Redesigning Medication Packaging

To be more sustainable for the Intensive Care Unit at Erasmus MC

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Glossary and Abbreviations

Sustainability = The ability to meet present needs without compromising nature and future generations' ability to meet their own, balancing environmental, social, and economic factors.

Hotspot = Sustainability hotspots are points in a process where the environmental impact is particularly high, often due to factors such as large volumes of materials or the use of materials with high carbon footprints.

EMC = Erasmus Medical Center

ICU = Intensive Care Unit

MFA = Material Flow Analysis

LCA = Life Cycle Analysis

CBG = College ter Beoordeling van Geneesmiddelen

SoPC = Summary of Product Characteristics

SZA = Specifiek Ziekenhuis Afval = Specific Hospital Waste

CRRT = Continuous Renal Replacement Therapy

API = Active Pharmaceutical Ingredient

Summary

While hospitals play a central role in healing, it is contradictory that healthcare activities contribute to climate change, ultimately creating a less healthy world. To achieve the goals of reducing waste and climate impact established to address this issue, action must be taken. Medication is responsible for a large share of Erasmus MC's emissions. However, research into the environmental impact of medication is still in its early stages. In particular, the impact of medication packaging remains largely unexplored and must first be mapped. For this purpose a Material Flow Analysis (MFA) was executed at the Intensive Care Unit (ICU) of Erasmus MC to assess its current environmental impact and to identify environmental hotspots (for potential reductions).

Patient care in the ICU is highly specialised and personalised, and medication plays a critical role in this. Medication packaging is composed of several components. The components included in this MFA study are primary packaging, secondary packaging, leaflets and accessories. All components come in many different shapes.

For all medications prescribed more than 250 times in 2023 within the ICU, the components of the packaging were assessed by weight. The three major hotspots in terms of material are plastic, glass and paper. A significant finding in terms of packaging was the share of dialysis bag boxes. These boxes alone account for 20% of the waste in the ICU.

In the second part of this study a redesign of the dialysis bag boxes was proposed. To redesign the dialysis bag boxes, their packaging was first examined and the surrounding system was mapped. The redesign process utilised the Circular R-strategies from Metabolic's Value Hill to reduce waste and the environmental impact of the packaging. During the ideation phase, two strategies were prioritised: reducing the paper content of the packaging and introducing reusable packaging. A cost analysis revealed that reusable packaging is both more sustainable and more cost-effective over time compared to single-use paper boxes. Existing reusable systems in healthcare and other industries, such as the fruit and vegetable sector, were also explored for inspiration.

From the ideation, four concepts were developed, and a final concept was selected: a dolly system combined with a box with a lid. This box can be sealed and is stackable and nestable, which is essential for transport and storage. Additionally, the reusable box is more user-friendly, saving nurses time and allowing them to focus more on critical patient care. By implementing this concept, 20% of the waste generated in the ICU can be eliminated.

This research primarily aims to highlight the challenges within the complex healthcare system and serves as an eye-opener for the industry to reconsider its strict regulations and environmentally harmful practices.

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Project Introduction

This is the introductory chapter of this report. It explains the importance of sustainability in the healthcare sector and how this report fits into this. The impact of medication packaging is highlighted and it discusses how sustainable design can make an impact on this.

1

1.1 Healthcare and Sustainability

1.1.1 Green Deal 3.0

While hospitals play a central role in healing, it is contradictory that healthcare activities contribute to climate change and thus affect public health. Healthcare in the Netherlands is responsible for 7% of its carbon footprint, 4% of its waste and 13% of its resource use. (Steenmeijer et al., 2022)

In recognition of this impact on the environment, healthcare institutions, insurance companies, medical device manufacturers and other stakeholders signed the Green Deal Sustainable Healthcare to create a more responsible way of providing healthcare. In it, they agreed on 5 goals to work towards (Figure 1). (Ministerie van Volksgezondheid, Welzijn en Sport, n.d.)

Because the focus on this project is about researching and redesigning the packaging of medication, the thesis project focuses primarily on goal 4, and aims to indirectly impact goals 3 and 5.

1. Promote health among patients, clients and employees
2. Raise awareness and understanding of the impact of healthcare on climate and vice versa
3. Reduce CO2 emissions by 55% by 2030 and to be climate neutral by 2050 compared to 2018
4. Reduce the consumption of primary raw materials by 50% by 2030 and maximise circularity in healthcare by 2050 compared to 2016
5. Reduce environmental harm caused by (use of) medication

Figure 1: Goals of the Green Deal 3.0

1.1.2 What does Erasmus MC do

To achieve these goals, the Erasmus MC has made its own goals in line with the Green Deal goals. For the carbon footprint, they want to target a 55% reduction by 2030 compared to the first measurements from 2019. They are committed to maximising the reusability of products and raw materials and minimising value destruction. They also have an ambition to raise the recycling rate to at least 40 percent by the end of 2024. Eventually, they aim to be fully circular and carbon neutral by 2050. (Erasmus MC, 2021)

To set the baseline and map the hotspots, Erasmus MC had the company Metabolic map its carbon footprint. They mapped out three scopes. Scope 1 is the direct emissions from the EMC. Scope 2 is the emissions from the generation of electricity, heating, and cooling. And scope 3 is the indirect emissions from for example travel, waste, products and medication. The greatest impact comes from scope 3, namely 72%, see Figure 2. This is mainly due to the purchased goods and services, among which are medicines. (Metabolic, 2023)

Different departments in the hospital set up green teams and projects to work on making their department and the hospital more sustainable. From these green teams, projects, initiatives and pilots have been started. Examples of some of these projects are:

- Mapping impacts: The obstetrics department mapped out the entire delivery process, from a visit and ultrasounds to childbirth. This makes it easy to find where sustainability interventions can be applied.
- Raising awareness: The "Goed gebruik handschoenen" (Good Usage of Gloves) project aims to provide insight into the unnecessary use and waste of gloves. This is done by informing staff and examining current gloves, their production and how they are packaged.
- Reducing emissions: Together with the Rotterdam municipality and other companies in Rotterdam, they are trying to make home-work and business travel more sustainable. This is done by encouraging employees to come by public transport or bicycle and by not allowing heavy trucks to make deliveries at the hospital.
- Becoming circular: With the Circular ICU project, the ICU green team, in collaboration with the TU Delft and others, aims to have the ICU fully circular by 2030. Hotspots of products were found from the MFA (Chapter 3.4). By improving these, they are taking steps towards a closed loop, using the R strategies. (Erasmus MC, n.d.)

Additionally, through collaboration with students from various universities, colleges, and PhD candidates, several more projects have been initiated. This thesis is one of these projects.

1.1.3 ESCH-R project

The ESCH-R project, which stands for "Evidence-based Strategies to create Circular Hospitals: Applying the 10-Rs framework to healthcare", is an ambitious initiative led by Erasmus MC and supported by a €5.3 million grant through the Dutch Research Agenda (NWA). (ESCH-R, n.d.)

This interdisciplinary initiative is a collaboration of universities, like TU Delft, hospitals and private sector partners like Philips, Medtronic, and PreZero. The project's goals include developing and implementing circular, scalable, and safe strategies for hospitals, such as designing systems for recycling and reducing single-use materials, while maintaining patient safety and operational feasibility. Behavioural research will also be conducted to encourage sustainable practices among healthcare workers.

Within this project, I work together with PhD candidate Jasper Klasen on mapping the packaging materials of medication. From this research, I will be redesigning one of the products to be more sustainable. This will be done with the R strategies. These strategies will be elaborated on in Chapter 1.4.

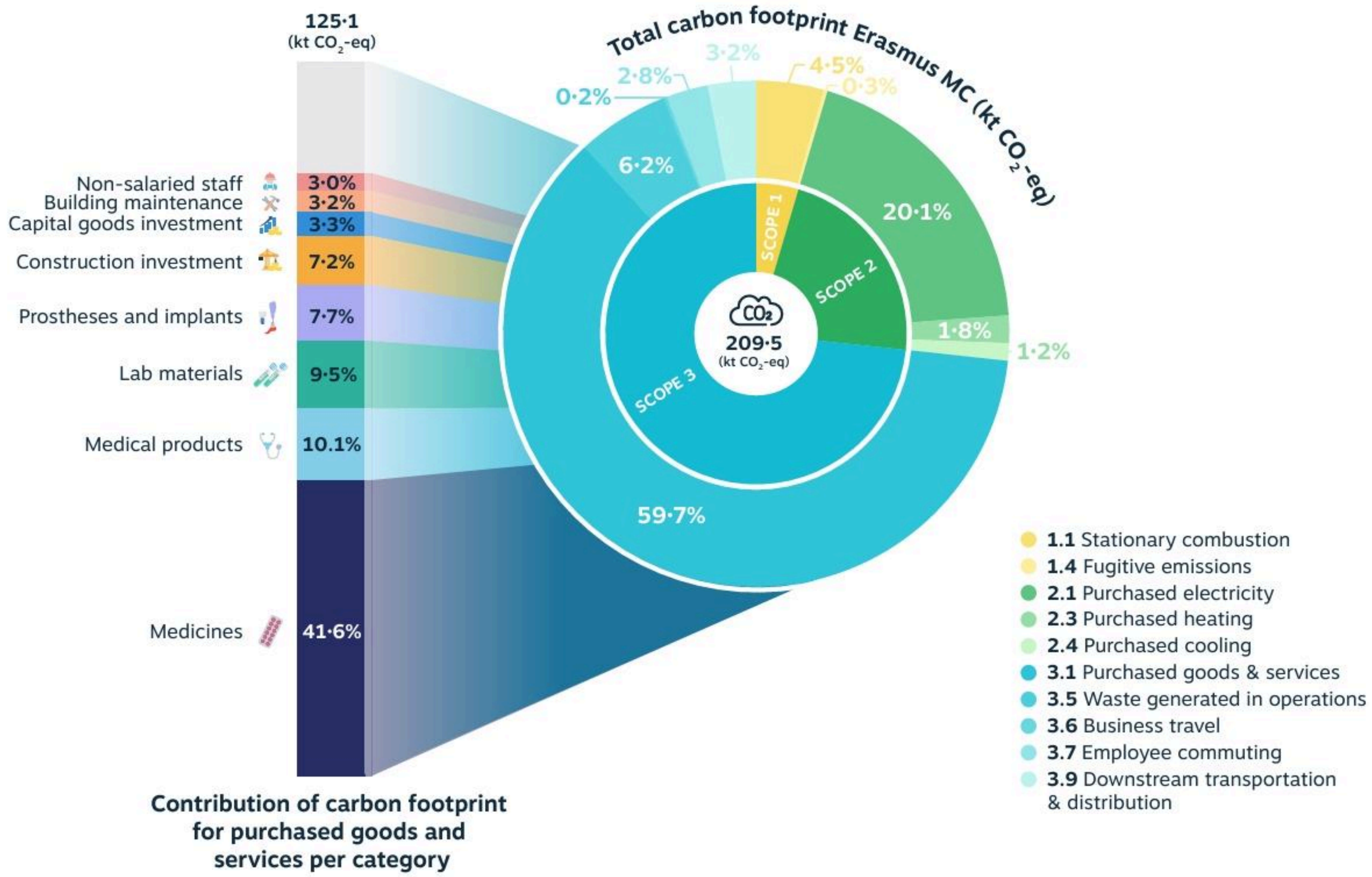


Figure 2: Carbon footprint Erasmus MC 2021 (Metabolic, 2023)

1.2 Impact of Medication Packaging

At the Erasmus MC a Material Flow Analysis (MFA) of the Intensive Care Unit (ICU) department has been conducted in order to gain insights into the material inflow and outflow of a representative Intensive Care department (Hunfeld et al., 2022). This research focused on the material flows that are required to take care of an average patient in the ICU on a daily basis. This MFA can be seen in Figure 3. Disposables play a significant role. However, when taking a look at the larger picture, they only account for 21% (disposables) of the total material flow. In contrast, medicines themselves account for 65% (medicines). The medicines part is composed of both active ingredients, fillers and packaging. For a more detailed version of the MFA, see the more elaborated report of Metabolic (n.d.).

Although it would be necessary to study this in more detail, due to the complexity of medicine production, the large number of companies that produce them and the unavailability of data, the impact of medicines hasn't been studied on a large scale as of yet.

The MFA also shows significant environmental and economic impacts of solid waste disposal in this system. Currently, a very small amount of waste is recycled while most of the waste is incinerated. There are two types of incineration. Normal incineration, similar to how municipal waste is processed, and Specific Hospital Waste (SZA) which has five times the environmental impact because of higher temperatures and is more expensive than normal incineration. (Rizan et al., 2020)

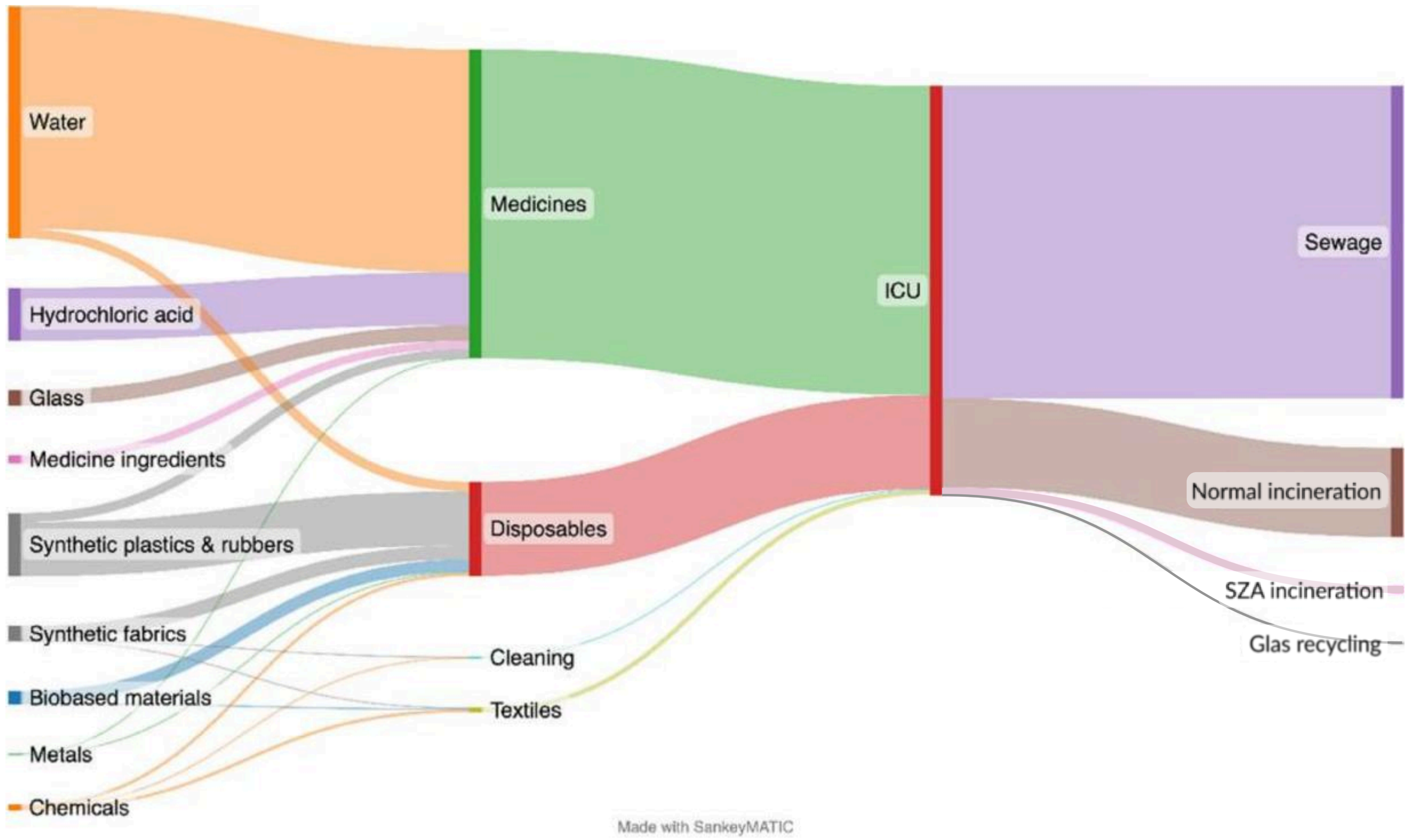


Figure 3: Material Flow Analysis of the Intensive Care Unit at Erasmus MC (Hunfeld et al., 2022)

Next to the above-mentioned study, there have been few studies on the Life Cycle Analysis (LCA) of specific medicines. To name an example and show the possible impact of packaging, one study (McAlister et al., 2016) examines the LCA of morphine, a painkiller mainly produced in Australia. The initial stages, including poppy farming and transportation, account for only 3% of the CO2 impact. The majority of emissions come from the production process: bulk morphine manufacture (9%), mixing with saline (13%), container filling (8%), and sterilisation (21%). Remarkably, sterile packaging alone contributes 46% to the total CO2 emissions, see Figure 4. This highlights the significant energy consumption in packaging, underscoring a critical area for reducing the environmental impact (McAlister et al., 2016).

Research on the topic of medication-specific sustainability is still in its infancy, with the study on morphine being one of the pioneers in the field. This study clearly shows that the impact of medication consists of two separate aspects: production of the medicine itself, and packaging. It has already become evident that medication and its packaging is a severely understudied topic that deserves more attention. This study will look at the packaging aspect of the medication.

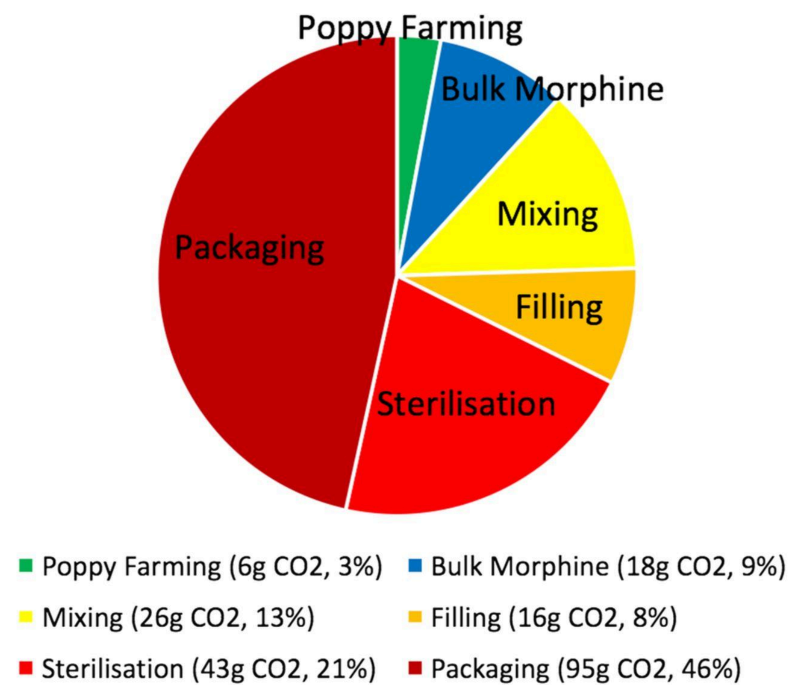


Figure 4: Life Cycle Assessment of Morphine (McAlister et al., 2016)

1.3 Approach

This graduation project aims to provide an, as complete as possible overview of the medication packaging used in a representative Dutch ICU with the goal of identifying key areas to focus on in making medication packaging more sustainable. The process involves several key steps:

Step 1: A general understanding of the use and storage of medicines in ICUs was gained. This was done through preparation by literature and desk research, followed by talking to experts and accompanying practitioners on their daily duties. In addition, the ICU provided a day's worth of medication packaging waste for field research purposes (see Figure 5). This was used to gain initial insights about the different types of packaging and the types of materials that are used.

Step 2: Based on these initial insights, a larger research set-up was created, aiming to produce an all-encompassing material flow analysis of medicine packaging at the ICU of the Erasmus MC. This research setup consisted of the following:

- Identifying packaging components (Chapter 2.3)
- Creating standard typology per component (Chapter 2.3)
- Defining the scope of medication that will be taken into account (Chapter 3.2)
- Setting up a protocol for standardisation of weighing each medication and its packaging (Chapter 3.2)
- Weighing of the medication packaging within the scope (Chapter 3.3)
- Requesting additional information from suppliers (Chapter 3.3)
- Data processing of all collected data and databases (Chapter 3.3)

Step 3: Based on the measured packaging, an analysis was performed to identify hotspots of packaging use. Sustainability hotspots are points in a process where the environmental impact is particularly high, often due to factors such as large volumes of materials or the use of materials with high carbon footprints.

Figure 5: A day's worth of medication packaging

Identifying these hotspots is crucial for targeting efforts to enhance sustainability and reduce the environmental footprint of medication packaging.

Step 4: Using these hotspots, design interventions could be developed to make a targeted impact on sustainability. Due to the scope of the project, only one of these hotspots was chosen to provide a template to improve on its contribution to overall sustainability goals: reducing the consumption of primary raw materials, reducing the amount of waste produced and increasing the circularity of the process by implementing circular design strategies. To be able to redesign medication packaging, important requirements in regulation and guidelines that need to be taken into where identified (Chapter 2.4).

1.4 Sustainable Design

1.4.1 Value Hill with R Strategies

Specific tools have been developed to redesign a product with sustainability in mind. For this project, The chosen tool was the Value Hill framework (Figure 6) (Metabolic, 2021), which employs R strategies (Morseletto, 2019), often also referred to as Circular Strategies. This was chosen because of its systematic approach to products and their place in entire production chains. The Value Hill systematically divides a product's lifecycle into three phases: pre-use, use, and post-use. During the pre-use phase, value is added through extraction, manufacturing, assembly and selling. The use phase represents the product's maximum value, while the post-use phase involves its decline. Circular strategies aim to maintain value throughout the lifecycle.

The R strategies from the Value Hill are: Refuse, Rethink, Reduce, Redesign, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover. These strategies are in order from being the most impactful strategy, keeping the most value, to the least impactful, losing the most value.

Refusing involves avoiding the use of certain materials or processes altogether. It's about saying "no" to unnecessary waste or harmful substances.
Rethinking involves questioning existing norms and finding innovative solutions. It encourages creativity and fresh perspectives.
Reducing aims to minimise resource consumption. It involves using less material, energy, or water.
Redesign involves reimagining products or systems to improve sustainability and reduce environmental impact.

