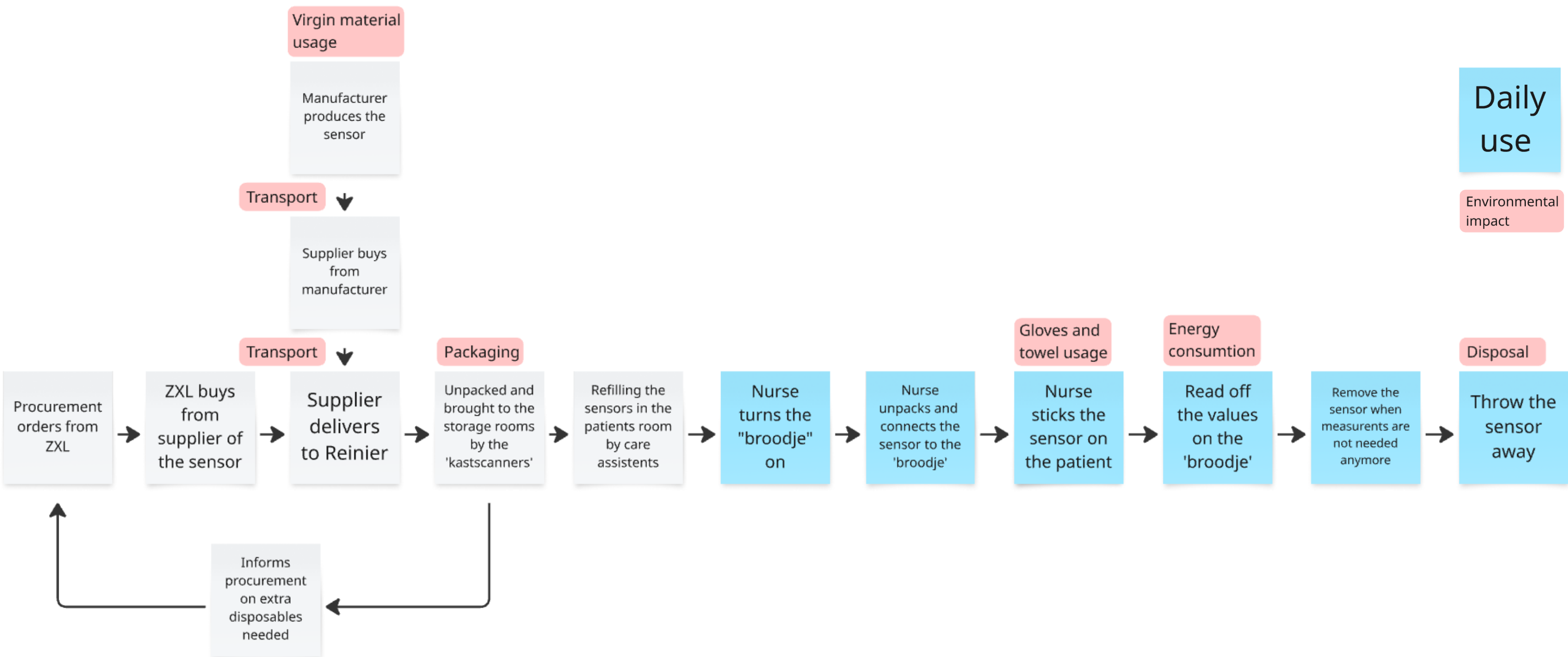


Figure C.1: Product life cycle of disposable pulse oximeters

Reusables
The process of buying a reusable pulse oximeter is more complicated and time consuming. A purchase file needs to be created, the manual of the supplier needs to be assessed and specific protocols need to be made for the department. Medical instrumentation, material advisory committee, department leaders and infection prevention are all involved. The sensor is ultimately ordered in Topdesk, which buys the sensor from the manufacturer's supplier. Also in this case, a lot of transport is needed to deliver the sensor to Reinier.

However, this transport and the needed materials and energy for manufacturing is only needed once. For reference, in 2024 only a total of 22 reusable sensors have been ordered for the whole hospital. During use, the measurement needs the same amount of energy and potential gloves. The only extra step is the use of cleaning materials. According to Duffy et al. (2023), in a low-use scenario of 385 uses per day, the impact of cleaning is only 17% of the impact of disposable pulse oximeters.