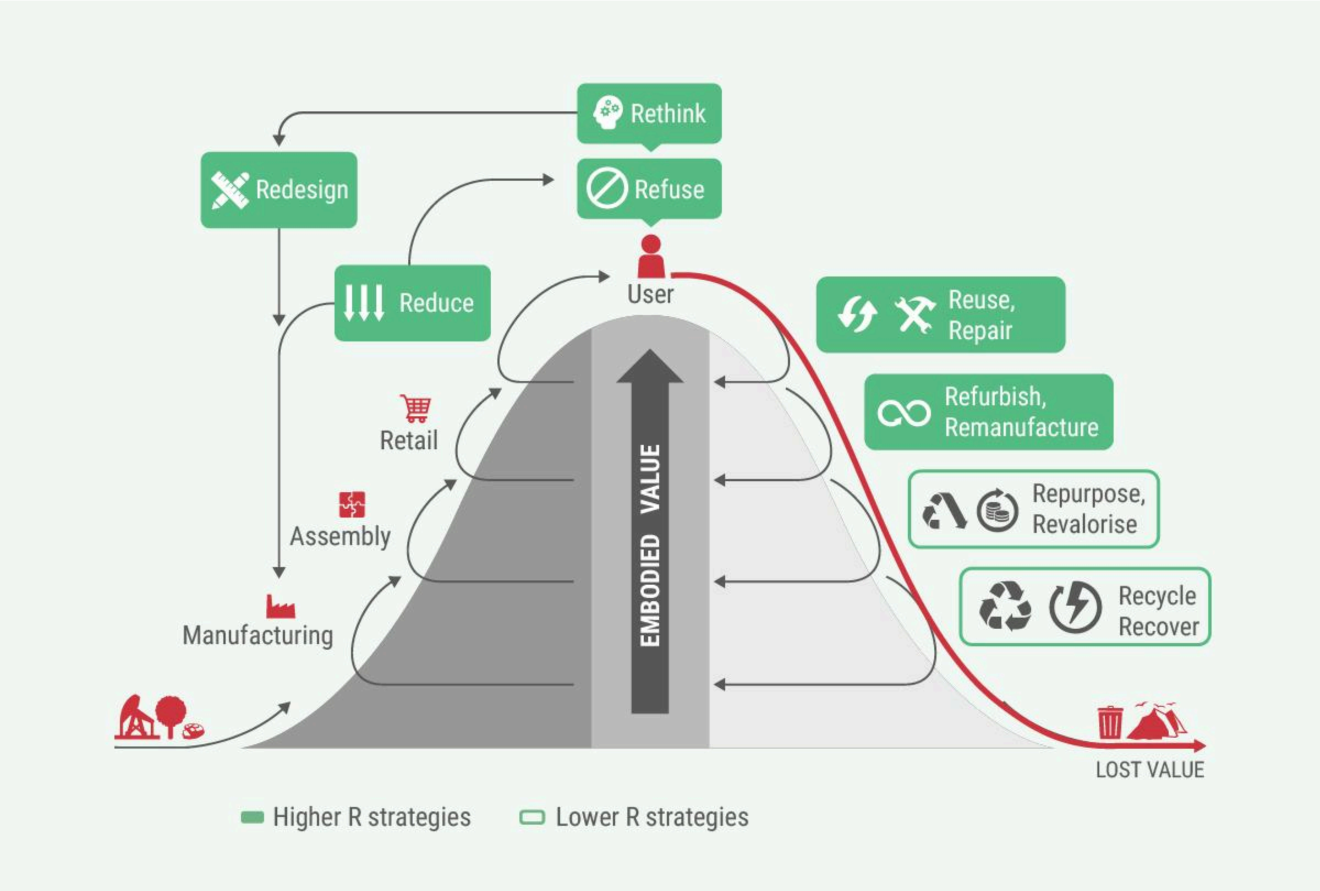


Figure 6: Value Hill with R Strategies (Circular Value Hill Model (Metabolic, 2021))

Reusing is extending the lifespan of a product by using it multiple times.
Repairing focuses on fixing products rather than discarding them. It extends their useful life.
Refurbishing involves restoring products to a like-new condition.
Remanufacturing takes used products, disassembles them, and rebuilds them to their original specifications.
Repurposing gives new life to products and parts by using them for different purposes.
Recycling involves converting used materials into new products.
Recovery focuses on extracting value from waste materials, like energy recovery from incineration.

These strategies can be combined to create holistic approaches to sustainability. By integrating these circular strategies for redesigning, we can contribute to a more sustainable healthcare sector and effectively communicate our plans to manufacturers. This tool can be used for brainstorming new concepts and iterating on them, resulting in actionable plans that demonstrate how medicines packaging can enhance sustainability.

1.4.2 Guidelines for Sustainable Redesign

For these strategies to be fruitful, there are guidelines to redesign an existing concept or system. The following guidelines could be useful to this project. They have been synthesised from courses in the Bachelor of Industrial Design Engineering and the Master of Integrated Product Design, together with literature. (PolyCE, 2021) (Hultgren, 2012) (Ellen MacArthur Foundation, 2016)

- The components need to be made from mono materials to ensure they can be recycled properly. This material itself needs to be recyclable.
- For recycling, it is important that materials can be recycled through existing recycling streams, in the companies as well as municipal waste. If this is not the case, a new (in-house) stream needs to be developed.
- If multiple materials are used, separation of these materials is essential. This should also be easy to do, making sure it actually happens and no extra or special tools are needed. This is necessary for recycling and for strategies like repairing, refurbishing and remanufacturing.
- The easy collection and separation of different components is also important. This can be done with clear instructions and well-labelled bins. This is again important for recycling but also for looping back the products or components for reusing, repairing, refurbishing and remanufacturing.
- For elongating the lifespan of the products for strategies such as reusing, repairing, refurbishing and remanufacturing, a more durable design is needed compared to disposable products. This influences material choice and functional aspects.

With these strategies and guidelines, we can try to contribute to the sustainability goals: reducing the consumption of primary raw materials, reducing the amount of waste produced and increasing the circularity of the process by implementing circular design strategies.

1.4.3 Strategies for Medication Packaging

Now the R strategies, together with the guidelines, are placed in the current context of medication packaging used at the ICU. The following factors are considered in the choice of useful R strategies for this project.

- **Refusing and Rethinking** are actions largely within the control of hospitals, though we can support these efforts by creating guidelines and raising awareness.
- **Reducing and Redesign** fall within our scope as designers, enabling us to improve existing packaging concepts or develop entirely new solutions.
- **Reusing** poses challenges due to strict regulations, but it remains a possibility worth exploring, particularly for non-critical components. Many of the regulations are part of a locked-in system, but these guidelines can be questioned and potentially revised to enable more sustainable practices.
- **Repairing, Refurbishing and Remanufacturing** are less relevant for packaging due to the strict healthcare requirements and the time-consuming nature of these processes, which is a challenge in an industry where time is already limited.
- **Repurposing** offers potential, such as reusing containers for sharps disposal, though this is primarily a decision for users or occurs after use. That said, we can still contribute by creating guidelines and raising awareness to encourage such practices.
- **Recycling and Recovery** serve as a last resort, emphasising the need to prioritise upstream solutions, but they should still be carefully considered during the design process to ensure materials can be effectively and safely recycled or recovered when disposal becomes necessary.

Next to the strategies, the material flow of the ICU can give insights. A visualisation of a new envisioned change in material flow, compared to the current material flow of medication packaging at the ICU, can be seen in Figures 7 and 8. It shows the R strategies that could be used to improve medication packaging at the ICU.

Together with the factors described above and the new envisioned material flow at the ICU, a selection is made. The selected R strategies that could be useful in this project are: **Reduce, Reuse, Recycle and Recover**. It's important to note that not all strategies are suitable for every scenario or type of packaging and combining several strategies has the most significant impact on the environment.

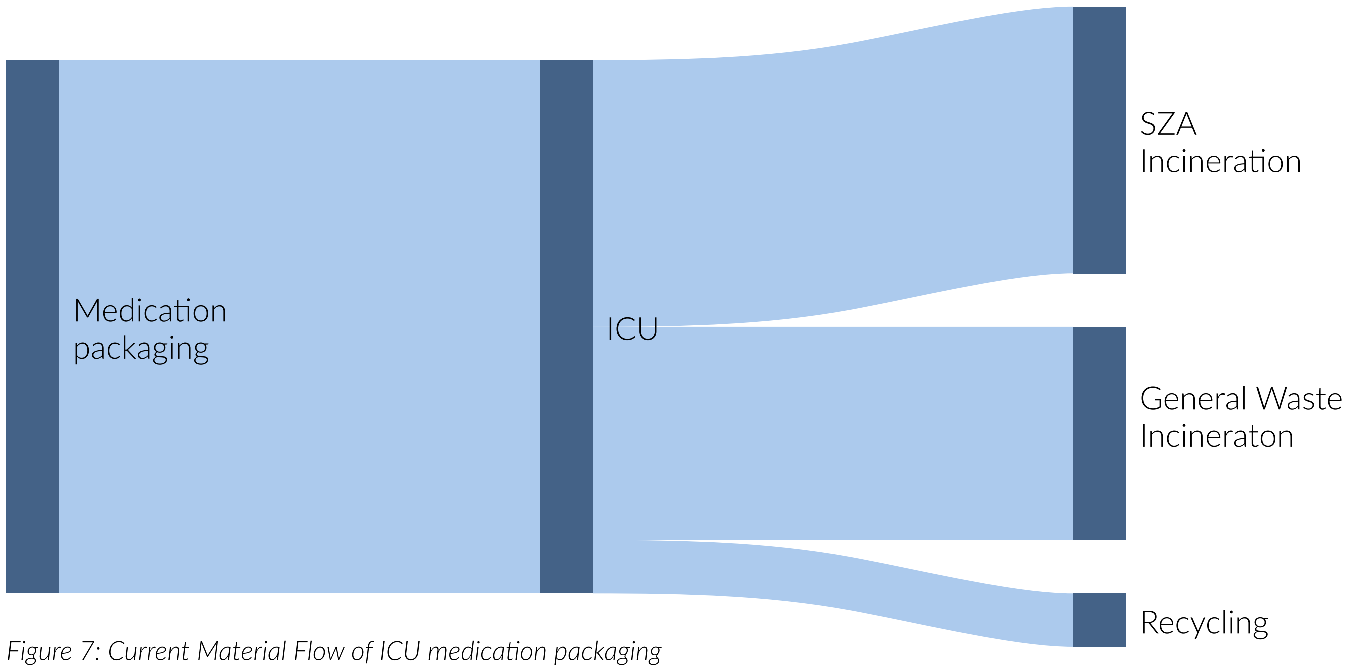


Figure 7: Current Material Flow of ICU medication packaging

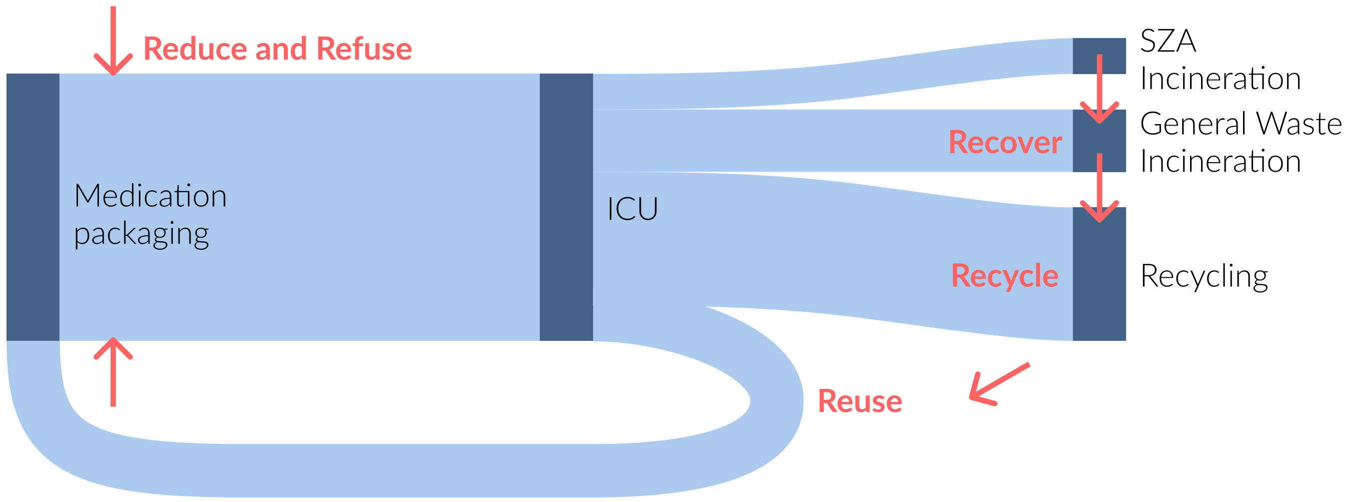


Figure 8: New envisioned Material Flow of ICU medication packaging

Context of the Intensive Care Unit and Medication

This chapter explores medication packaging and its role within the context of the ICU. First, the ICU is explained, along with how the medication gets to the unit and how it is used there in the satellite pharmacies. Then, the packaging of the medication and its different components are explained, and typologies are made for each component. After this, all requirements, rules, and guidelines to be taken into account when redesigning are discussed. Finally, how the packaging is disposed of and what happens to this waste are discussed.

2

2.1 What is the Intensive Care Unit

The Intensive Care Unit (ICU) in a hospital is a specialised unit equipped with advanced medical technology and staffed by highly trained professionals. Patients admitted to the ICU usually face serious or life-threatening conditions and require 24-hour monitoring and treatment. From ventilator support to constant monitoring of vital signs, the ICU provides specialised care tailored to each patient's needs, ranging from severe infections to recovery from surgery. In addition, patients in the ICU often require complex medication treatments, carefully administered by the medical team to address their specific conditions.

The Erasmus MC has 5 ICU units, 4 located on the 4th floor (general Intensive Care Adults) and one big unit of 18 beds on the 6th floor (Thoracic surgery and cardiac monitoring). Together all units provide a total amount of 56 beds. In Figure 9 a patient room at the ICU can be seen.

To help patients on these units, there is a wide variety of different types of medication available. To name some types, antibiotics are used to fight infections that can occur when a person's immune system is weak. Also, painkillers and sedatives help patients feel more comfortable, especially when they are on machines to help them breathe. Some drugs help keep blood pressure stable and ensure organs get enough blood and others prevent blood clots.

Figure 9: Patient room at the Intensive Care of Erasmus MC (De Bruijn, 2024)

Figure 10: Storage in the satellite pharmacy

Figure 11: Separate storage room for dialysis bags

2.2 Pharmacy at ICU Erasmus MC

It is important to highlight the role of the pharmacy in ensuring the safe and efficient management of these essential medicines. In a hospital setting, the pharmacy serves as the focal point for the procurement, preparation and distribution of medication.

The central pharmacy of the hospital supplies the entire hospital, including the ICU, with medicines. Whenever a patient requires a specific medicine, it can always be found here. In addition to the central pharmacy, there are three ICU-specific pharmacies, called satellite pharmacies. These satellite pharmacies store medicines commonly and frequently used in the ICU, to decrease the number of long trips to the central pharmacy. The satellite pharmacies are evenly distributed among the different ICU units and are located in the corridors between the patient rooms.

Each satellite pharmacy can provide medication for around 18 beds. Due to the size of the ICU department, these pharmacies differ mainly in location, not in the type of medicine stored.

In each of the three satellite pharmacies, medication is stored in a structured manner, making sure the right medication can be quickly found and grabbed (see Figure 10). For an example, see the floorplan of one of the satellite pharmacies in Figure 12. All three satellite pharmacies share this general layout. Additionally, there are separate storage rooms (Figure 11) for the bigger medication, like for example infusion and dialysis bags.

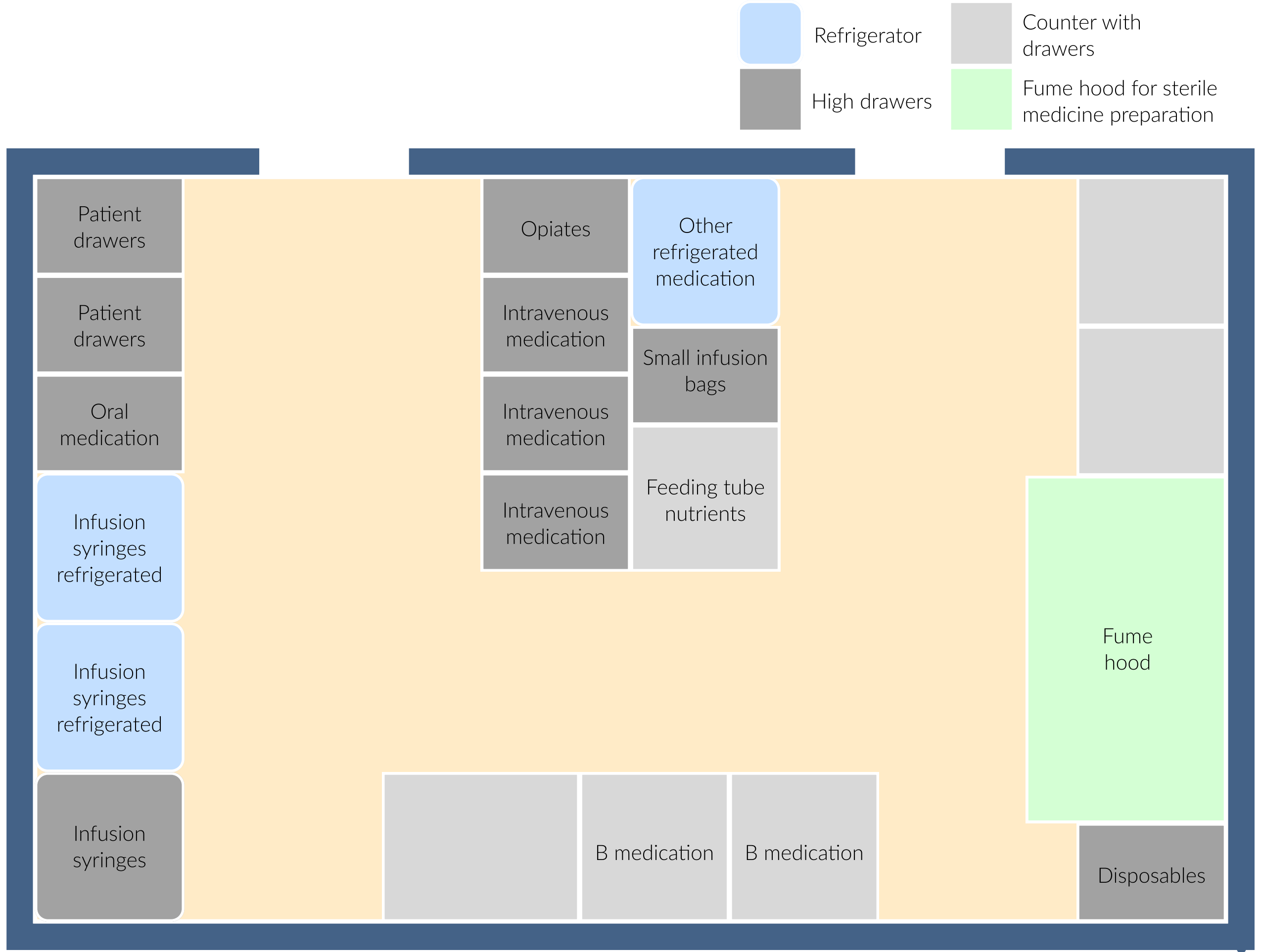


Figure 12: Floorplan of satellite pharmacy

At the start of the day, all ready-to-administer medication is put in the patient-specific drawers, divided by shifts of the nursing staff (see Figure 13). All medication that is not yet ready to get administered is then prepared in the fume hood (see Figure 14) by the pharmacists and subsequently put in patient-specific drawers too.

The nurses can easily collect the correct medication out of these drawers whenever they need to. All medication that could not be prepared for direct use at the start of the day, such as for example refrigerated medicine and opiates, is manually grabbed or prepared on demand instead. This is especially interesting in the case of opiates, as these substances are expensive and addictive, thus having a specific protocol, explained later in Chapter 2.4.4. Also, medication stored in different storage rooms is separately collected by the nurses.

Figure 13: Patient-specific drawers

Figure 14: Fume hood for preparing medication

With both ready-to-administer medication and medication that needs to be prepared and the central and satellite pharmacies and different storage rooms, multiple scenarios are present for the flow and disposal of the medication packaging. In Figure 15, an overview of the flows between the different spaces is shown. It also shows when packaging is seen as waste. In Chapter 2.5, the waste streams will be discussed in further detail.

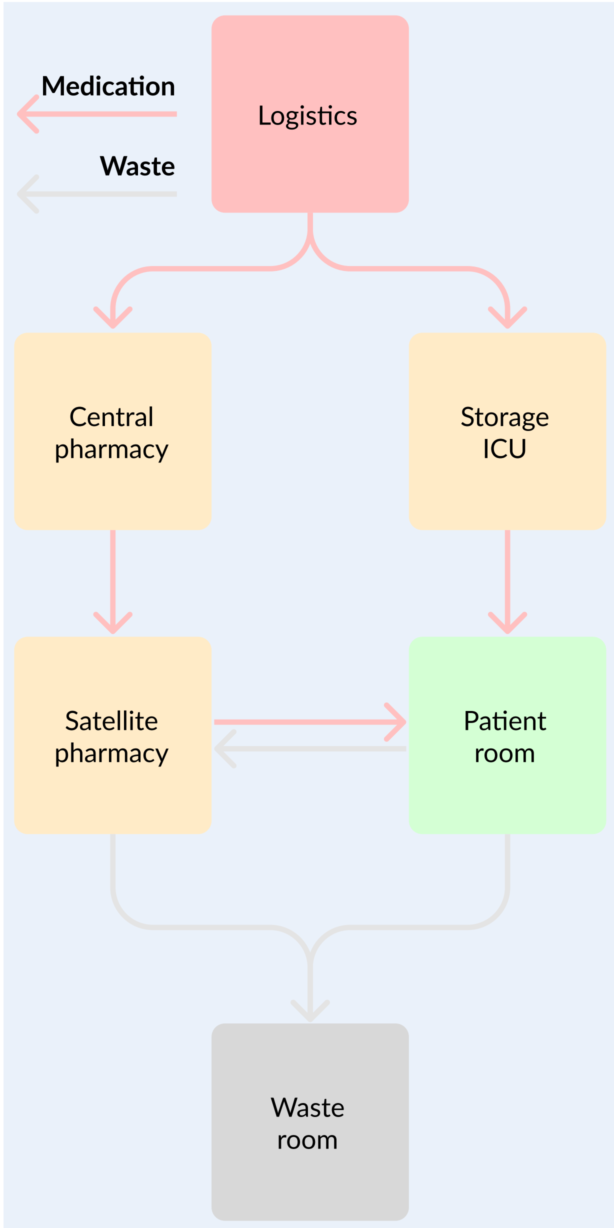


Figure 15: The flow of medication packaging and waste throughout the hospital and ICU

2.3 Medication and Packaging at ICU

The medication comes in many forms. Most medication is administered intravenously or orally. Intravenous medication is typically applied through a needle (injection) or an IV tube (infusion), straight into the veins of the patient. This medication can either come as fluid or as a powder that needs to be solved into a solution. Oral applications mainly come in the shape of pills, capsules, liquids and insoluble powders for suspension. While intravenous and oral applications are the two most commonly used application methods at the ICU, some cases ask for different methods such as topical (e.g., nicotine patches and various ointments), nasal (nose sprays), rectal (suppositories) application, and many more.

Because of the different functions of the packaging like protecting contents, informing the user and easy distribution, commonly packaging can consist of multiple different components. The functions will be further discussed in Chapter 2.4. An example picture of of the components of how ampules are packaged can be seen in Figure 16. In Figure 17 a visual of the different components can be seen.

Figure 16: Picture of packaging components ampules

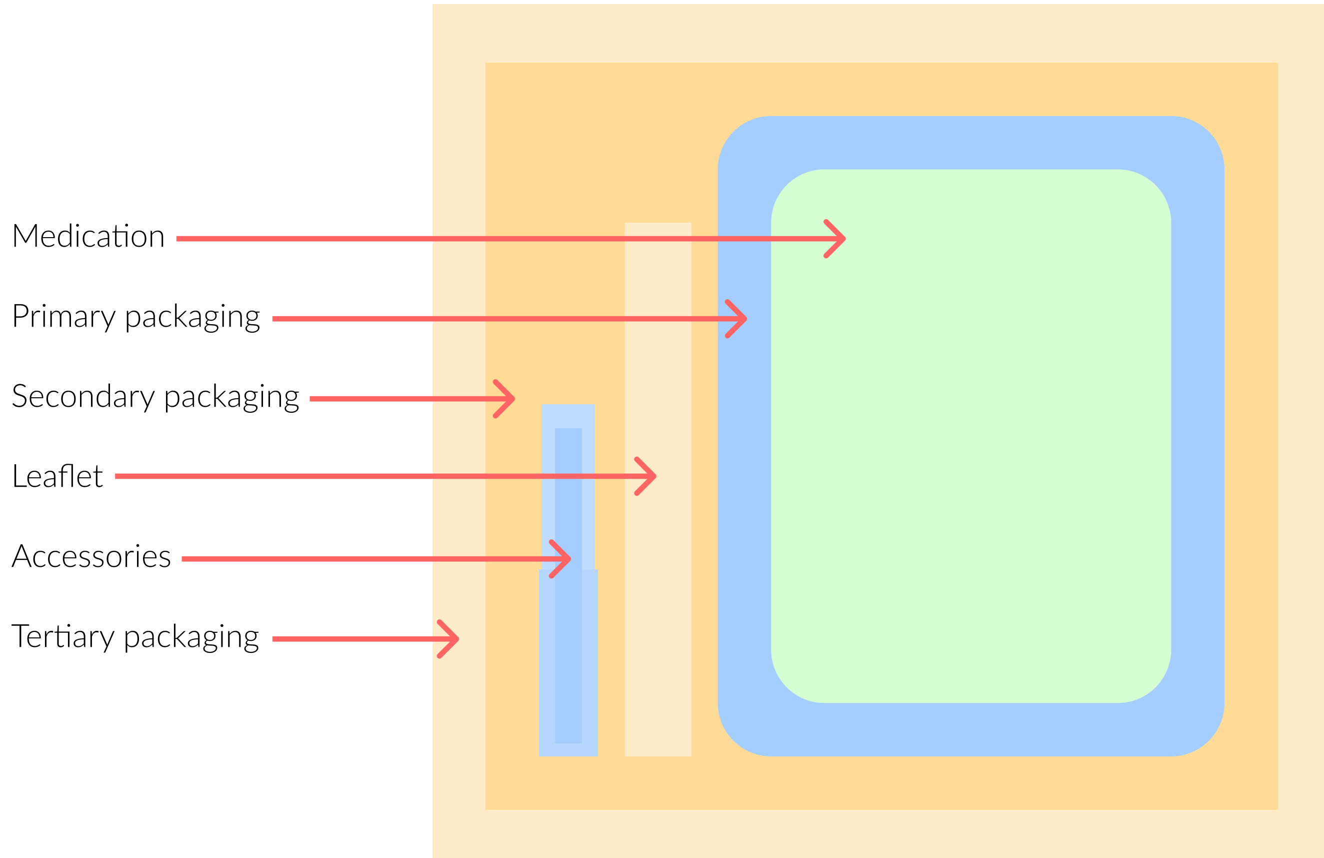


Figure 17: Medication Packaging Components

Each packaging component explained by the example of the ampules in Figure 18:

1. The **medication** is mostly liquid or solid and consists of active ingredients (API) and fillers (excipient).
2. The medication is contained in the **primary packaging**, the packaging directly in contact with the medicine.
3. The **secondary packaging** holds the primary packaging and is meant for hygienic or structural purposes, or to keep multiple primary packaging together.
4. Most of the secondary packaging has a **leaflet** with all the information about the medication inside.
5. Some medication is shipped together with **accessories**, such as needles, filters or solution liquids.
6. **Tertiary packaging** is used for the transport of the medication, to keep the bulk of the medication together and for protection, also displaying information about contents and destination. This tertiary packaging is not considered in this research.

In the initial sampling of the packaging present at the ICU, a typology of the different components has been made. In Figures 19, 20 and 21 the most common primary packaging, secondary packaging and accessories can be seen. Other packages also exist but have been excluded from the typologies because they are infrequent in the ICU, these fall under "other".

Depending on the form of medication, application and many other reasons that will be discussed in Chapter 2.4, different primary packaging is used. In Figure 22 the different types of primary packaging used for different types of administration methods can be seen.

Medication that still needs to be prepared is often made for IV administration. The process of preparing this medication involves several steps, varying in the case of injections or infusions:

- For injections, the liquid medication is either drawn directly from an ampule or a solvent is injected into a vial, mixed with the medication, and then drawn up. Both methods result in a syringe that can be administered directly into the patient's IV tube.
- For infusions, intravenous bags are combined with medication from a vial or ampule. This mixture can be connected to the patient's IV line for slow administration. Alternatively, the combined solution and medication can be carefully drawn into an IV syringe, which is then ready for administration to the patient via the pumps in the patient rooms.

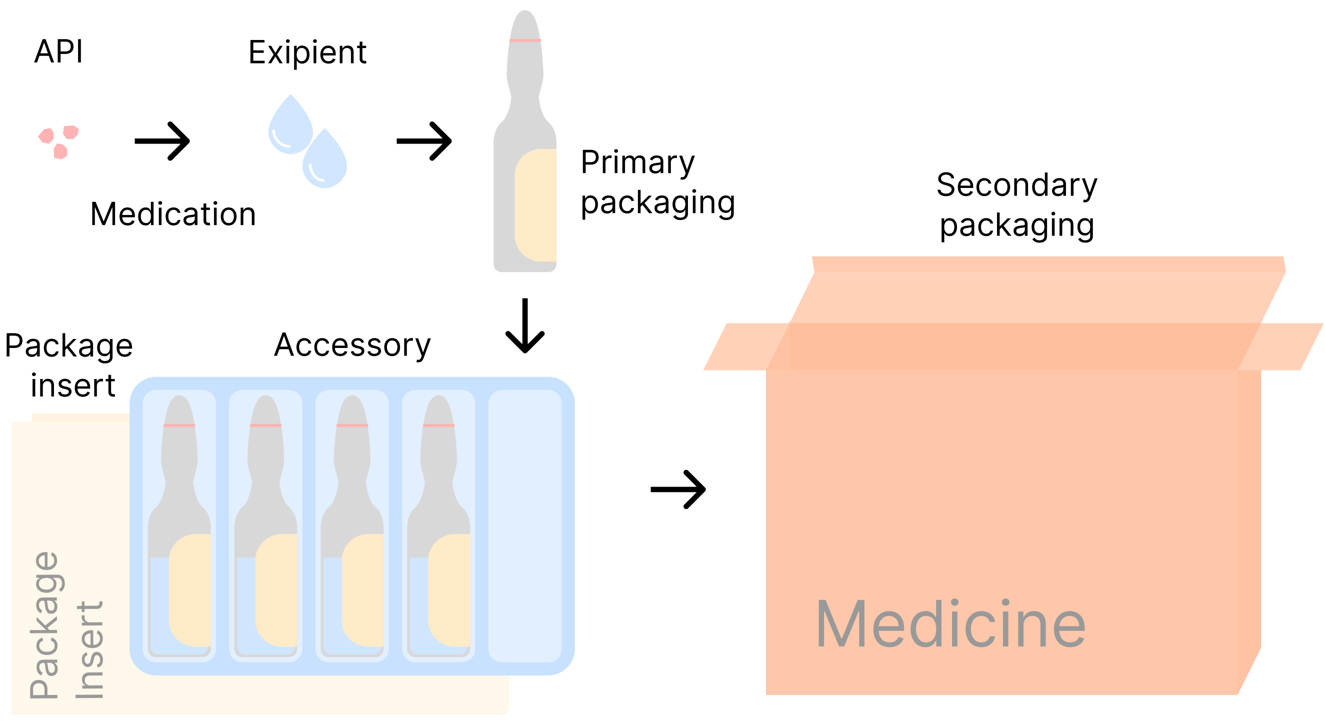


Figure 18: Example of packaging components ampules

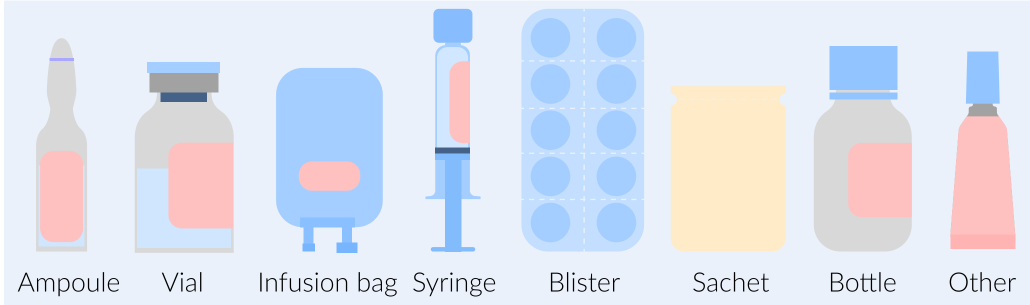


Figure 19: Primary packaging typology

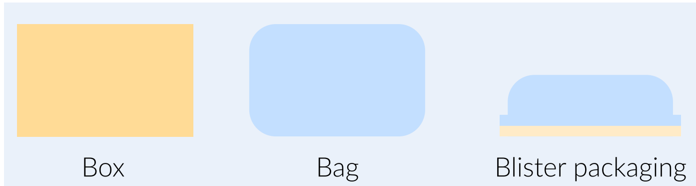


Figure 20: Secondary packaging typology

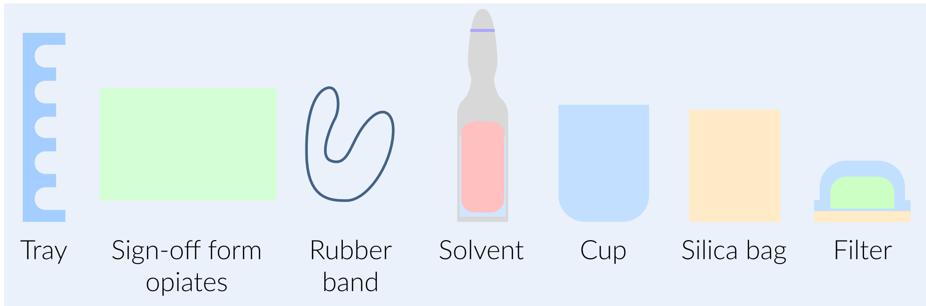


Figure 21: Accessories typology

	Ampule	Vial	Infusion	Syringe	Blister	Sachet	Bottle	Other
Infusion	✗	✗	✗	✗			✗	
Injection	✗	✗		✗			✗	
Oral					✗	✗	✗	✗
Rectal							✗	✗
Other							✗	✗

Figure 22: Types of primary packaging per types of administration methods

2.4 Context Medication Packaging

The packaging of medication must meet important requirements at various levels and aspects. For redesigning new packaging in this project, these requirements need to be kept in mind. The following paragraphs delve deeper into these requirements. Some of these aspects overlap, but an effort has been made to provide a comprehensive overview. These aspects have been synthesised from current guidelines, laws and preferences of staff.

2.4.1 Shelf Life and Purity

The shelf life and purity of all medications are crucial and are determined by a maximum storage period. The following aspects, which are important for packaging, influence these storage periods.

Temperature: Some medications need to be stored in a refrigerated environment, typically between 2-8°C. Most medications, however, should be stored at room temperature (15-25°C). Higher temperatures than room temperature are not required and can even be damaging. The impact on packaging components includes:

- The storage temperature is indicated on the packaging (Figure 23) and more detailed in the leaflet. It also specifies if the medication must be stored in the refrigerator or freezer or not.
- In the refrigerator, medications are stored in smaller quantities with fewer primary packages per secondary package, often in single units.

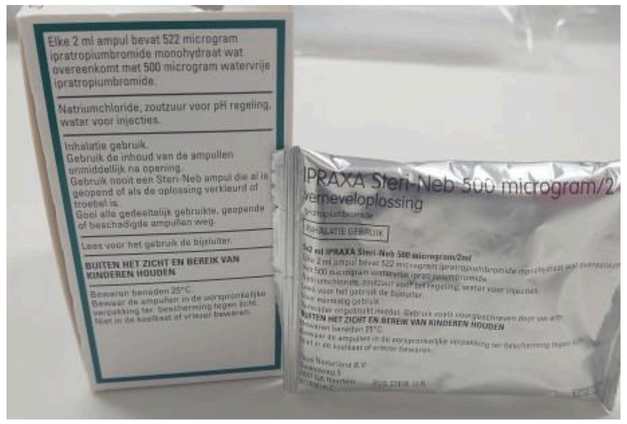


Figure 23: Two secondary packaging components with conditions of storage

Humidity: Some medications are sensitive to humidity, which affects their efficacy and active ingredients, thereby influencing their shelf life and packaging. This is particularly relevant for medications made from dry substances, such as pills and powders.

- The packaging must minimise the penetration of humidity.
- Airtight packages sometimes contain moisture absorbers, like silica gel packets (Figure 24).
- If a medication is sensitive to humidity, this is stated on the packaging (Figure 25) and in the leaflet, with information about additional storage requirements if necessary.

Figure 24: Silica gel packets as accessory

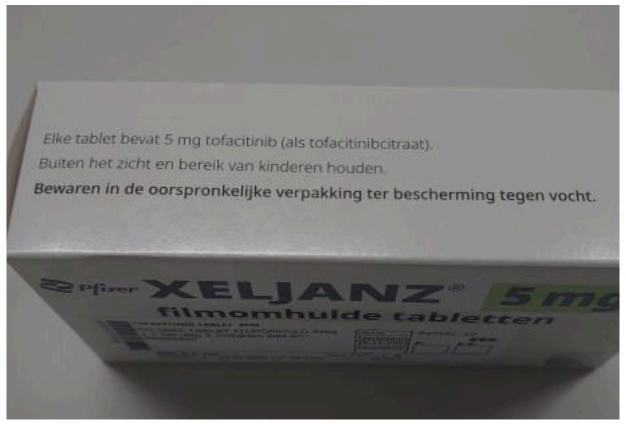


Figure 25: Secondary packaging with conditions of storage regarding humidity

Light sensitivity: Certain medications cannot or should not be exposed to light. Light can degrade or chemically alter certain medications, reducing their effectiveness or causing unwanted side effects. To maintain their stability and efficacy, these medications must be stored in a dark place or in light-blocking packaging (Figure 23). This requirement is indicated on the packaging (Figure 23) and in the leaflet.

Chemical composition: The medicine itself can influence packaging. This may be the case, for example, with certain high-acid substances. They cannot be stored in plastic vials but are stored in glass. It is beyond the scope of this project to go into specific details here because they are not important for the design process except to take them into account, for example in the choice of material.

Permeability: Permeability refers to the extent to which a solid allows another substance to pass through it, such as a medication passing through its packaging. Liquid medications can evaporate, influencing the packaging in the following ways:

- Some liquid medications are overfilled to compensate for potential evaporation, ensuring sufficient quantity remains by the expiration date.
- The packaging can be made from materials with low permeability to prevent evaporation.

2.4.2 Hygiene

Hygiene in the packaging and administration of medication is critical to prevent patients from becoming sicker or encountering other complications.

Sterility: This means that the medication must not be contaminated by its environment and must remain absolutely pure. The impact on packaging includes:

- The packaging must keep the medication sterile.
- The packaging must be designed so that opening it does not compromise sterility.
- Packages such as ampules, vials, and infusion bag connections must be able to be sterilised before or after opening. The packaging design must facilitate this.

Foodsafe: This means that while a medication does not need to remain sterile after being removed from its packaging, it must be handled in a way that minimises bacterial or other forms of contamination. The impact on packaging includes:

- Some medications, usually pills and orally administered liquids can be stored in bulk, such as pills in a pot and liquids in a bottle. This type of packaging can be opened and closed again.

2.4.3 Communication and Information

Medication packaging must meet specific requirements to ensure effective communication and information provision.

Readability: Medication packaging should be easy to read without the need for additional aids. All text on the packaging should be clear and readable to ensure correct usage. Commercially sold medicines should include Braille (Figure 26) for the visually impaired to ensure accessibility.

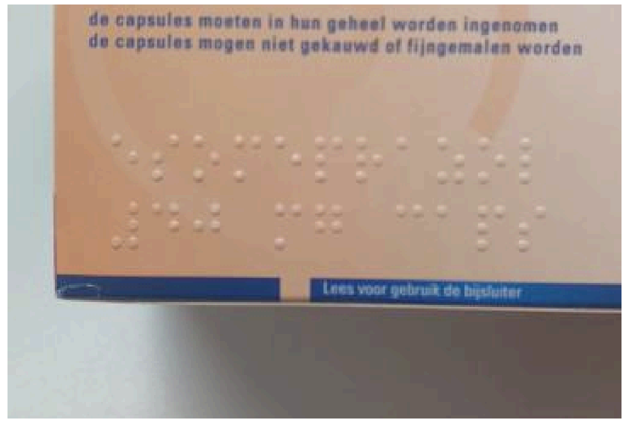


Figure 26: Secondary packaging with Braille

Primary Information: Verified by the College ter Beoordeling van Geneesmiddelen (CBG), secondary packaging must show the expiry date, storage conditions, name of the medicine, active ingredient and dosage and method of administration (Figure 27). Sometimes the RVG number (registration number) (Figure 27) and a QR code or barcode (Figure 28) are present for linking to additional information in the hospital system or CBG database. The primary packaging itself should also contain essential information such as the name, dosage and expiry date (Figure 29).

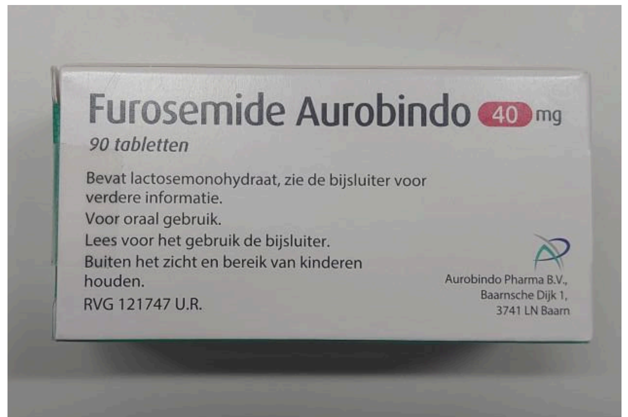


Figure 27: Information on secondary packaging with RVG number

Figure 28: QR code and barcode on boxes

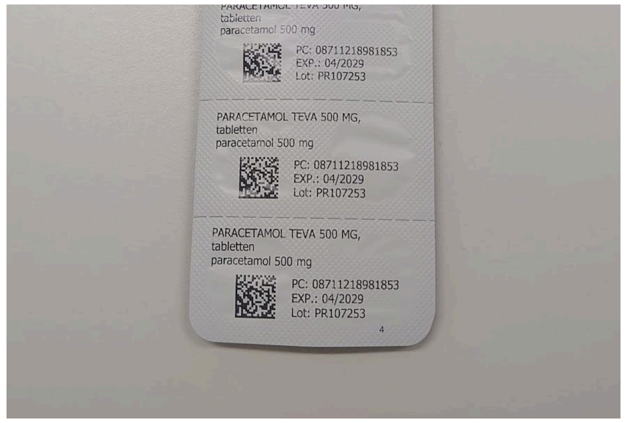


Figure 29: Information on primary packaging

Patient Leaflet: The medication comes with a CBG-certified and standardised leaflet containing detailed information such as instructions for use, side effects, use with other medicines and contraindications. Some medicines that are repackaged or prepared in pharmacies do not have a package leaflet because they are only used by hospital staff.

SoPC: Medicines must have a Summary of Product Characteristics (SoPC) with additional information for doctors and pharmacists. This document is also certified and standardised by the CBG and can be found online or in the hospital database.

Language Requirements: It is required that the information of medicines sold in the Netherlands contain Dutch information. If the packaging is from another country, a language sticker must be attached (Figure 30) and additionally, online the patient information leaflet and SoPC are available in Dutch.

Figure 30: Language sticker for foreign medication

2.4.4 Safety and Preventing Misuse of Medication

Ensuring the safety and preventing the misuse of medication are critical aspects of pharmaceutical packaging and its components. Various measures are in place to address these concerns:

Sealed packaging: Medication boxes are often sealed to prevent tampering, forgery or theft. These seals ensure that the medication remains intact from the moment of manufacture to the moment of use. Tamper-proof packaging clearly indicates whether the seal has been broken, discouraging fraud and ensuring patient safety. (Figure 31)

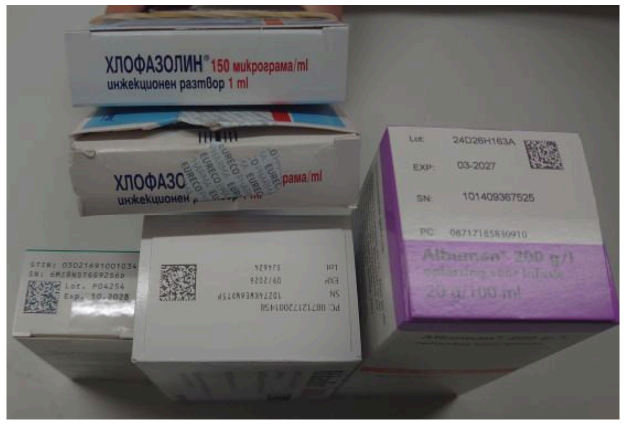


Figure 31: Different seals for tamper proof packaging

Protocol for Opiates: Because of their addictive nature, opiates have a strict protocol. Every time a nurse prescribes and takes an opiate from the satellite pharmacy, a second nurse has to be present and check that this is going well and not too many are taken. This is recorded with a dedicated green sign-off sheet (Figure 32) on which the names of the nurses and the patient are noted. This detailed recording ensures accountability and minimises the risk of misuse for non-medical use.

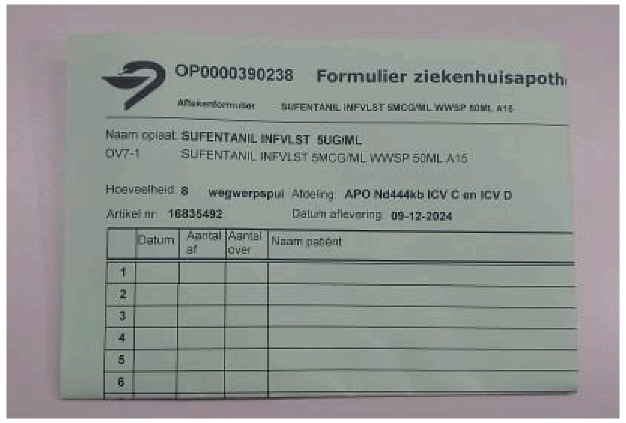


Figure 32: Green sign-off sheet for opiates

Access Control: Access to medicines, especially opiates and other addictive drugs, is restricted to authorised staff. These medicines are kept in a locked cabinet (Figure 33) at the satellite pharmacy that can only be opened with an authorised pass. This measure prevents unauthorised access and ensures that medicines are administered only by trained and qualified staff.

Figure 33: Locked opiate cabinet satellite pharmacy

Figure 34: Refrigerators satellite pharmacy

Refrigerated Medications: As discussed earlier, medicines that require refrigeration must remain in their cool storage (Figure 34) environment to maintain their effectiveness. These medications can be temporarily removed from the fridge but must be used within a specified timeframe or placed back in the fridge within half an hour if not used immediately. This protocol prevents degradation of the medication due to temperature fluctuations and ensures that the medication remains effective for patient treatment.

Use after opening: Medicines should be used within a certain time after opening. This is indicated on the packaging (Figure 35) or in the patient leaflet. For some medicines, it is days, and for others weeks or months. Pharmacists and nurses note the opening date on the packaging (Figure 36) to keep track of this timeline. This practice ensures that the medication is used while it is still effective and safe, reducing the risk of administering affected or ineffective medication.

Figure 35: Indication of expiration date after opening

Figure 36: Opening date written on packaging

2.4.5 Logistics

Due to the unpredictable nature of ICU admissions, maintaining an adequate stock of medications is crucial. However, overstocking can lead to medications expiring and being wasted. To manage this balance, a specialised team is responsible for inventory control. ICU satellite pharmacies typically stock a wide range of medications to ensure availability for any potential patient needs. Effective inventory management is essential to avoid financial losses and ensure sustainability.