This is in the scenario of staff using extra wipes for the cleaning of the sensor and not using the same as they use for the rest of the monitor and cables. The energy consumption of the measurement itself stays the same. The impact of the end-of-life reusables is only 0.14% compared to disposables, as reusable sensors last much longer. So the initial ordering of a reusable sensor takes more time and costs more money, but they last much longer, reducing costs and impact in the longer run.

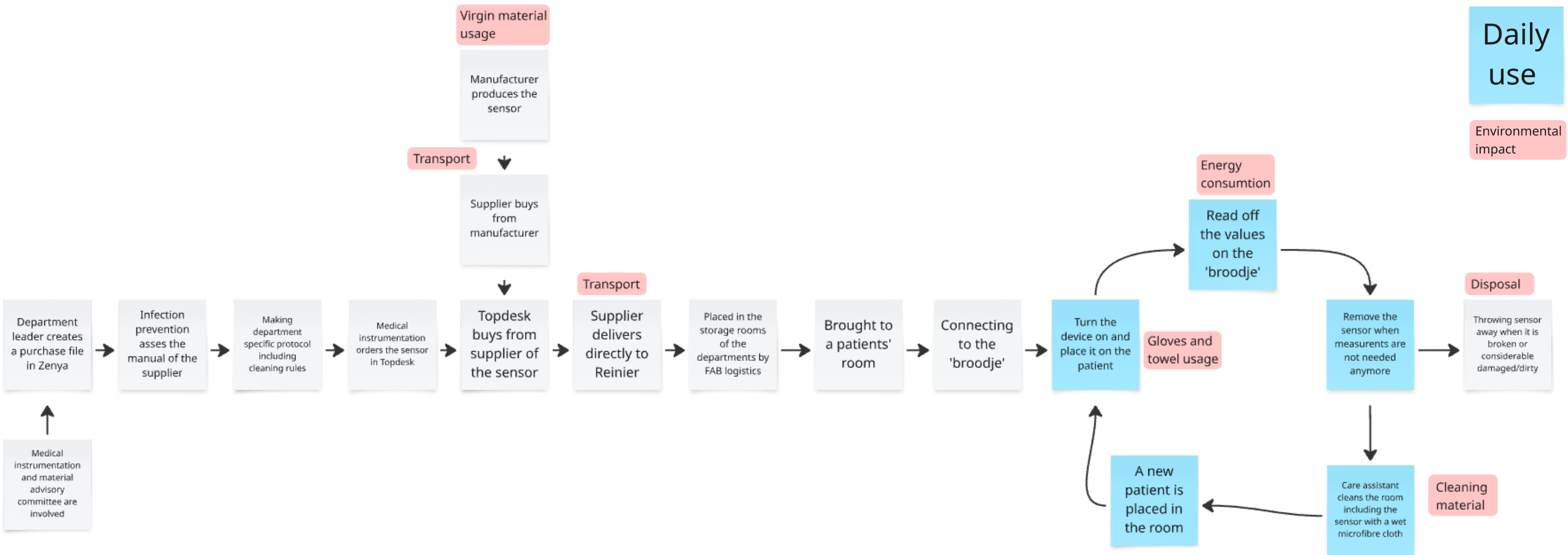


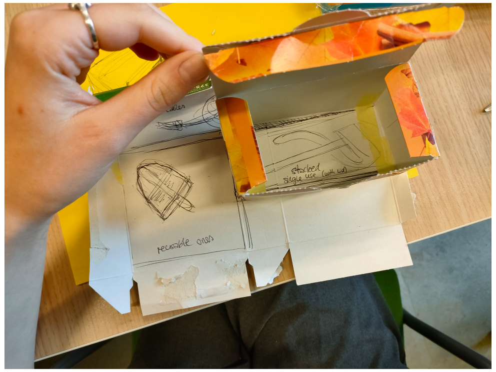
Figure C.2: Product life cycle of reusable pulse oximeters

Appendix D: Co-creation with students

A cabinet on the wall with different comparments. Three different wholes are made for the different sizes sensors. Open comparments are for reusable, to make them easy accesable

A fun storage box for sensors, placed on the bed to be easy reachable by nurses. Children who are staying longer can personalise the box (choose a color, add their name).