Transport: Packaging must be robust enough to protect medications during transportation. Normally this is provided by the tertiary packaging (Figure 37) but often medication comes already unpackaged from this tertiary packaging from the central pharmacy to the ICU satellite pharmacies. Additionally, packaging that is easy to handle and stack facilitates smoother and more efficient transportation.

Figure 37: Tertiary packaging component

Storage: Quantitative inventory management relies heavily on effective packaging. Medications need to be packaged in a way that allows for efficient storage and easy tracking of expiration dates. For refrigerated medications, packaging must maintain the appropriate temperature to prevent spoilage.

Restocking: Efficient restocking requires packaging that is easy to scan and label. Barcodes or QR codes on the packaging and corresponding storage shelving and drawers (Figure 38) should integrate seamlessly with the pharmacy's inventory management system. This allows for quick and accurate updates to inventory levels. Regular checks using scanning devices help maintain proper stock levels, and new orders are placed as needed to refill shelves.

Figure 38: QR codes on drawers and packaging

Order Picking: During the order picking process, as explained in Chapter 2.2, packaging must support easy identification and organisation of medications for individual patients. Clearly labelled packages and the QR codes help pharmacists accurately prepare and distribute medications. Secondary packaging must facilitate quick and easy access, with features like easy-tear openings (Figure 39) or pre-measured doses to streamline the preparation process.

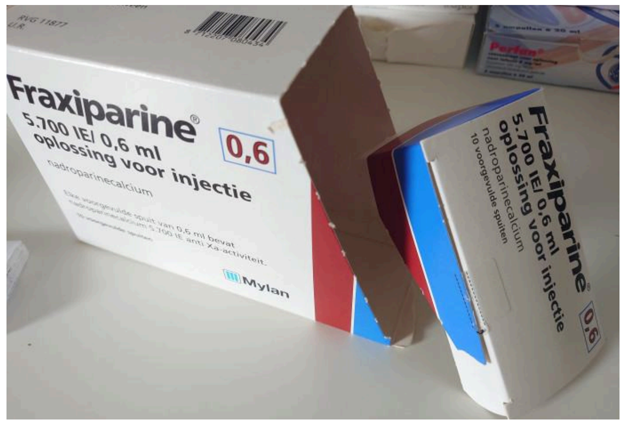


Figure 39: Easy to open packaging

2.5 Packaging Waste

As mentioned earlier in Chapter 2.2, there are multiple flows of medication packaging and its disposal (Figure 40). This flow and disposal is different for each type of preparation, the medication and the type of material packaging. As examples, in Figure 41, 42 and 43, three possible scenarios have been shown in the visual: blister, dialysis bag and infusion bag with ampule.

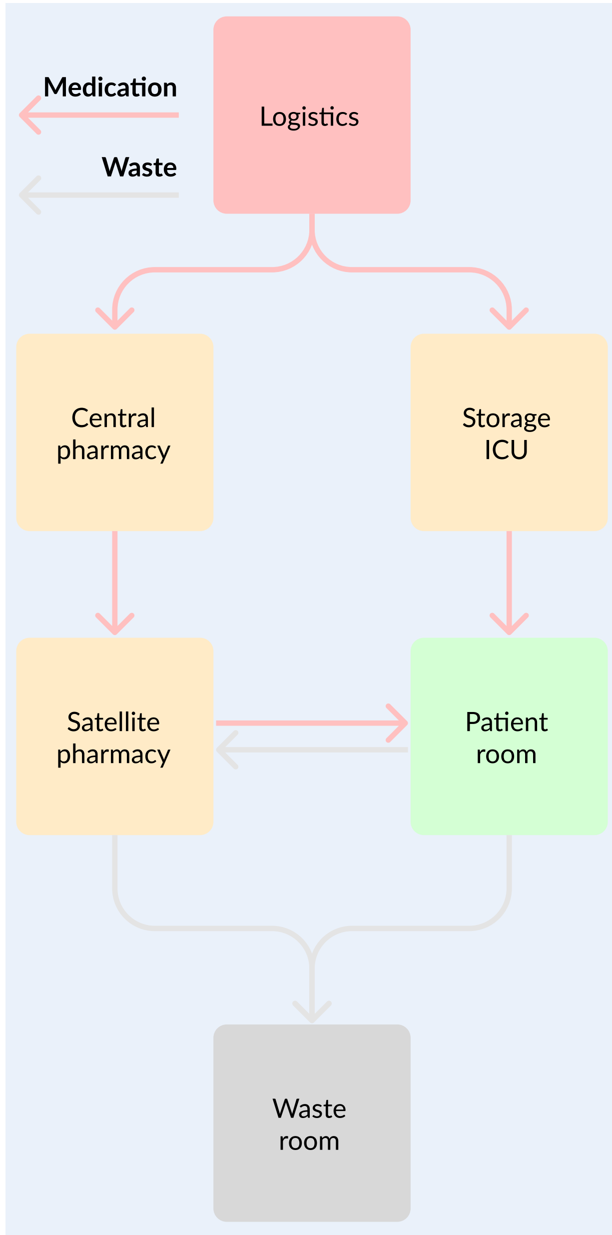


Figure 40: The flow of medication packaging and waste throughout the hospital and ICU

1. The blister scenario shows the flow of a ready-to-administer medication that has been stored in the satellite pharmacy and put into the patient drawer. The secondary packaging is thrown away at the satellite pharmacy. The medication is taken to the patient by a nurse, administered and then the primary packaging gets disposed of in the patient's room. Eventually, both scenarios meet up again in the central waste room of the ICU.

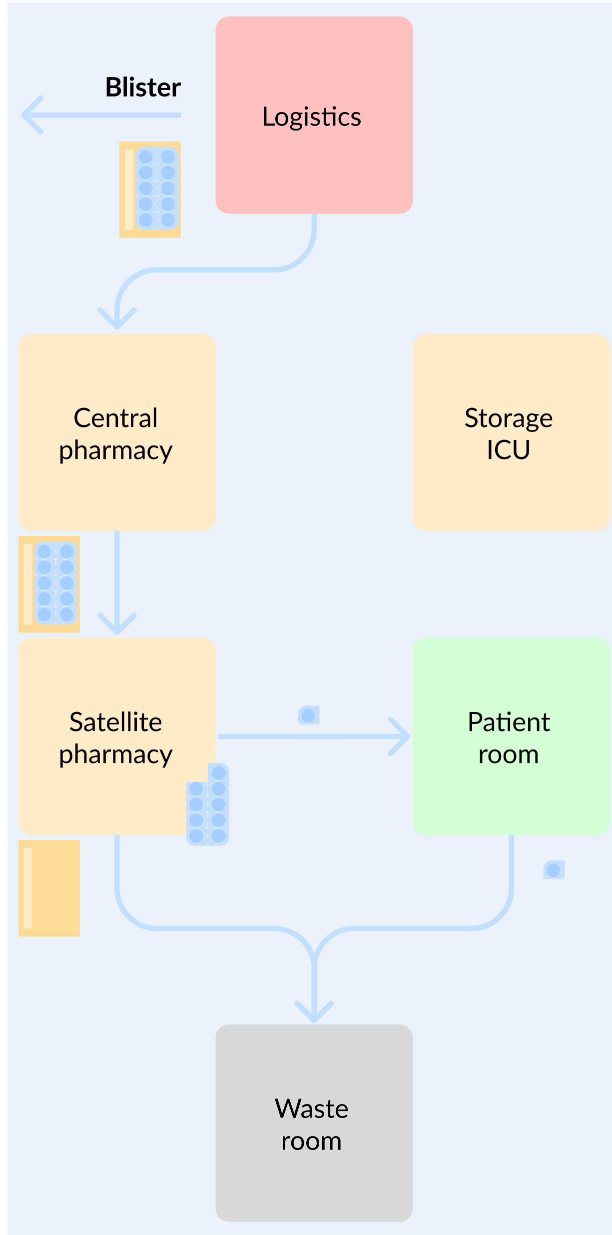


Figure 41: Example of the flow of medication packaging: blister packaging

2. The dialysis bag scenario shows the flow of a medication that is stored in a separate room and does not go through the satellite pharmacy at all. The secondary packaging is opened before it goes to the the patient's room and is disposed of in the central waste room. After administration of the medication, the primary packaging follows.

3. The infusion bag with the vial scenario shows the medication that is not ready to administer yet. This is prepared in the satellite pharmacy, as described in Chapter 2.2, and this is also where most of the packaging is disposed of, then going to the central waste room. Only the primary packaging, the infusion bag, goes to the patient's room and is then disposed of.

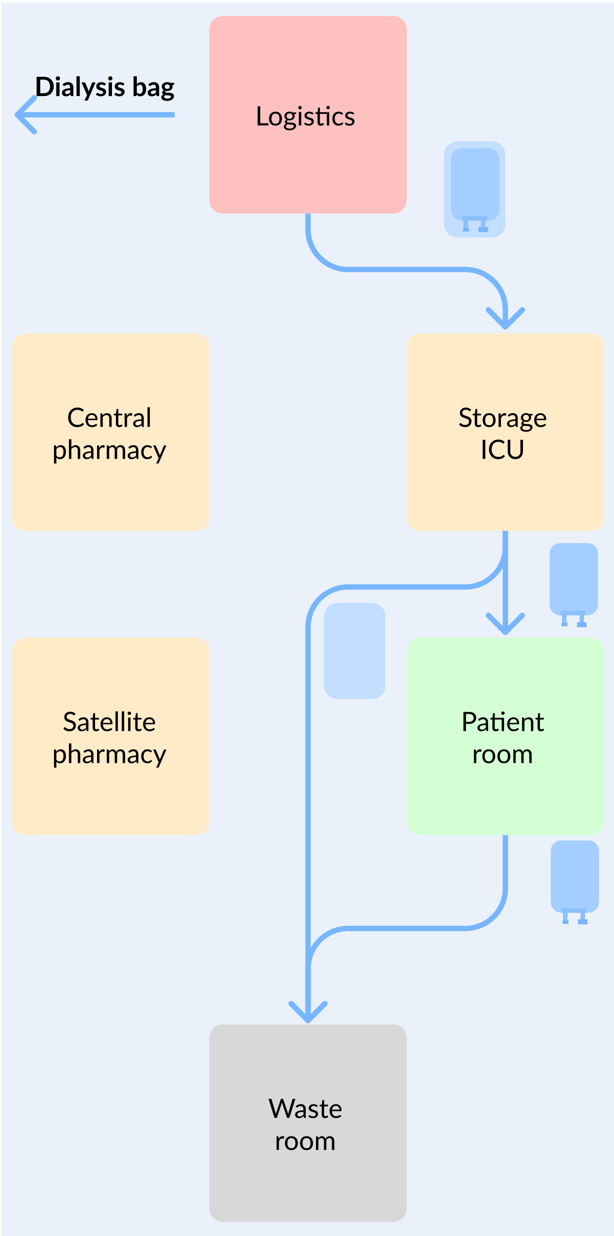


Figure 42: Example of the flow of medication packaging: dialysis bag packaging

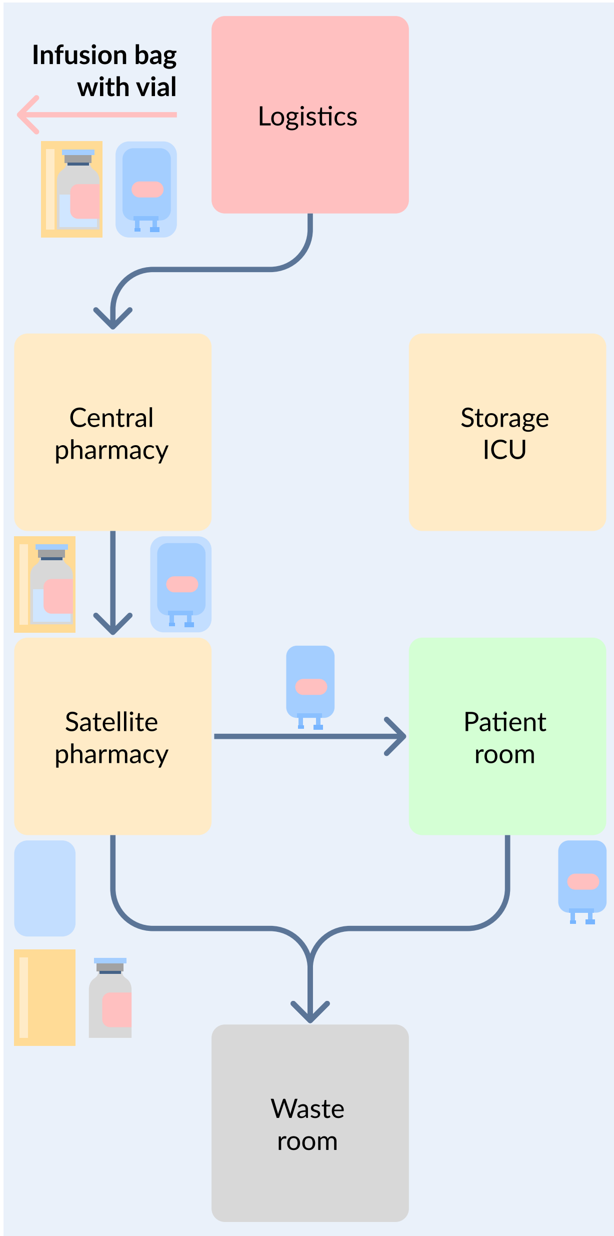


Figure 43: Example of the flow of medication packaging: infusion bag packaging

As briefly discussed in the MFA in Chapter 1.4, at the ICU, multiple waste processing streams are present. For these streams, different separation bins are in place. Also, per processing stream, smaller separation streams are needed. In Figure 44 the floorplan of the satellite pharmacy with the locations of the different waste containers can be seen. Currently, the different waste processing streams are as follows:

SZA waste incineration
The SZA waste incineration process involves the treatment and disposal of hazardous medical waste, ensuring it is done safely and efficiently. This process is more expensive than normal waste incineration and the hospital needs to pay a fee for the volume they deliver. Next to that, SZA waste incineration costs five times more energy and generates more emissions than normal waste incineration (Rizan et al., 2020). Sharps, medication residues and other chemical waste are part of the SZA waste.

General waste incineration
The waste that is not harmful or dangerous is collected as normal municipal waste and incinerated, trying to recover energy. This mainly covers the packaging that is not separated for recycling or reuse and other materials used for the preparation of the medication.

Recycling
In the satellite pharmacy, only paper is being collected to be recycled. Paper with patient information is collected separately to ensure privacy. Next to this, the secondary packaging bags and the primary packaging (without connections) of the medication for dialysis are collected in the general waste room for a trial of recycling these.

Reuse
Currently, only the grip bags are reused within the hospital, going back to the central pharmacy where they are repacked again.

Medication that has been ordered for refilling the drawers is transported in plastic containers if they do not have tertiary packaging. These boxes are then collected and reused for other deliveries. This is common practice in other pharmacies as well, thus these boxes are part of a bigger system than the grip bags are.

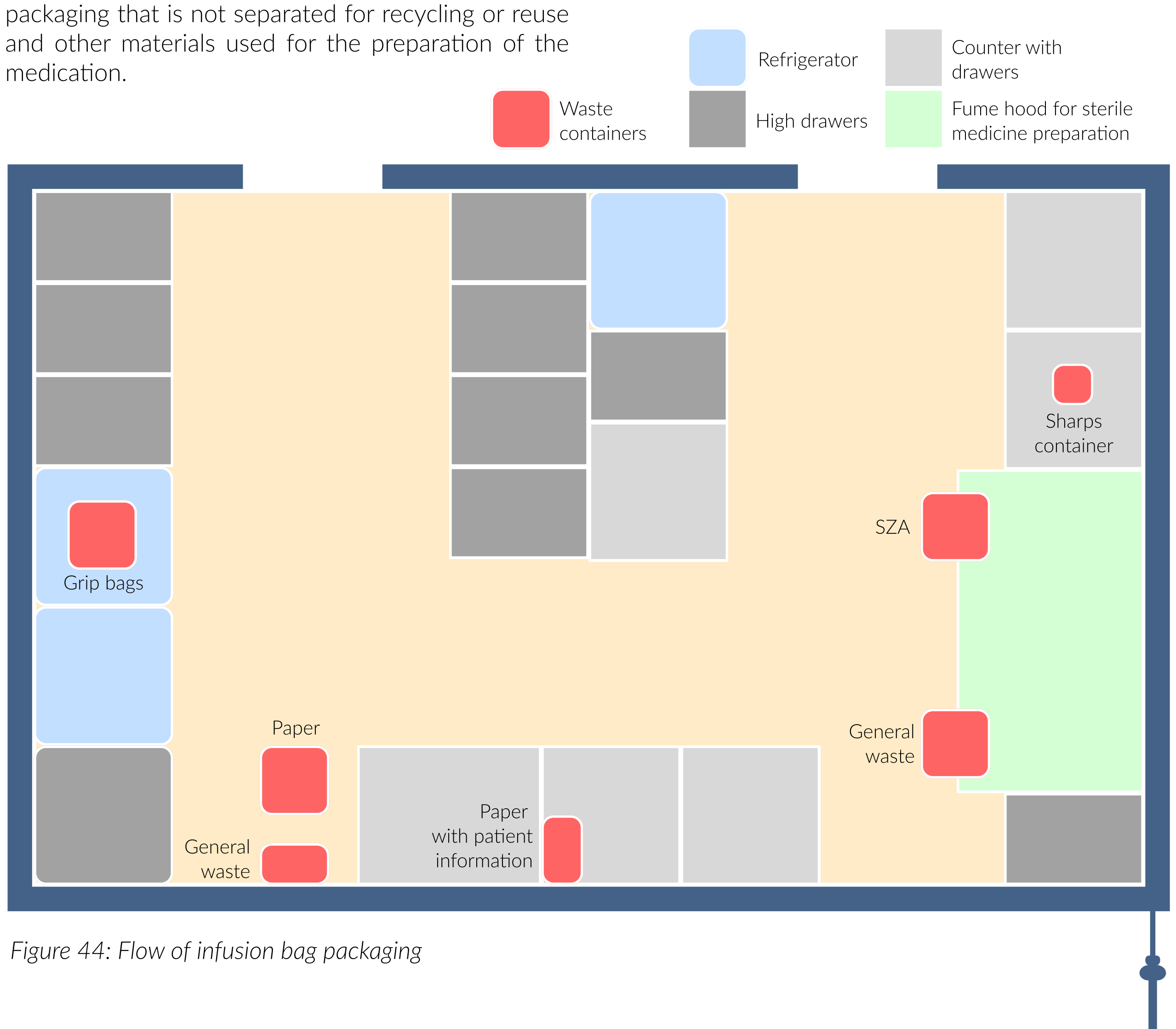


Figure 44: Flow of infusion bag packaging

Measuring Medication Packaging

3

This chapter describes the study of medication packaging weighing. This research was done together with PhD candidate Jasper Klasen in the ICU at Erasmus MC. First, the research questions are discussed. Then the preparation, approach and implementation are covered. The results are then explained. Finally, the conclusion addresses the hotspots.

3.1 The Research Question

To determine which packaging waste stream has the greatest impact and can be isolated as the hotspot to focus on for the design activities, this study aims to provide insight into the various types and amounts of materials used in packaging at an ICU. The research question and its sub-questions are as follows:

What type of packaging waste is most common and represents the greatest impact?

- What types of materials are used in medication packaging?
- What types of packaging consist of what kinds of materials?
- What is the quantity used for each type of packaging?

To this end, the types of materials and their corresponding amounts were measured. Based on the results, an in-depth overview of specific hotspots, both overall and per type of packaging, with high potential for improvements was created. This comprehensive analysis will serve as a foundation for identifying areas for design interventions to enhance sustainable practices in ICU settings.

3.2 Method, Approach and Scope

The approach of this research involves breaking down the medications and their packaging into individual components and materials, and then weighing these components.

1: The dataset used as a starting point includes all medications prescribed in the ICU at EMC in 2023.

2: From the above-mentioned dataset, the research focuses on medications prescribed more than 250 times per year, which accounts for 90% of the prescriptions, narrowing the scope from 1700 medications to around 400 medications.

3: The initial dataset only provided article codes, prescription frequencies, and prescription names and missed information about its type of packaging. It was combined with data from the EMC pharmacy and the CBG to determine the type of administration (e.g., ampule, pill), the supplier of the medication, and the packaging materials.

4: Additionally, specific information such as the mass of the drug (in the case of pills and powders) was requested from suppliers. Measuring the medication and primary packaging separately at the hospital would have necessitated discarding the medication for safety reasons. Given the high cost and occasional shortages of some drugs, this approach would have been irresponsible and unsustainable, countering one of the key objectives of this project. With the information on the mass of the drug, this amount could be subtracted from the weight weighed to obtain the weight of the primary packaging itself.

Packaging was weighed as stored in the satellite pharmacy, using sealed, full packages whenever possible, without including outer or tertiary packaging. This process took place from February to April 2024. Using a laptop with Excel and a scanner (used for QR codes or barcodes), items with more than 250 prescriptions per year were identified in the satellite pharmacy. For every drug found in the dataset, a sealed product was taken. Only if there was no sufficient supply of the drug for patient care the medication was collected another day.

The medications were collected in the following amounts per run to the satellite pharmacy:

1. Medication with long preservation times outside of storage was taken in batches of 25.
2. For refrigerated medication, only 5 were taken, which were stored in a cooling box.
3. Opiates were only allowed to be taken one at a time.

A rolling cart with drawers (Figure 45) was used to transport the medication efficiently. This was also used in the weighing process to separate the products that were already weighted from the ones that still needed to be done.

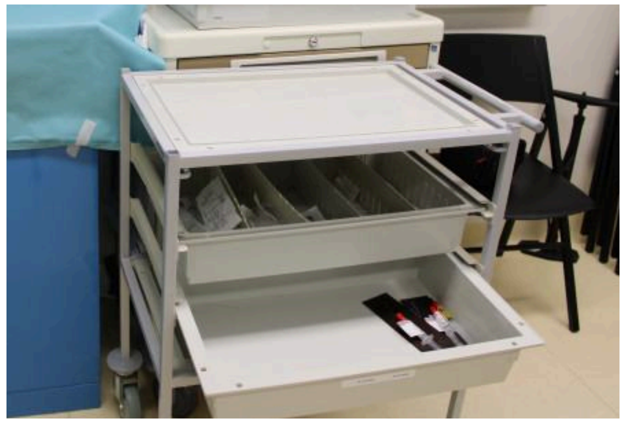


Figure 45: Rolling cart with drawers

For each drug taken from the satellite pharmacy, a form, that was specifically created for this research, was filled in to standardise the measurements and to instantly save the data to the cloud to prevent loss of data. The form starts with a section where the user can fill in the total mass while sealed and the corresponding article number of the drug (to cross-reference the original database). In the next sections, component-specific questions are asked such as the type of material used, the mass of the components, the presence of any stickers or seals and the amount of components per packaging. Furthermore, packaging type-specific questions were asked if relevant. For a more detailed view of the form, see Appendix B.

In some cases, the components of a drug could not be measured in an isolated manner. In some cases, specific methods were developed to allocate the weight correctly.

Blisters
The different materials of the blisters could not be separated. To find the weight distribution between the top and bottom layer of the blister the bottom layer of the blister was assumed to have a thickness of 20.32-µm (Baehr et al., 2023). Together with the specific density, length and width, the weight of the bottom could be calculated. The remaining weight of the blister was allocated to the top part of the blister, using the assumptions in the Life cycle assessments of blister packaging by Baehr et al. (2023) and Bassani et al. (2022).

Vials
The components of the vials could not be separated without the need to empty the packaging, which was undesirable. To find the weight distribution between the different materials of the vials, the empty vials that were acquired from the days worth of waste samples of the ICU were used. Each material from these empty vials was separated and weighed, as can be seen in Figure 46. It was found that the lids of the vials came in three standardised sizes, which were designated small, medium and large (Figure 47). In these three sizes, the rubber stop, aluminium seal and plastic flip-offs had similar weights. Thus having designated the weight to these three components and per size, the remainder of the weight was allocated to the material of the bottle itself.

Figure 46: Separated components of a vial

Figure 47: Different sizes of vials, S, M and L

Syringes
For the syringes, the standard ones have been collected empty to weigh each component separately. For most syringe types, ranging in different sizes and volumes, five syringes were disassembled. The different components can be seen in Figure 48. For the syringes that could not be collected to be separated, like the prefilled syringes, the material shares have been guessed using the shares in the ones that we had excess to.

Figure 48: Separated components of a syringe

Stickers
The stickers and seals on the different types of packaging are all in different sizes. For the share of paper or plastic from these, stickers and seals were divided into different size categories: small, medium, large and extra large. In these categories, stickers and seals have been removed and weighed from the samples of packaging that could be accessed. For each size category, an average weight was used.

At the conclusion of the Excel protocol, a picture of the product is taken and its corresponding picture number is noted. This picture serves as a reference during later stages of the research, providing visual information and aiding in tracking progress. Additionally, in scenarios where analysis highlights a particular product as a hotspot for material waste, these pictures serve as a sanity check.

In addition to the photo studio (see Figure 49) needing a fixed location, there are other reasons for taking the weight measurements at a fixed place in the ICU, in patient box 10. The first reason is that it's close to the satellite pharmacy, which reduces travel time. The shorter travel time was mainly important in limiting the time that the stock would be unavailable to the satellite pharmacy. In the case of refrigerated drugs, keeping the travel time short was desirable to prevent the drugs from going bad and being thrown out. In the case of opiates, the strict rules of the hospital and the fact that only one drug could be measured at the same time made the execution of the protocol much more efficient when performed in the ICU itself. Also, for other expensive medications, it was undesirable to move them far away from the satellite pharmacy.

Figure 49: Photo studio setup in patient box 10

For our measuring setup, several key materials and instruments were utilised. These included four scales capable of measuring various weight ranges suitable for medication packaging. These scales were used in the ranges of 0-100 grams, 100-500 grams, 500-1500 grams and 1500 and up, with a scale accuracy of two decimals, one decimal and whole numbers respectively. A calliper with an accuracy of one decimal was used to measure the length and width of the blister packaging. Additionally, a dedicated cart was used for transporting medications within the ICU and hospital, equipped with a laptop with a scanner for capturing barcode or QR code data. For the photo setup, a Canon camera on a tripod with a dedicated flashlight was used. As a background, a sheet of blue wrap, normally used to package instruments in the surgery department, was used. The setup can be seen in Figure 50.

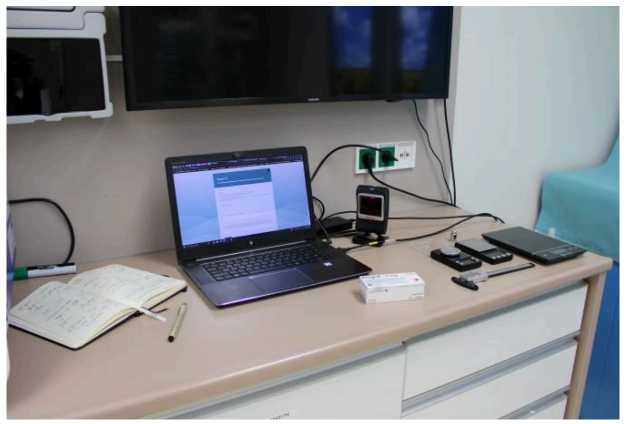


Figure 50: Measuring setup in patient box 10

3.3 Execution of the Measurements

This research was set up and conducted together with PhD candidate Jasper Klasen at Erasmus MC. This is part of a larger study and several publications will follow. This report does not go into every aspect and was mainly used for finding the hotspots.

The measuring and weighing of the products took place in February and April 2024. It started with weighing the medication in the satellite pharmacies with the weighing protocol and set-up.

Throughout the process, it was found that not all medications were present in the satellite pharmacies. There were two reasons for this. Firstly, some products were stored in other rooms or departments. Secondly, the medication was not available. This could be due to shortages or changes in suppliers.

The central pharmacy of the Erasmus MC was contacted and they could collect part of the missing products or replacements for them there. Additionally, they provided the locations of part of the rest of the products.

Because the initial dataset was not exported correctly, not all drugs were taken into account and weighed. The dataset exported the medications from January 2022 till February 2023. As the 2023 data was required, this had to be exported again. This resulted in new drugs that had to be weighed using the same protocol. These medications have been weighed in July 2024.

Eventually, data from 2022 and 2023 have been collected. Around 513 medications in the database were covered. These consist of a total of 418 weighed products (selected products and replacements), and extrapolated proxies to the ones that were not available or replaced. With this amount, 91 per cent of the total prescriptions were covered.

After collecting the information, the data in Excel was linked to the large pharmacy and CBG database. In this, data was processed, errors were corrected, missing information was added and the substitutions were linked and proxied to the corresponding medications.

The most important information that was missing was the weight of the medication itself. This information was requested from suppliers. Not all suppliers could or wanted to share their information so for these a proxy was taken from other similar products.

Additionally, one supplier provided information on nominal volume and filling volume for liquids. There appeared to be a difference in this, making the assumption of subtracting the nominal volume given on the packaging inaccurate. This required approaching the suppliers of liquids again to get the correct weight.

3.4 Results

In this chapter, the results of the weighted medication packaging are presented. The results are from the data on prescriptions in 2023.

In Figure 51, the Material Flow Analysis of the Intensive Care Unit in 2023 can be seen. This is a quantitative outcome. It displays the share of all different components per primary packaging typology defined in Chapter 2.3. The biggest mass is from Excipients in the medication. Looking at the packaging itself, most of it is from primary packaging with the share of secondary packaging second. The majority of the packaging is used in Infusion CRRT bags. In total, medication packaging accounts for 39923 kg of waste.

In Figure 52, the average use of medication per patient per day can be seen, divided in the previously defined typology for primary packaging. It shows the vast amount of different medications that are used at the ICU and that a patient will get a lot of types of medication administered.

Next to the quantitative analysis in the Material Flow Analysis, a qualitative analysis of the typology components has been done to display what these different components consist of and what components often appear together. This analysis can be seen in Appendix C. This quantitative analysis clearly shows the large amount of different materials used in different packaging components. In the case of most primary packaging, the component consists of a blend of materials or is made from different materials joined in such a way that they cannot be separated anymore. The secondary packaging tends to exist more as monomaterials or materials that could be separated, but still has exceptions. For the accessories, the same applies to the secondary packaging.

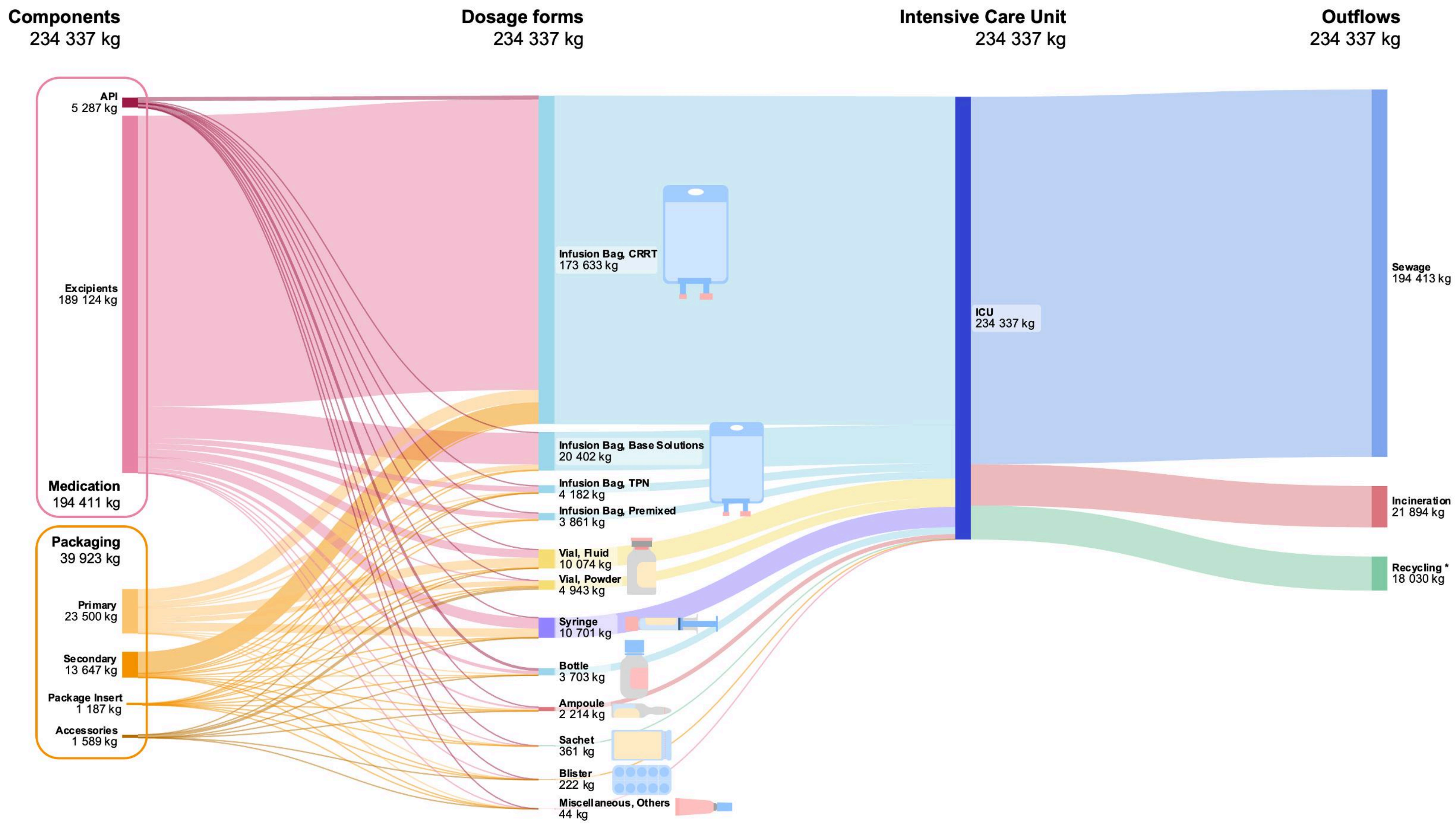


Figure 51: Material Flow Analysis of medication per primary packaging type (Klasen et al., n.d.)

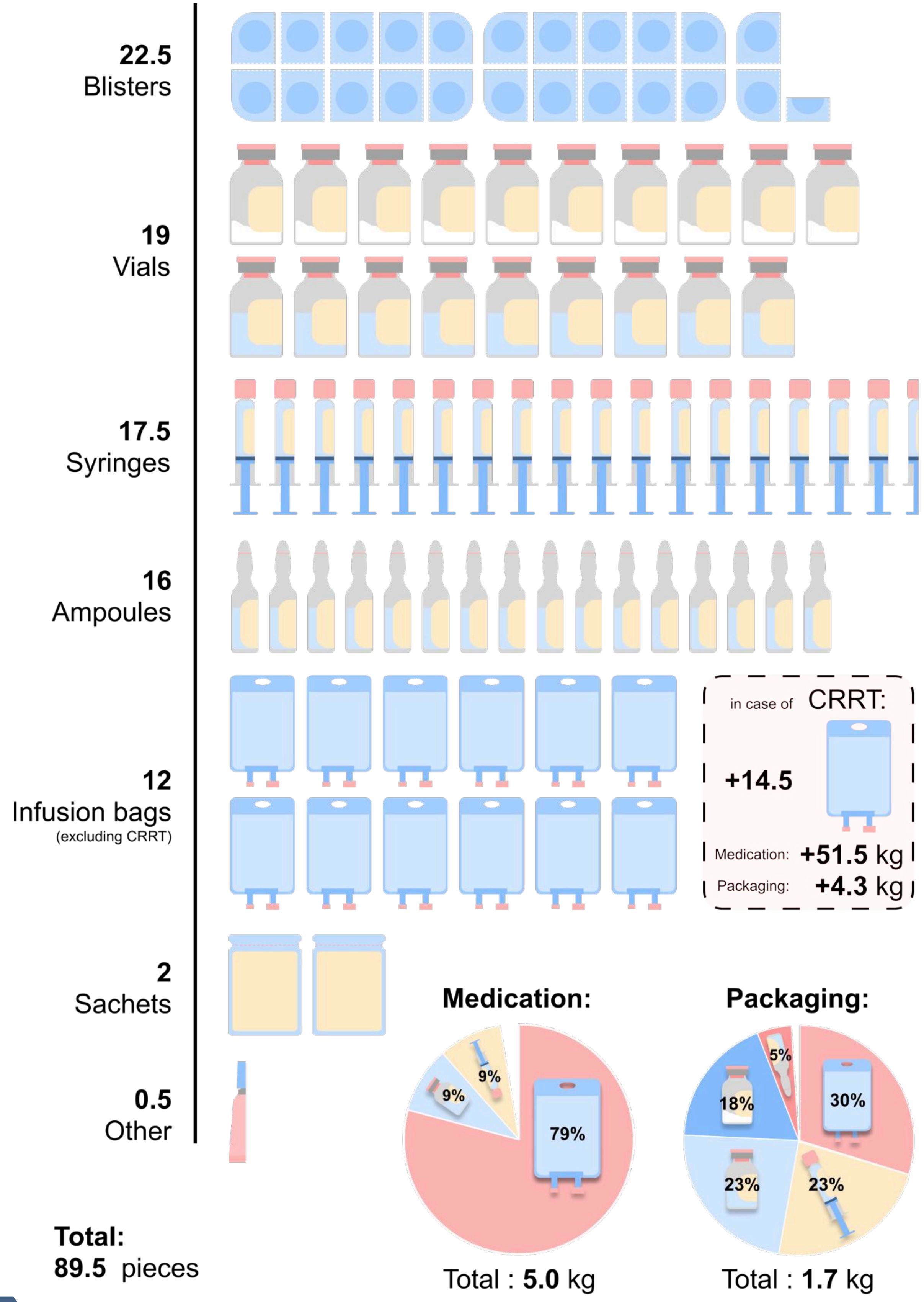


Figure 52: Medication used per patient per day

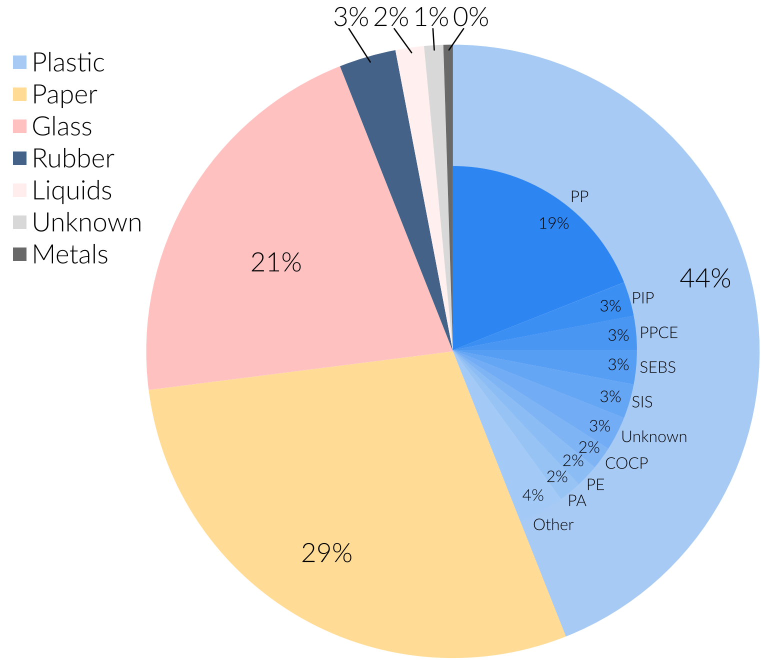


Figure 53: Weight per material of total waste

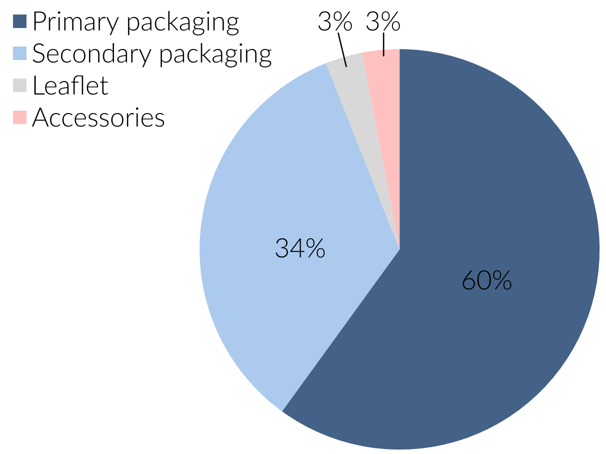


Figure 54: Weight per component of total waste

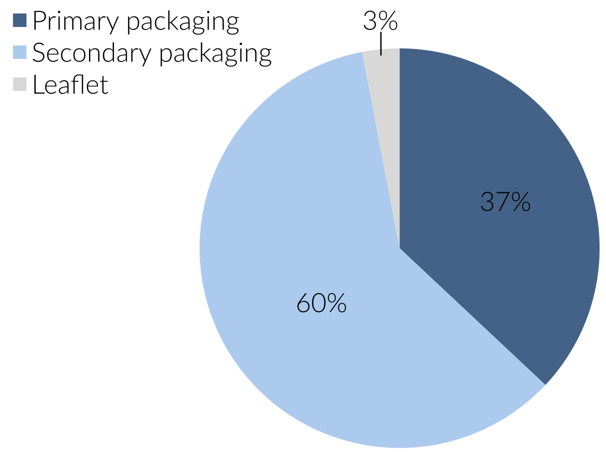


Figure 55: Weight per component of infusion dialysis bags

In Figure 53, the weight per material can be seen for all packaging components combined. It shows that 44% of the packaging consists of plastic. Next to the plastic two other hotspots can be seen: paper (29%), consisting of boxes and leaflets, and Glass (21%), coming from mainly ampules and vials.

The Figure also shows that the share of plastic is divided into a lot of different types. The majority, 19% of the total waste, is PP, mainly coming from infusion bags and their protection bags, syringes and plastic ampules. The other types of plastic are present in small quantities, with a maximum of 3%. Additionally, a lot of the different types of plastics are part of a blend.

Figure 54 shows the weight divided over the different packaging components with the medication itself left out. It shows that the biggest mass is in primary (60%) and secondary (34%) packaging and that both the leaflet and accessories have a low share of 3%.

In the Material Flow Analysis (Figure 51) analysis it shows that most of the material is in the infusion CRRT bags. If this is isolated, as can be seen in Figure 55, it shows that for this packaging type, most of the materials are in the secondary packaging (60%). When the secondary packaging is split into the two components it exists of, it shows that almost half (48%) of the material weight is from the secondary packaging paper box, see Figure 56.

Looking at the CRRT bags, the bag with the most prescriptions in 2023 is Ci-Ca Dialisate K4 plus of 5 litres, namely 22946 times. As three other bags of 5 litres (Ci-Ca Dialisate K2 plus, Multibic Kalium 4 mmol/L and Multibic Kalium 2 mmol/L) are packaged in the same paper box, the prescriptions of these were added, resulting in 28368 prescriptions. These four bags are responsible for 89% of the CRRT bags waste produced.

The prescriptions of the four CRRT bags resulted in 8067 kg of waste in paper boxes in 2023. From the total waste of 39923 kg generated, the share of this specific paper box is 20%

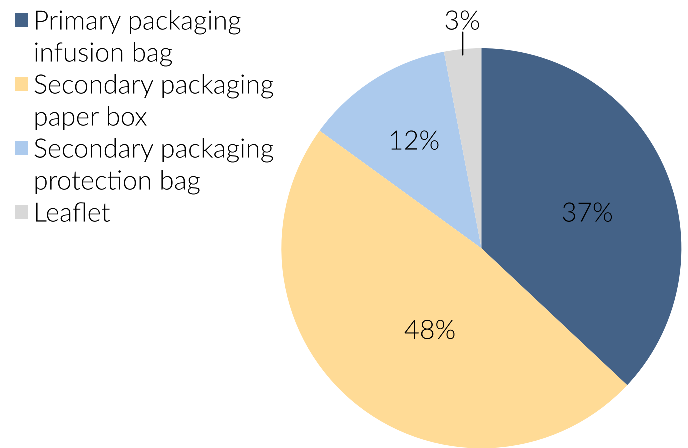


Figure 56: Weight per packaging of infusion dialysis bags

3.5 Conclusion

The results presented in this chapter provide a comprehensive overview of the materials and quantities involved in medication packaging within the ICU. The most mass of the Material Flow Analysis is in the medication itself. But when looking at the packaging itself, three main material hotspots were identified: plastic, glass, and paper.

Paper
The paper components of the packaging consist of only paper trays as an accessory, the leaflets and paper boxes as secondary packaging. And since the results show that leaflets and accessories are only a very small part of the total waste, the focus on boxes was chosen for this project. This is also because a box as packaging has the same function in every typology of primary packaging. This direction was chosen because redesigning one box can already make a significant impact on waste production.

Plastic
For this project, plastic packaging will not have a focus because in order to make a significant difference in reducing waste and environmental impact, many different materials and packaging need to be investigated. This is because there are a lot of different kinds of plastic in different types of packaging. Next to this, this project would become more of a material science research and not a design project. So plastic packaging is beyond the time and scope of the project.

Glass
Redesigning glass packaging as vials and ampules is challenging due to strict healthcare regulations, which require maintaining sterility, chemical stability, and safety. This would make redesigns with for example reuse very hard to implement. Additionally, recycling is complex due to contamination and quality requirements, and alternatives would require significant investment and adaptation of production processes. Next to that, recycling would need very big quantities of glass to be profitable enough.

Besides the materials, it is clear that a substantial impact can be made in the primary and secondary packaging components and leaflets and accessories can be ignored in this project. For the primary packaging, there are more regulations and requirements that are hard to get around in designing new packaging. To give more freedom to the project, secondary packaging could be more interesting to look at. As paper boxes are secondary packaging, this is chosen as the focus.

As CTTR bags are the largest contributor to the amount of waste and contain mainly secondary packaging, redesigning these could result in a significant amount of waste reduction. This is why this project will focus on only the boxes of these bags. As the biggest part of the secondary packaging consists of the paper box, this is the component that will be redesigned.

In Figure 57, the focus of the paper boxes in CRRT bags can be seen in the full picture of the Material Flow Analysis. The yellow highlighted part consists of the dialysis boxes. This is the largest part by mass of the largest mass of drug packaging of the entire stream.

As discussed in Chapter 3.4, The CTTR bags of 5 litres with Ci-Ca Dialisate K4 and K2 plus and Multibic Kalium 4 mmol/L and 2 mmol/L have been taken into account. When redesigning the boxes of these four bags, 20% of the total waste is being addressed.