Reusable sensors always visable, with their cables being hidden. Disposables are available in a separate closed box.



A sticker roll is placed at the back of the box, making it possible to pull out a new sticker. The disposables are stored in a separate box with a lid, under the stickerroll.

Appendix E: Moodboard product families

Hema

Mepal

Ikea

Appendix F: Environmental impact of possible future scenarios

	Current scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Disposable sensors	4135	3504	2336	2080	26
Extra stickers	414	350	234	208	3
Hybrid sensors	-	47	47	70	70
Stickers	-	989	1979	2265	4530
Cleaning wipes	-	600	1199	1370	2739
SatuSaver pole	-	15,65	15,65	15,65	15,65
SatuSaver basket	-	-	-	23,3	23,3
SatuSaver drawer	-	15,65	15,65	7,67	7,67
Total impact (kg CO2 eq)	650,204	645,294	479,502	557,595	275,464

	Kg CO2 eq
Disposable sensors	0,15605849
Separate stickers	0,01184626
Hybrid sensors	0,35437821
Cleaning whipes	0,010233
SatuSaver pole	1,303
SatuSaver basket	2,5186
SatuSaver drawer	5,3718

The top table shows the amount of each element needed for each scenario.

The bottom table shows the environmental impact of each element in kg CO_2-eq.

The total is calculated by multiplying the amount by the environmental impact of each element and then adding everything up.

Personal Project Brief – IDE Master Graduation Project

DESIGN FOR our future

TU Delft

Name student Irene Algra

Student number 5,070,643

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

Project title Designing an intervention to reduce the impact of disposable pulse oximeter use in pediatric care

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

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

The healthcare industry is a large contributor to environmental waste, as hospitals generate high amounts of waste from disposable medical products. Single-use medical devices are used because of their convenience and perceived safety, but they have a high environmental impact. Hospitals are increasingly looking for sustainable solutions to reduce medical waste and lower their environmental impact. This project takes place within the sustainable healthcare domain, focusing on reducing waste and environmental impact of single-use medical devices.

The main stakeholder in this project is the hospital Reinier de Graaf, which aims to decrease its hospital waste to reduce costs and meet the goals of the Green Deal Duurzame Zorg 3.0. This agreement states that in 2026, at least 20% of all medical tools used in hospitals should be reusable. The focus of this project is the pulse oximeter, a device used to measure oxygen levels in patients. The NFU has identified oximeters as the second most environmentally harmful medical product, making them a priority for sustainable redesign.

Many hospitals already have reusable alternatives for medical devices, but healthcare providers often choose disposable versions. Since they are the end users making clinical decisions, their choices directly influence how many disposable products are used and purchased. To make reusables a more desirable choice, this project will focus on understanding social barriers that lead healthcare providers to prefer single-use devices and designing an intervention to address these barriers and make a more sustainable option more practical, convenient, and trusted.

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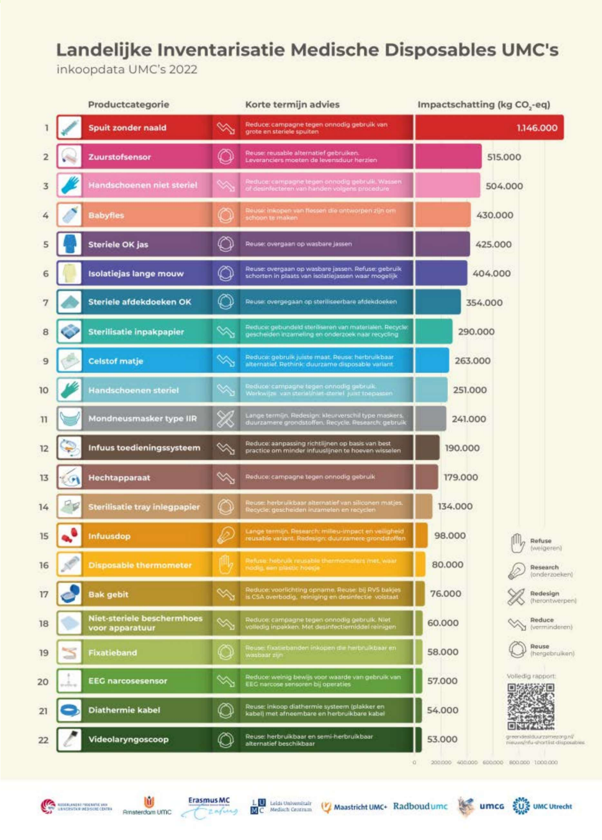