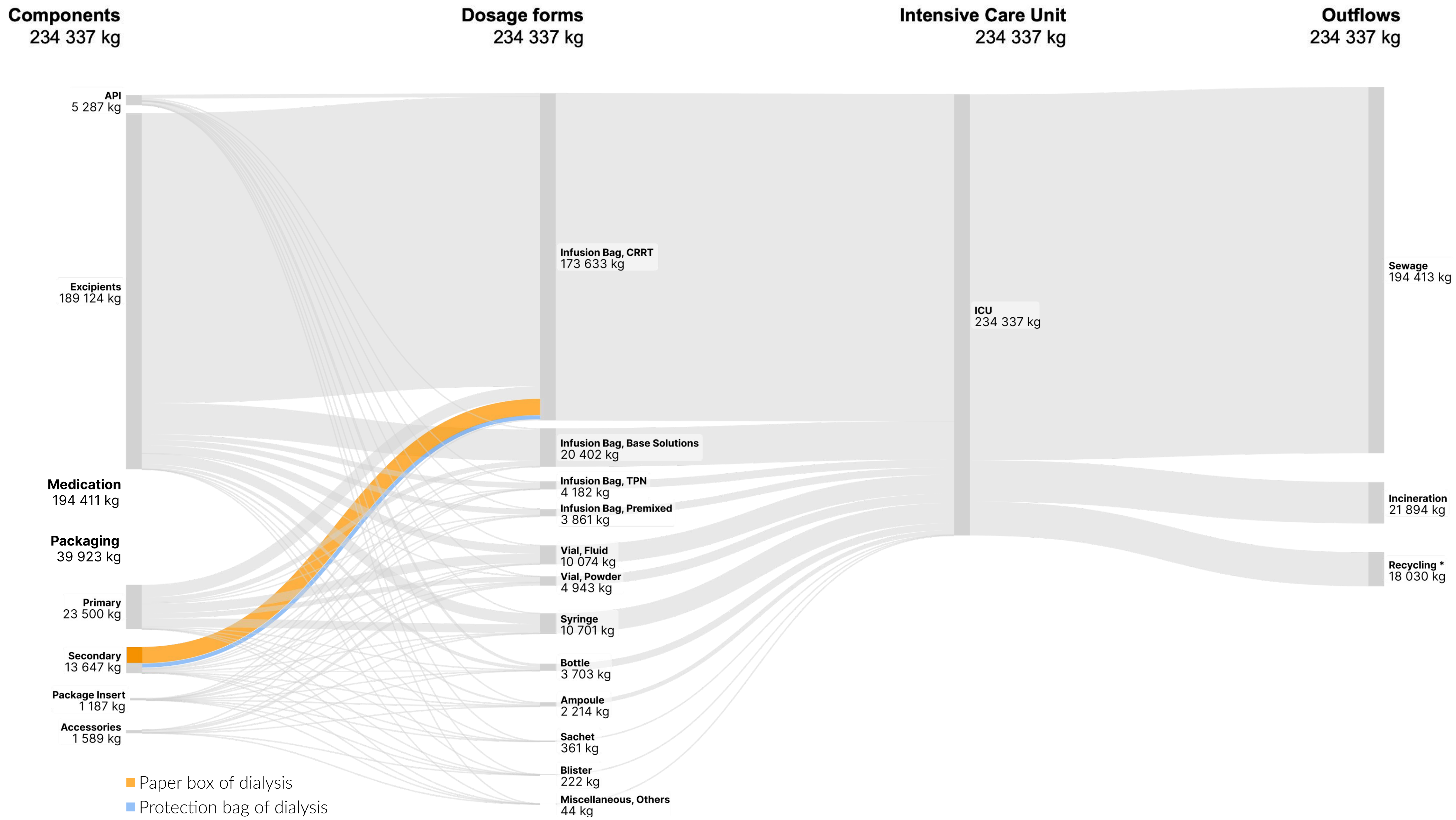


Figure 57: Material Flow Analysis of medication per primary packaging type, highlighting the share of CRRT infusion bags

Redesigning Packaging

4

This chapter explains the process of redesign. First, it describes how the current paper box is designed. It also explains everything revolving around the paper box, such as logistics and usage. Then, the first concept ideas are discussed in the four new envisioned scenarios. Cost-price analyses were done for the four scenarios. From the cost price analysis and filtering of the concept ideas, four concepts emerged. These concepts were developed and assessed against the established requirements. Using a Harris profile, the final choice was made for the dolly cart concept combined with the box with lid. The final concept is further explained and the new envisioned situation is described.

4.1 Directions for Intervention

From the research in Chapter 3, it was found that the boxes containing the 5 litre dialysis bags are 20% of the total waste produced by ICU at the Erasmus MC. This means, by only focussing on this component for a redesign, a big impact can be made.

Before explaining the design directions and context surrounding dialysis boxes, a broader view of boxes was taken. Based on the insights gathered in Chapter 2.4, the function of a paper box used in medication packaging has been mapped. This can be seen in Figure 58.

After this, an initial brainstorming session was conducted using the R strategies of the value hill. This brainstorm can be seen in Appendix D. In Chapter 1.4.3, a selection was made of the strategies that had the most opportunities in this project, namely the strategies Reduce, Reuse, Recycle and Recover.

- The strategy Recovery is in this case the last resort and will not be used for this project as the strategy Recycle is already in use in the current situation, making Recovery not fruitful to design for.
- For Recycling improvements could still be found but it will not reduce the impact of the packaging significantly.
- Reducing the amount of waste will result in a bigger positive impact and could be done by reducing the amount of paper used in the boxes.
- As researched in the fruit and vegetables industry (Albrecht et al., 2013), reusable packaging could reduce the environmental impact compared to single use paper boxes.

This means that mainly the two strategies Reduce and Reuse were used in the design of a new concept.

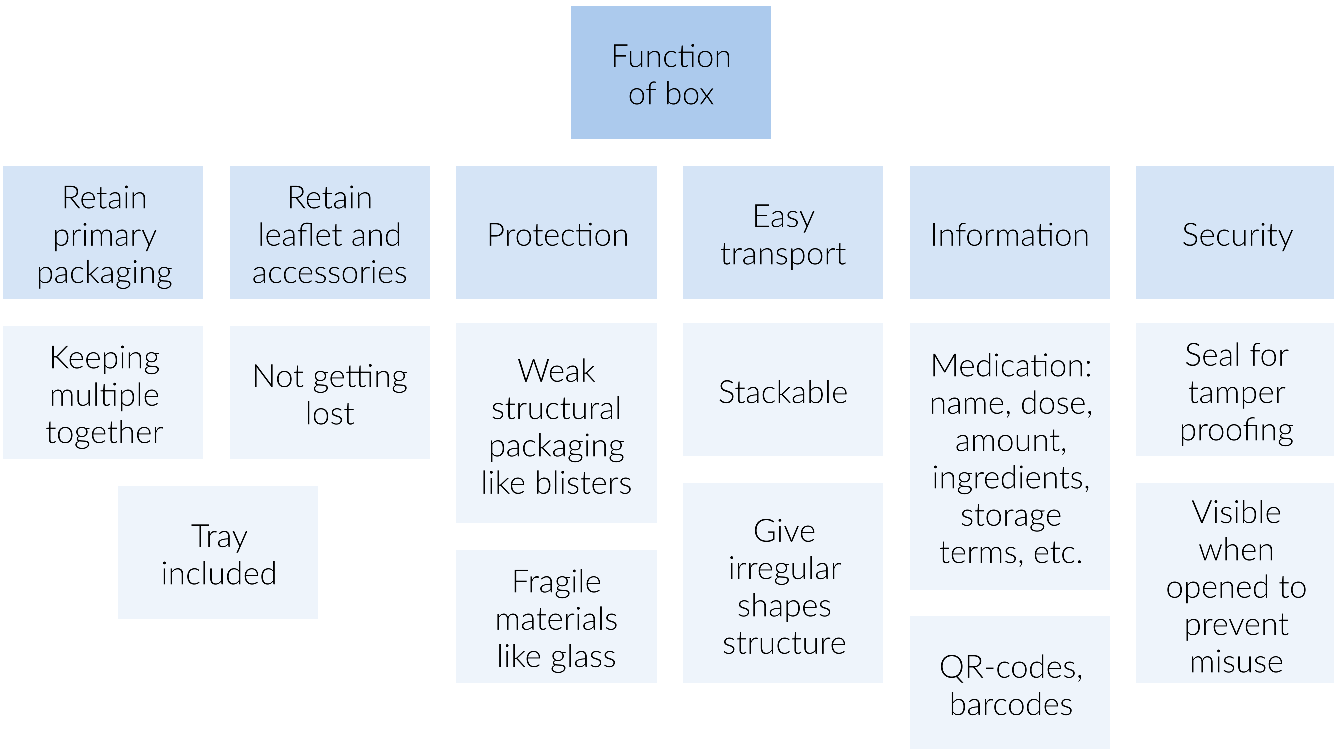


Figure 58: Functions of paper boxes as packaging

4.2 Current Dialysis Packaging

The full packaging of the dialysis bags consists of two bags of dialysis with medication, two types of secondary packaging (one paper box and a protection bag per dialysis bag), and a leaflet. The components can be seen in Figure 59 and Figure 60 shows how the components are packaged together. The complete packaging that is delivered has a weight of 11.1 kg in total.

Figure 59: Picture of all components of dialysis bags

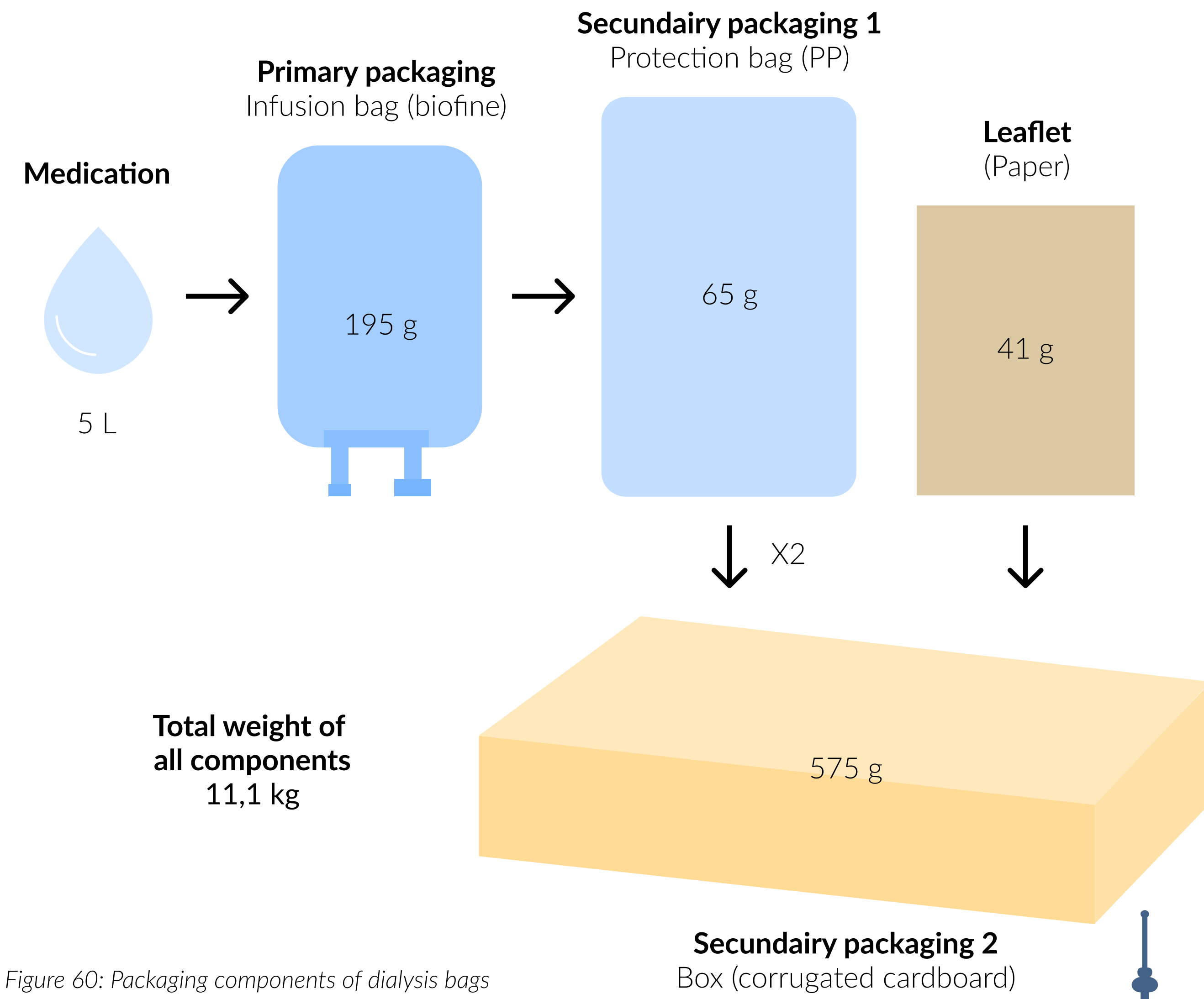


Figure 60: Packaging components of dialysis bags

4.2.1 Leaflet

The leaflet (Figure 61), made from paper, will be discussed shortly, as this component is only 3% of the waste in this medication, but still has a total of around 582 kg wasted per year. If all the leaflets used in 2023 were to be stacked on top of each other, they will reach a height of around 26 meters.

The only reason that these leaflets are included in the packaging is because of the strict legislation around the packaging of medication in the EU. In an interview, the head of the nurses of the ICU said that nurses think a leaflet in each box is not necessary as they get 15 boxes delivered on a cart, 2 to 3 carts per day depending on the number of patients. The leaflets almost always go straight (and unread) into the paper bin when the bags are being unpacked. Nurses know how they need to use the product and the medication system used in the ICU will calculate and tell the nurses how much each patient needs. They also state that if they would have the need to consult the leaflet, they can find it online or in the system.

The leaflets consist of many pages with 8 to 15 different languages of all the countries they sell in. This makes the leaflet bigger and less useful then they need to be.

4.2.2 Dialysis Bag and Protection Bag

As already stated in Chapter 3.5, the redesigning of the protection bags and dialysis bags (Figure 62) was not included in this project. Still both components are important to mention in the system. The dialysis bags are made of Biofine, a mix of the plastics PPCE, SEBS, SIS, PP and PIP. The protection bags are made of PP. Both the Biofine and PP bags are, compared to plastic packaging from households like food packaging, clean and are believed to be easy to recycle.

The Erasmus MC has already started a pilot to investigate if these bags can indeed be easily recycled into new products. As the outlets of the dialysis bags are made from a different material then the bag itself, they are being cut of. Then both the dialysis bags and protection bags are collected in a separate bin in the waste room.

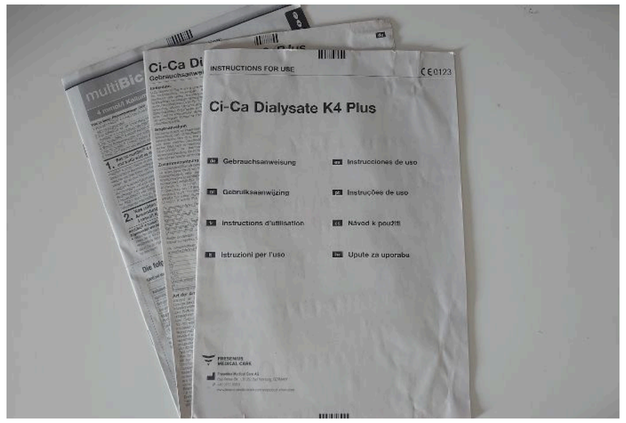


Figure 61: Leaflets packaged with dialysis bags

Figure 62: Dialysis bags in protection bags

4.2.3 The Paper Box

After briefly having mentioned the less important components, the paper box itself will be discussed. The box was taken apart and folded back to the sheet form to make it easier to analyse. In Figure 63 the paper box and its aspects has been mapped.

From the analysis, a quick estimation of design opportunities that could be changed was made and can be seen in the numbers and corresponding list. All opportunities can be optimised on to make an impact on the sustainability of the design. For ease of use, the opportunities 4 and 5 can be improved.

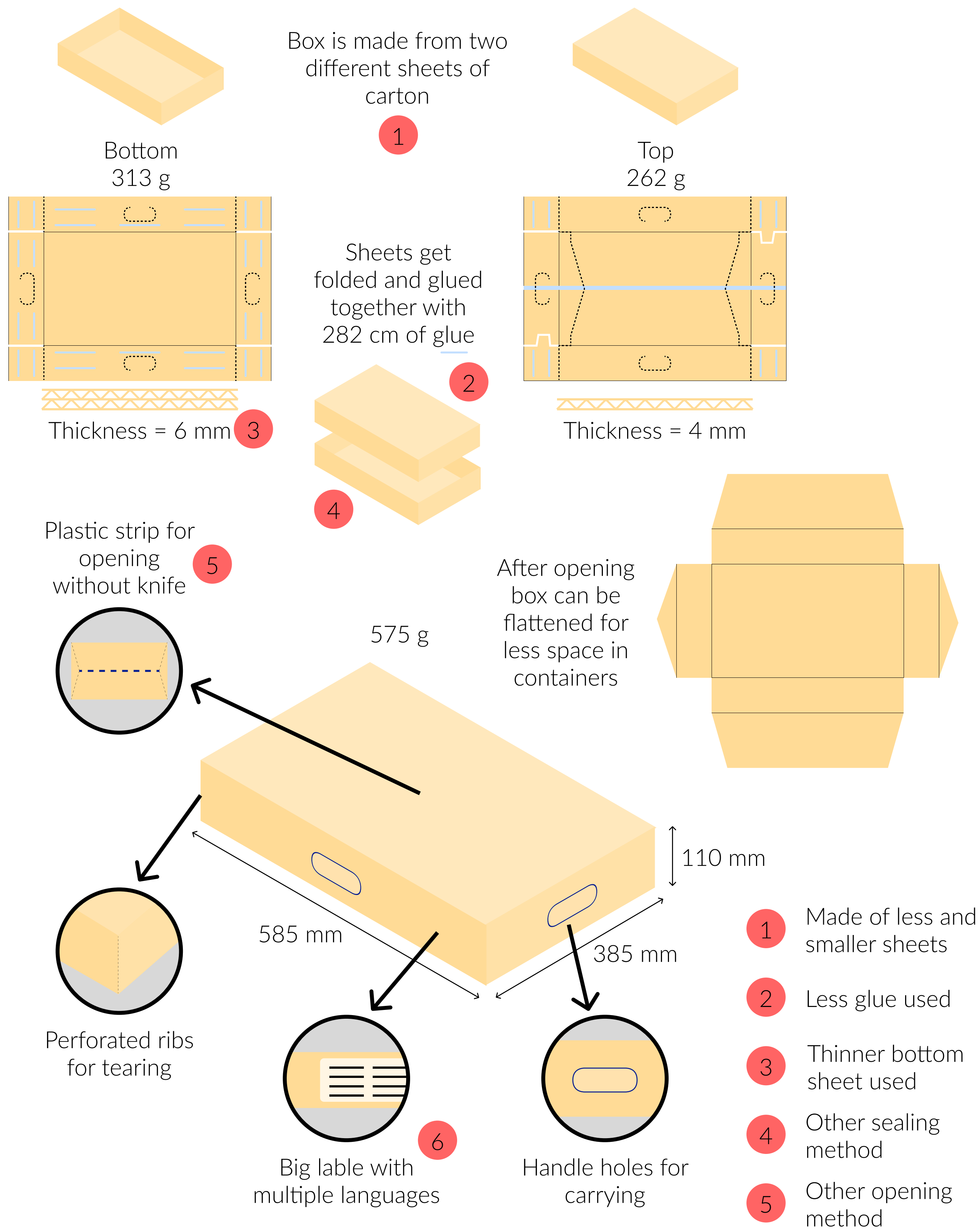


Figure 63: All aspects of the corrugated cardboard box

4.2.4 Tests Using Thinner Sheets

One of the opportunities found was to use thinner sheets (opportunity 3). This would mainly concern the sheet of the bottom of the box. To see if this would be a possibility, two tests were carried out.

First, the weight that the box could hold on the bottom was tested. In testing this, the top part was used. The bottom of the box is stronger due to the double corrugated sheet and the top of the box is made of a single corrugated plate and is weaker (see Figure 64). Only the question is whether this thickness could still be enough to hold the bags. In the test, the top part of the box could hold 25 kilos, see Figure 65. This is 2.5 times more than the 10 kilos the box has to hold now. This indicates that one could look at changing the bottom of the box from a double corrugated sheet to a single one like the tested top part.

For the second test, we looked at how much the box could support when stacking multiple boxes on top if the bottom of the box were changed to a single corrugated plate. This test was done by combining two top parts of two separate boxes into one box, see Figure 66. This combined test box was then placed on the ground after which unopened boxes were placed on top. At first, it was assumed that the test box should be able to hold 12 boxes, considering the fact that the boxes are stacked 13 high on a pallet from Fresenius Medical Care (Figure 67). When the test box seemed to hold this, the stack was increased to 18 boxes on top of the test box. This was the maximum amount that was physically possible to lift and that still felt safe. Both stacks can be seen in Figure 68.

These two test both show the possibility of making the bottom sheet thinner, despite this being a static situation. To be certain the boxes will hold, follow-up testing is necessary in more dynamic situations as the boxes are moved by truck and forklift.

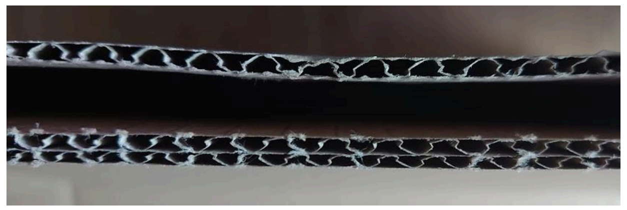


Figure 64: Profiles of the top and bottom sheets

Figure 65: Top parts with 25 kilo

Figure 66: Two top parts combined into test box

Figure 67: Boxes stacked on pallets, 2 by 2 by 13

Figure 68: 12 and 18 full boxes stacked on top of test box

4.3 System Around the Packaging

Now the focus shifts outward to identify the situation around the box. The box is mapped in the system, with all components, flows and stakeholders.

4.3.1 Stakeholders

There are mainly four main stakeholders present in this system:

- Fresenius Medical Care produces the medication and the packaging.
- Hospital Logistics stores the boxes, transfers the boxes from the pallet to a cart and transports the cart to the hospital.
- Erasmus MC is where the carts and bags are being stored and transported by logistics personnel. At the ICU, the nurses use the boxes, opening and discarding them.
- Pre-zero collects and processes the waste of the medication. Erasmus MC has a contract with them for this.

4.3.2 Overview of the System

In Figure 69 on the next page, the mapped system can be seen.

First starting at Fresenius Medical Care, it is where the medication is produced, packaged and transported on a pallet. For other hospitals, nursing homes, and home care facilities, the medication is delivered directly by pallet.

For the EMC, this is different as it is delivered to Hospital Logistics first. There are two reasons for this. Firstly, because large polluting trucks are not allowed to enter Rotterdam, all shipments to the EMC are delivered to Hospital Logistics and then taken to the EMC by smaller and cleaner transport. The second reason is that the EMC is a pallet-free hospital. This is because pallets can carry bacteria and other contamination. At Hospital Logistics, the boxes are loaded from the pallets onto carts, which are returned to Hospital Logistics. Previously, twenty boxes were stored on the carts but as the carts were too heavy to roll responsibly, the logistics branch decided to only allow fifteen boxes per cart.

For other products, such as smaller infusion bags from Baxter, for example, these are also removed from the paper boxes and brought to the EMC in crates so that no small paper particles enter the hospital either. Because the dialysis bags are packed in pairs and are large, this does not happen with these.

Once the carts reach the EMC, they are first stored in the basement of the hospital as there is not much space in the ICU itself. Here in the basement, emergency stock is also delivered on pallets for when Hospital Logistics has delivery problems. The empty carts are exchanged with full ones upstairs at the ICU. Once the carts are in the unit, they are stored in a separate room and the nurses remove them from the carts when the bags are needed for the patients. Lifting the boxes from the trolley is heavy for the nurses as the box weighs 11.1 kg. The use of the boxes by the nurses will be explained in Chapter 4.3.3.

Depending on the treatment and number of patients, the number of dialysis bags used in the ward varies. On average, there are 5 patients in the ICU per day requiring dialysis treatment. The treatments vary from person to person but often four bags are attached to the dialysis machine and need to be replaced every 6 hours. This results in an average of 16 bags per patient per day. Figure 69 shows the numbers of all quantities used and the weights of waste produced. As was already clear in Chapter 3, more than half of the waste of the dialysis packaging is from the paper.

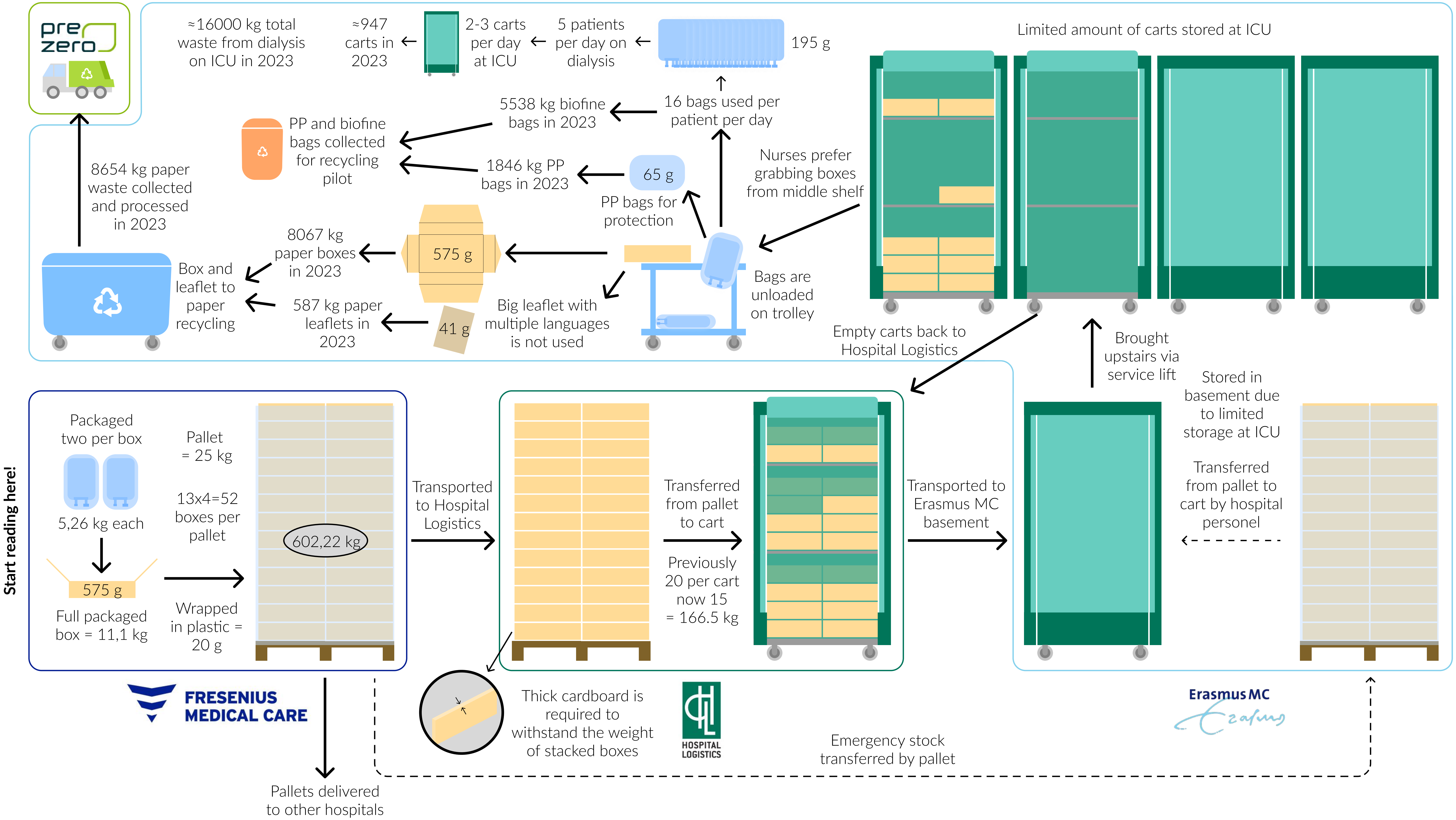


Figure 69: The system around the dialysis bags

4.3.3 Use of the Paper Box

Now the focus is on the use of the box by nurses. The way the box has to be made small is not desirable in several ways. This was experienced first-hand by trying it out. First, it takes too much time for the nurses and they sometimes skip this step, leaving the boxes unflattened. The logistics department is then not happy about this because the paper waste container fills up faster and has to be emptied more often.

If the box does get flattened, the box has to be placed on the floor to tear it open because force with the foot is required. The box has to be picked up from the ground. This gives two other reasons for undesirability. First, it is physically uncomfortable for the nurses to bend over. Secondly, this is also not hygienic and the nurse has to wash their hands which again takes more precious time. The current time it takes to open and dispose of the box has been recoded to be 39 seconds. The use scenario of the box is shown in Figure 70.

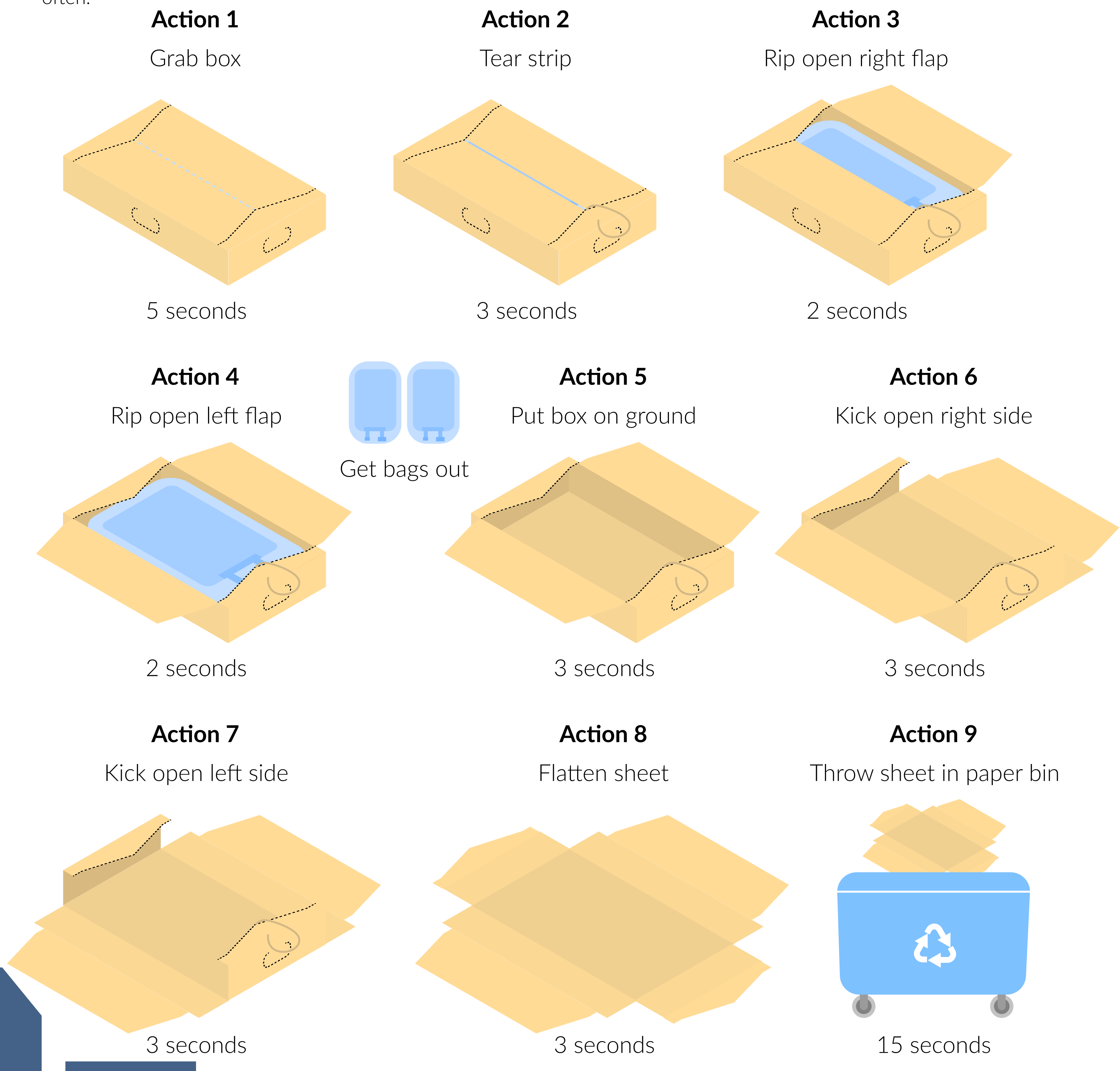


Figure 70: Use scenario of opening and disposing of the paper box

Total time: 39 seconds

4.4 Redesigning Dialysis Boxes

Now that the box is analysed and the situation around it is mapped, the redesign can be made. The design directions are explained and after ideation, a choice is made between four concepts using the PMI method and a cost analysis

4.4.1 New Design Directions

From the brainstorming (Chapter 4.1) of the R strategies, the strategies Reduce and Reuse have been used to redesign the box. Implementing these strategies will change the system. In Figures 72 to 75 on pages 58 to 61, four scenarios with changes, can be seen on the next pages. For the four scenarios, there are both advantages and disadvantages identified. First scenario is reducing the paper in the box (Figure 72). Second, scenario is a hybrid paper/reusable system to not have paper packaging waste in the hospital, still using the cart system from Hospital Logistics (Figure 73). Third scenario a full switch from paper to reusable, also still using the cart system from Hospital Logistics (Figure 74). Last scenario is a full redesign of the transport system (Figure 75).

4.4.2 Ideation on Directions

Because the four scenarios described earlier, have an overlap in the use of boxes and systems, the ideation directions have been reduced to three: Paper box redesign, Reusable box redesign and Reusable system cart redesign.

To get some inspiration, a collage of existing transportation of products has been made, see Appendix E. These products were found on a field trip and with online research.

Also for the ideation for the paper concepts, examples from the FEFCO code are used. These are standardised designs for cardboard packaging (FEFCO Code, n.d.). From this code, concepts are used to try and reduce the amount of sheets, glue and paper used in the paper packaging.

From the inspiration, ideation has been done to find ideas for possibilities that fit the scenarios, see Appendix F. From this ideation, scale models have been made. The first scale model (Figure 71) is the current box to be able to compare the ideas with. All ideas for the three ideation directions can be seen in Figures 76 to 78 on pages 62 to 67.

For the first direction of the paper box, the FEFCO blueprint and the weight have been documented. The paper models have been weighed to see if there is less paper used and to see if there is a reduction in waste produced. If the weight was higher than the original, the concept was not chosen. For the second and third directions of the reusable box and reusable system, the product it is based on is shown.

For the selection of the ideation concepts, the PMI method is used (Van Boeijen et al., 2014). The letters in this method stand for "Plus, Min, Interessant" in Dutch, highlighting the positive, negative and interesting parts of the design. From this, an initial selection was made to quickly choose what ideas would be fruitful. This first selection is noted in the final column of the tables with a check (V), maybe (~) or rejected (X).

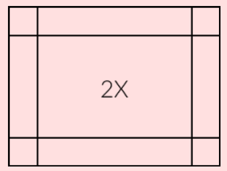
Nr.	Picture	FEFCO	Weight	+ ~ -
O		 2X	2,131	+Possible to make flat ~2 sheets -Plastic strip -Lots of glue -Thick bottom sheet -3 actions to open -4 actions to make flat

Figure 71: First scale model of original paper box

Advantages
- Less packaging waste
- Can be implemented in the short term
- No change to current system

Disadvantages
- Waste remains
- Inefficient with quantity of boxes per cart

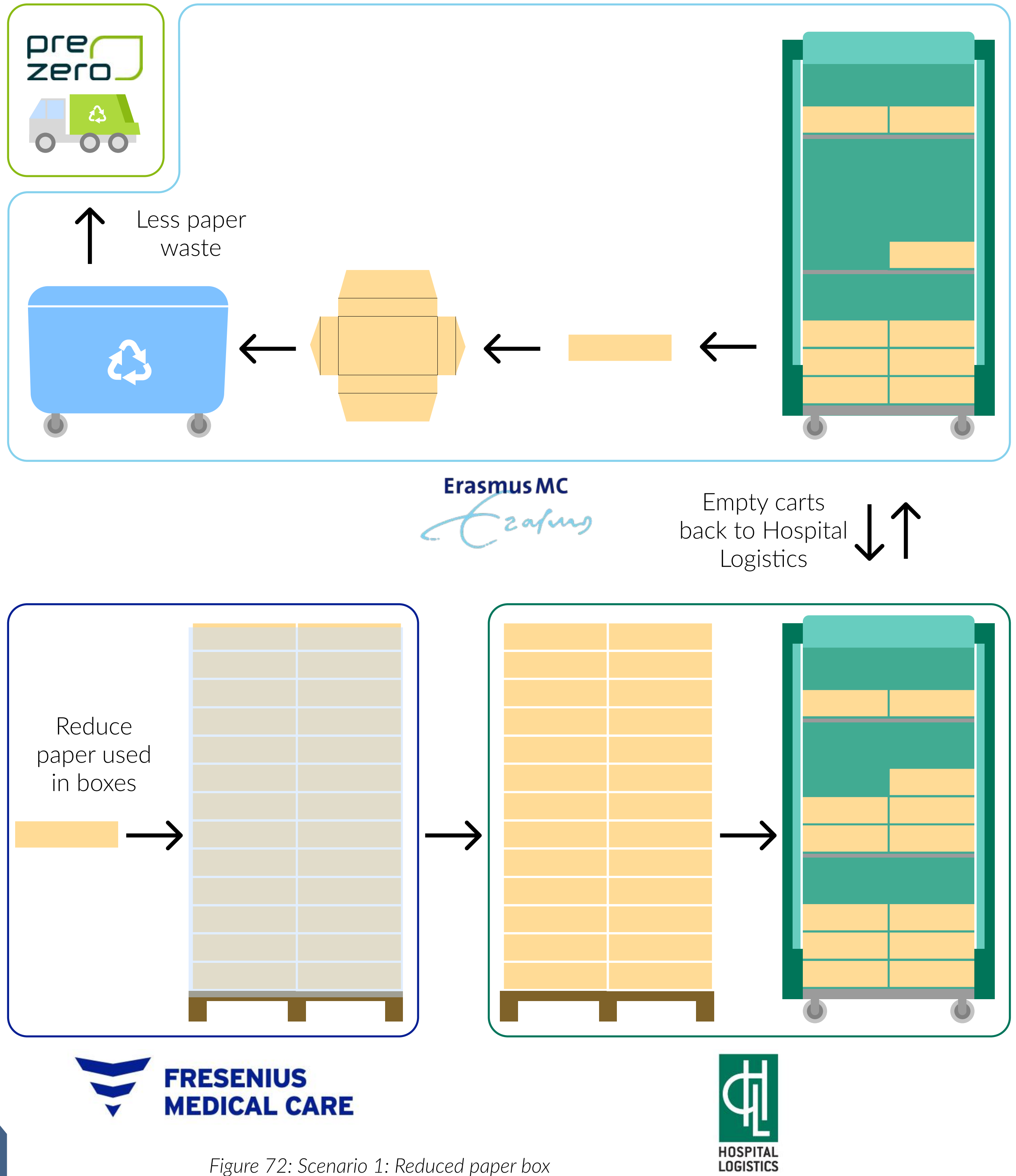


Figure 72: Scenario 1: Reduced paper box

Advantages
- Packaging waste no longer in the hospital
- Minor changes current system
- Reusable boxes together with cart back to Hospital Logistics (same system as Baxter bags)

Disadvantages
- Waste remains but moved to Hospital Logistics
- Double production, two types of boxes used
- Repacking bags takes more handling

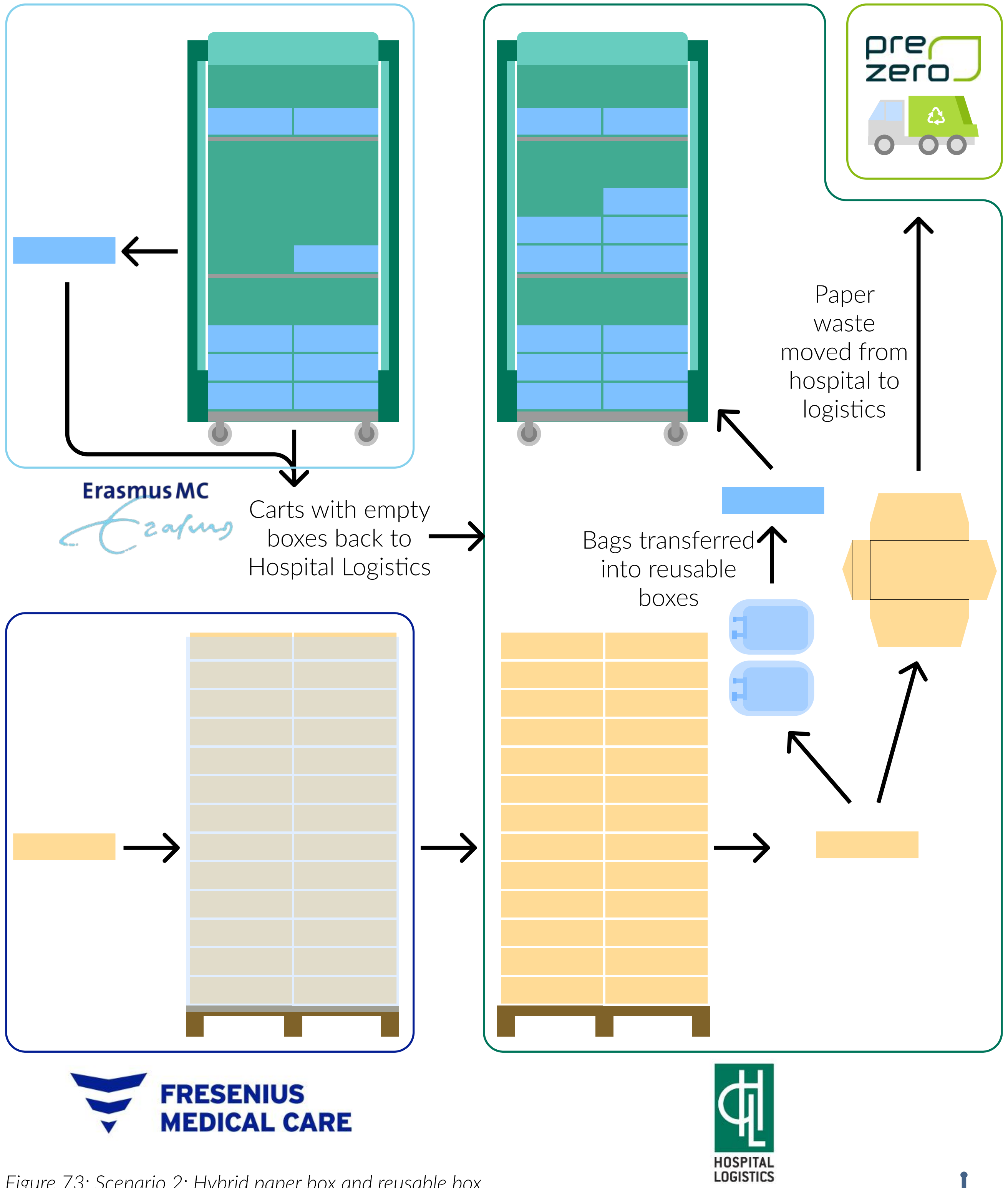


Figure 73: Scenario 2: Hybrid paper box and reusable box

Advantages
- No packaging waste
- No paper particles in the hospital
- Less handling for staff

Disadvantages
- Boxes still need to be transferred to cart
- Cart has to go to Hospital Logistics and boxes to Fresenius Medical Care
- Fresenius Medical Care production line has to be adapted
- Large initial investment

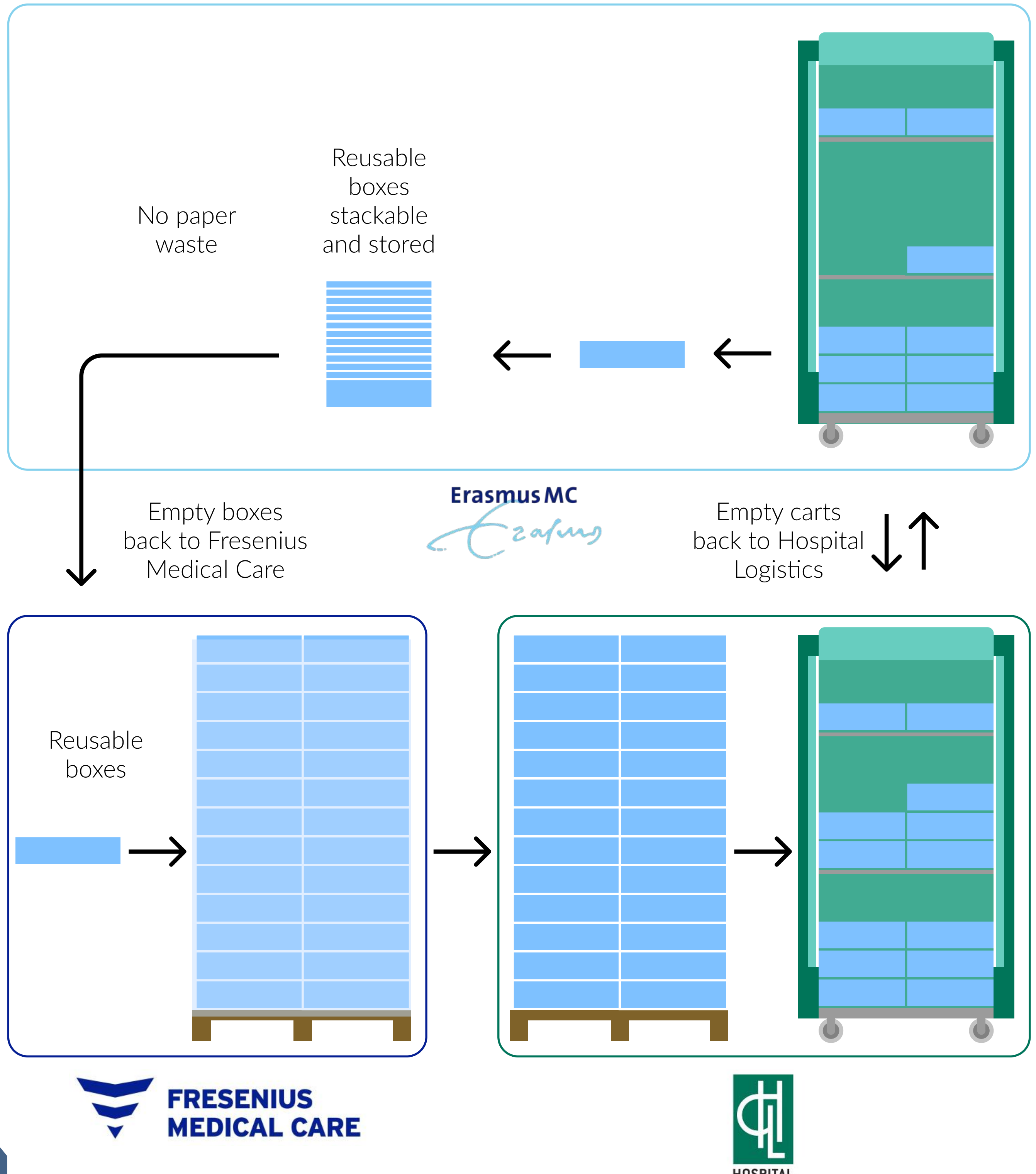


Figure 74: Scenario 3: Reusable box in current system

Advantages
- No packaging waste
- No paper particles in the hospital
- Less handling for staff
- Only storage at Hospital Logistics
- Efficient logistics