image / figure 1 Total impact per product category, with the pulse-oximeter in second place, in UMC's (NFU, 2024).

image / figure 2 Disposable pulse oximeters used in the Reinier de Graaf hospital for children and infants.

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

The main problem this project will address is the preference for disposable pulse oximeters in pediatric care over reusable alternatives. For almost all adult patient care, Reinier de Graaf is already using reusable pulse oximeters. Despite the availability of reusable options for children, single-use devices are still often chosen, leading to unnecessary medical waste and increased environmental impact. While previous research has focused on adults and regulatory and financial challenges, this project will focus on pediatric care and also adress social barriers such as the behavioral and cultural factors that influence decision-making in hospital environments.
This project will focus on understanding why healthcare providers hesitate to use reusable pulse oximeters for children and what design improvements can make them a more attractive option. Opportunities for added value lie in both behavior and design: by identifying key social barriers, such as concerns about convenience, hygiene, and workflow integration, this project can develop a redesigned reusable oximeter that aligns with the needs and preferences of healthcare providers.
The project will take a holistic approach, not only taking the technical aspects of the device into account but also the broader hospital environment. This includes improving user experience, reducing perceived inconvenience, and increasing trust in reusable medical devices. The ultimate goal is to provide Reinier de Graaf Hospital with a practical, evidence-based solution that supports their sustainability goals while ensuring high-quality patient care.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Design an intervention to reduce the impact of disposable pulse oximeter use in pediatric care by tackling the social barriers that healthcare providers at the Reinier de Graaf hospital face when making the choice between reusable and disposable oximeters in a hospital environment.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

I will start with doing research by doing hospital observations and short interviews with staff to understand current practices, challenges, and perceptions of reusable medical devices. I will create infographics to visualize key insights and complex processes. These results will be shared with important stakeholders during a session to achieve co-understanding of the problem. Later, a co-creation session will be organized to generate solutions together.
For the design phase, I will use multiple ideation methods such as morphological charts, SCAMPER and how-to's to generate solutions. Prototyping and testing will be done in the next design phase, ensuring usability and alignment with healthcare providers' needs. Additionally, Life Cycle Assessments will be made to compare the environmental impact of different design choices, making sure the final solution is both practical and sustainable.

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting**, **mid-term evaluation meeting**, **green light meeting** and **graduation ceremony**. 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 course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	6 Feb 2025
Mid-term evaluation	25 Apr 2025
Green light meeting	16 Jun 2025
Graduation ceremony	14 Jul 2025

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

For my design project, I want to use my strengths in user research, context investigation, and testing to create a meaningful and useful solution. I enjoy asking the right questions and studying the environment where a product will be used to find real needs. I also like making clear test plans to get results that can help improve the design. Additionally, I want to grow my idea generation skills by coming up with many creative and different ideas to explore.

In this project, I hope to learn more about sustainable materials: understanding which are recyclable or long-lasting and what barriers there are to implement such materials. I also want to design something that fits into a bigger system, not just a concept that sounds nice but something realistic with all different factors of the bigger context taken into account. Another goal is to improve my skills in working with different stakeholders, learning how to listen to everyone's opinions, handle disagreements, and make decisions confidently.

Personally, I want to be braver in my decisions: stop overthinking and just try things out. Meanwhile I do want to confirm my assumptions more with experts, including environmental and medical professionals, especially in the beginning of the project. Additionally, I plan to challenge myself to go beyond simple, low-fidelity prototypes and create something that works well and can be properly tested. This will help me deliver a design that is both functional and impactful.