Disadvantages
- Entire system has to be changed
- Large initial investment
- Fresenius Medical Care production line has to be adapted

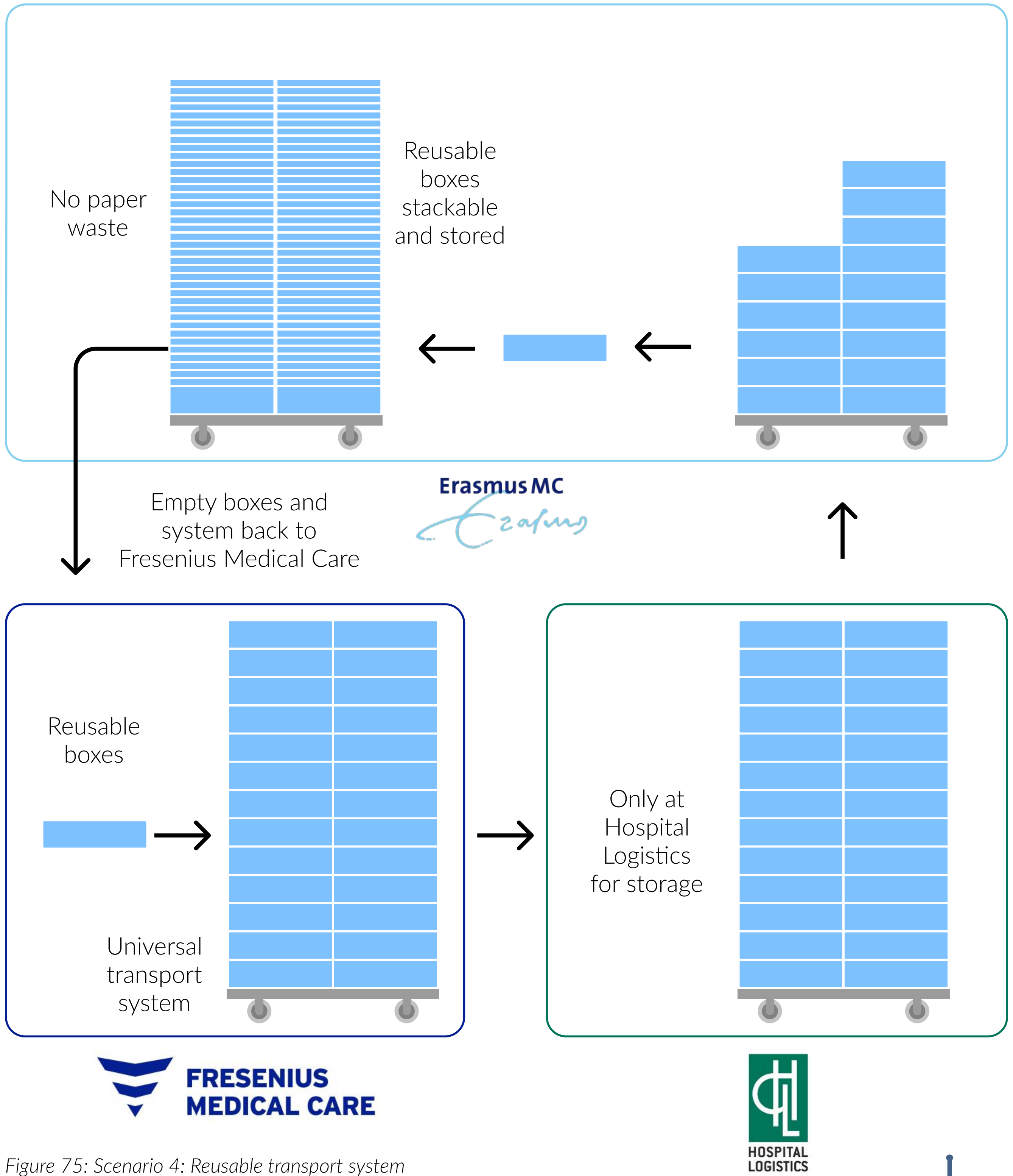


Figure 75: Scenario 4: Reusable transport system

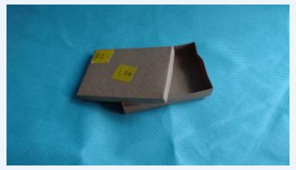
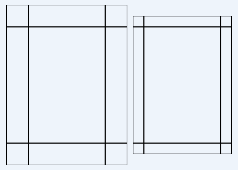
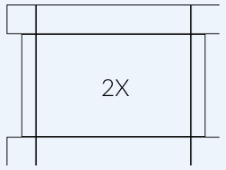
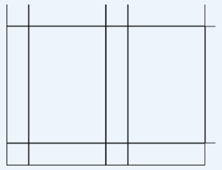
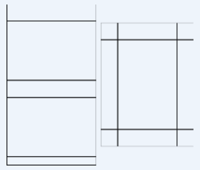
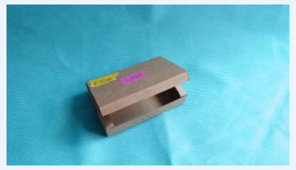
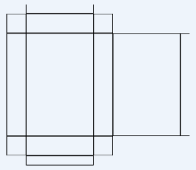
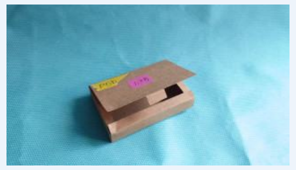
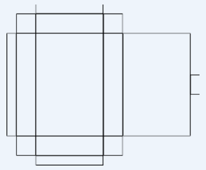
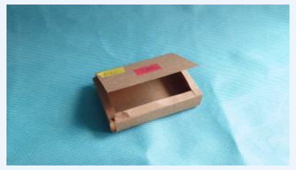
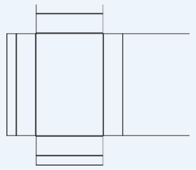
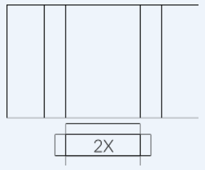
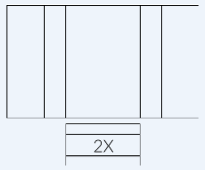
Nr.	Picture	FEFCO	Weight	+ ~ -	v ~ x
P1			1,714	+Lighter -No double walls for strength	~
P2			1,952	+Lighter ~Structural? ~How to carry?	X
P3			1,898	+Lighter +Less glue -Same opening -No double walls for strength	X
P4			2,381	-Heavier	X
P5a			1,759	+Lighter +Less glue +1 action to open -No double walls for strength	V
P5b			1,779	+Lighter +Less glue +1 action to open -No double walls for strength	V
P5c			1,613	+Lighter +Less glue +1 action to open -No double walls for strength	X
P6a			1,714	+Lighter +Less glue ~2 actions to open -No double walls for strength	~
P6b			1,665	+Lighter +Less glue ~2 actions to open -No double walls for strength	X

Figure 76a: Ideas first direction: redesign paper box

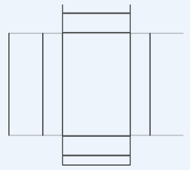
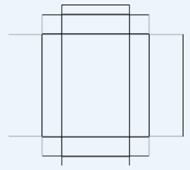
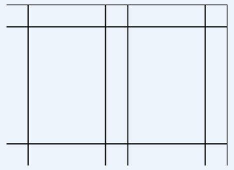
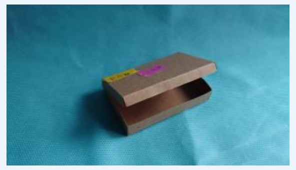
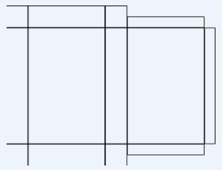
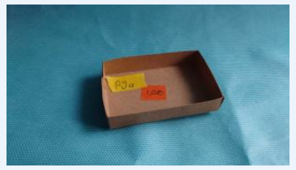
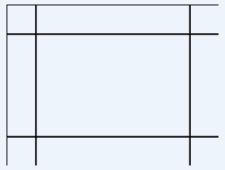
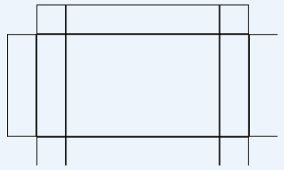
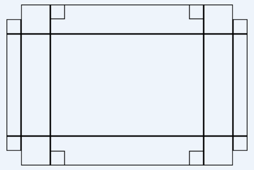
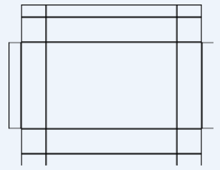
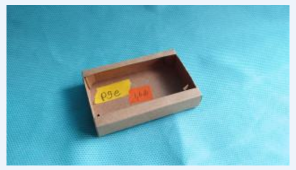
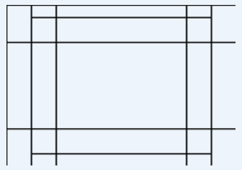
Nr.	Picture	FEFCO	Weight	+ ~ -	v ~ x
P7a			1,541	+Lighter +Less glue, one sheet ~2 actions to open -No double walls for strength	X
P7b			1,677	+Lighter +Less glue, one sheet ~2 actions to open -No double walls for strength	V
P8a			1,969	+Lighter + No glue? ~1 action to open	~
P8b			1,737	+Lighter + No glue? ~1 action to open	~
P9a			1,089	+Less paper, sheets -No lid -Not stackable	X
P9b			1,343	+Less paper, sheets -No lid -Not stackable	X
P9c			1,190	+Less paper, sheets +Stackable ~Structural? ~No lid	~
P9d			1,377	+Less paper, sheets +Stackable ~Structural? ~No lid	~
P9e			1,681	+Less paper, sheets +Stackable +Strong because of triangle ~No lid	V

Figure 76b: Ideas first direction: redesign paper box

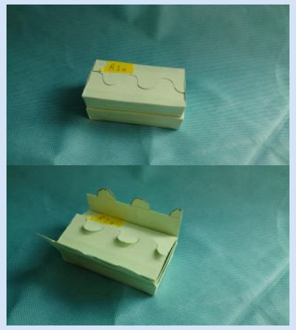
Nr.	Picture	Based on	+ ~ -	v ~ x
R1a			+Sealable +Stackable +Nestable +Already used in hospital	V
R1b			+Sealable +Stackable +Nestable +Already used in hospital	V
R2			+Stackable +Nestable +Already used in other industries ~Lose lids	~
R3			+Sealable +Stackable +Nestable ~Keeping bags in without sticking out	X
R4			+Stackable +Foldable +Already used in other industries ~Top one needs lid?	V

Figure 77a: Ideas second direction: redesign reusable box

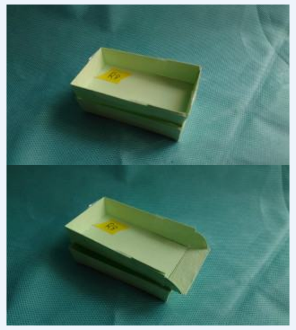
Nr.	Picture	Based on	+ ~ -	v ~ x
R5			+Stackable +Nestable ~Top one needs lid? -Structurally too weak to stack up high	~
R6			+Stackable +Nestable +Already used in bread industry ~Top one needs lid? ~Open front?	~
R7			+Stackable +Nestable ~Top one needs lid? -Big action, it needs 180° rotation -Fall in when not placed correctly	V
R8			+Access from top and side ~Top one needs lid? -Not nestable	X
R9			+Stackable +Foldable -Uses a lot of material - Multiple actions to fold and unfold	X

Figure 77b: Ideas second direction: redesign reusable box

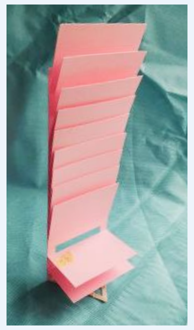
Nr.	Picture	Based on	+ ~ -	v ~ x
S1			+Closable +Well protected -Uses a lot of material -Heavy and bulky -Laying bags on shelves hard from the side	X
S2			+Shelves/baskets closed off by upper +No need for stacking +Compact when empty, folded up and slide into each other ~Structurally? -Lifting from high and low	~
S3			+Could be more efficient then current cart +Compact when empty, folded ~Structurally? -Not enclosed -Lifting from high and low -Laying bags on shelves hard from the side	X
S4			+More efficient then current cart +No need for stacking +Drawers can be taken out -Lifting from high and low	V

Figure 78a: Ideas third direction: redesign reusable system

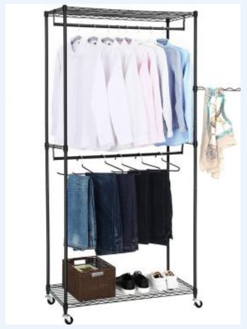
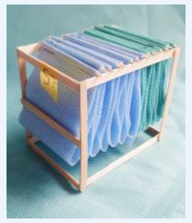
Nr.	Picture	Based on	+ ~ -	v ~ x
S5			+Compact when empty +Works with multiple types of boxes +Customised amount per order ~Lid for on top? -Could be too little surface, chance of tipping over?	V
S6			+No boxes needed +No need for stacking +Slimmer cart needed -Less efficient, bags thicker on bottom when vertically -Not closed off	~
S7			+No boxes needed +No need for stacking +No lifting high -Less efficient, lower cart -Less efficient, bags thicker on bottom when vertically	~
S8			+No lifting high +More bags per box -Not liftable, to heavy when full -Not nestable - Less efficient, lower stack	X

Figure 78b: Ideas third direction: redesign reusable system

4.4.3 Cost Analysis

A quick cost analysis was conducted for all four scenarios. This cost analysis assumed a calculation with 15 boxes because, in the current system, 15 boxes are delivered per cart. For the calculation, the following assumptions were made.

Purchase of equipment

- Paper boxes are €1.12 (Profipack, n.d.) for one-time use, times 15.
- Reusable boxes are €20 (Transoplastshop, n.d.), which last 10 years and are refilled 10 times a year (Albrecht et al., 2013). Also times 15.
- Pallets cost €11.95 each (EPAL Europallet 80x120cm, n.d.) and are used 10 times, and pallets are stacked with 52 boxes.
- A cart costs €320 (Kruizinga.nl, n.d.) and, like the reusable boxes, is refilled 10 times a year over 10 years (Albrecht et al., 2013).

Transport

- The pallets are transported from the factory in Duidsland, Saint Wendel, to Hospital Logistics in Barendrecht in a truck. Appendix G shows the cost for a full truck (Quote&GO - Book Your Transport Online, n.d.). These costs are converted per 15 boxes.
- From Hospital Logistics in Barendrecht to Erasmus MC, a van is used to transport the carts. Appendix G shows the cost for a full van (Quote&GO - Book Your Transport Online, n.d.). These costs have also been converted per 15 boxes.

Use of the box

- The cost of using the box is the hourly wage of the user times the time of the transfering, opening and disposing.
- The wage cost of an ICU nurse is €25.30 (Ic Verpleegkundige Salaris in Nederland - Gemiddeld Salaris, n.d.) and that of a logistics worker is €13.50 (Logistiek Medewerker Salaris in Nederland - Gemiddeld Salaris, n.d.).
- The times of operations are recorded. They are documented in the different use scenarios in this report.

Waste disposal

- Disposal of waste is estimated at one full paper container per week in the case of 15 boxes per day and is €55, shown in Appendix G (PreZero NL, n.d.).

The calculated numbers per scenario can be seen in Figures 79 to 82. The full calculation can be seen in Appendix G.

The cost of paper boxes is higher than that of reusable ones because reusable ones pay back in the long run.

Transport costs are high. Because the reusable boxes and the system have to be returned in situations 3 and 4, it is higher than in situations 1 and 2.

The cost of use is mainly higher when the boxes are opened and disposed of by the ICU nurses, as in situation 1. The cost of use goes down with the reusable boxes which take less time than the paper boxes. Because in situations 1, 2 and 3 the boxes have to be transferred, contrary to situation 4, situation 4 saves time and money.

As no waste is produced in situations 3 and 4, these save on the high cost of waste disposal.

From this cost analysis it is concluded that scenario 3 and 4 are the cheapest options.

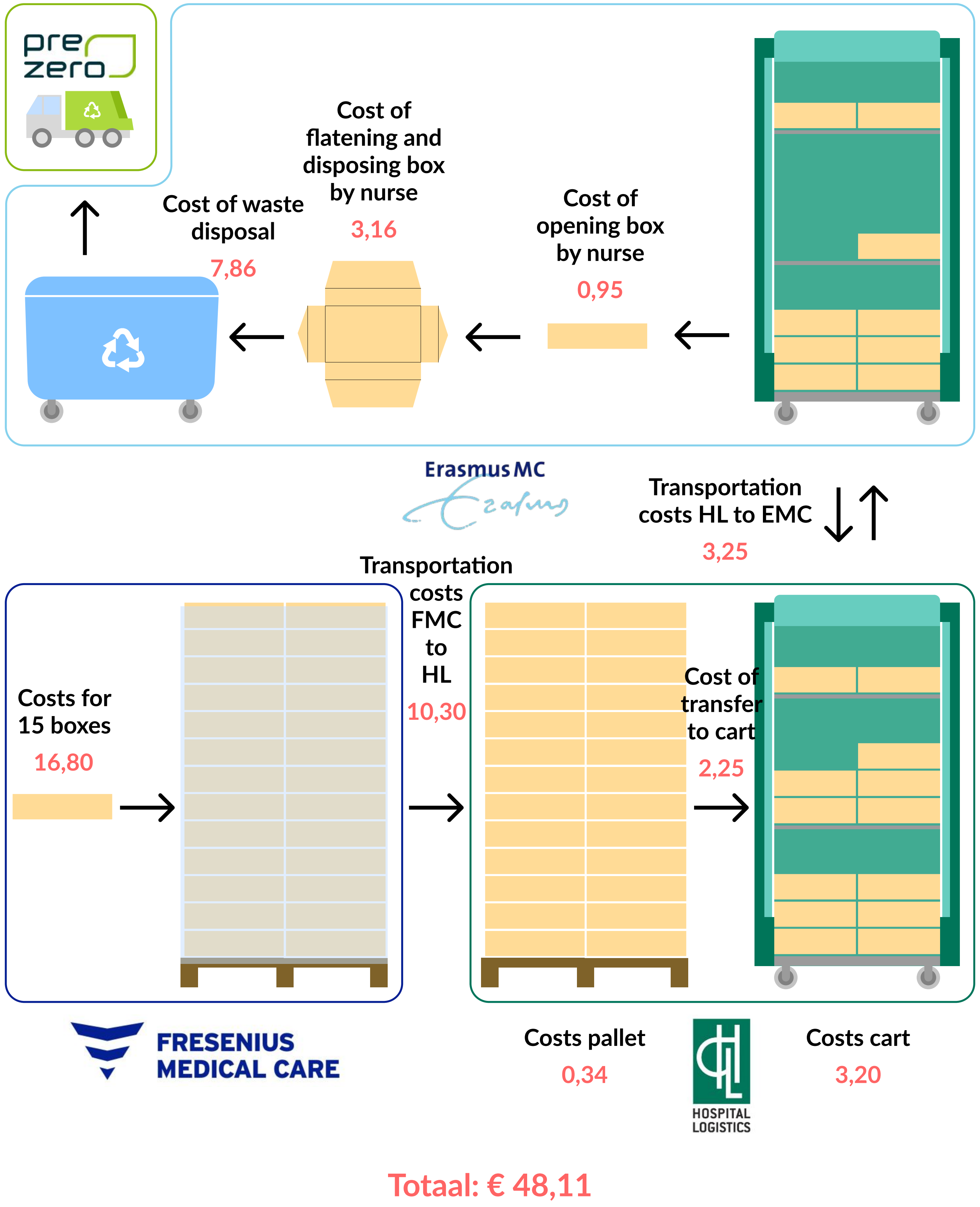
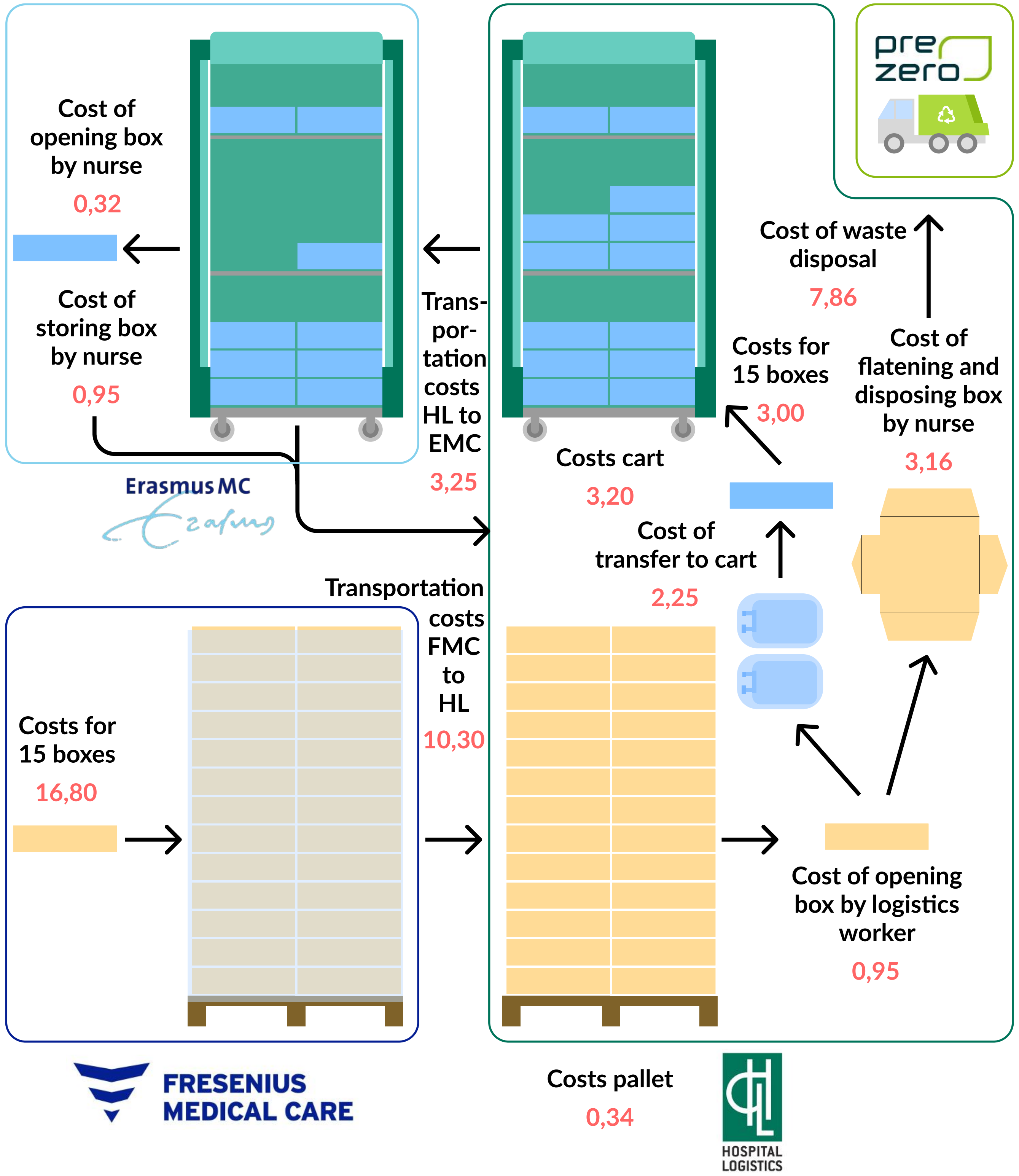
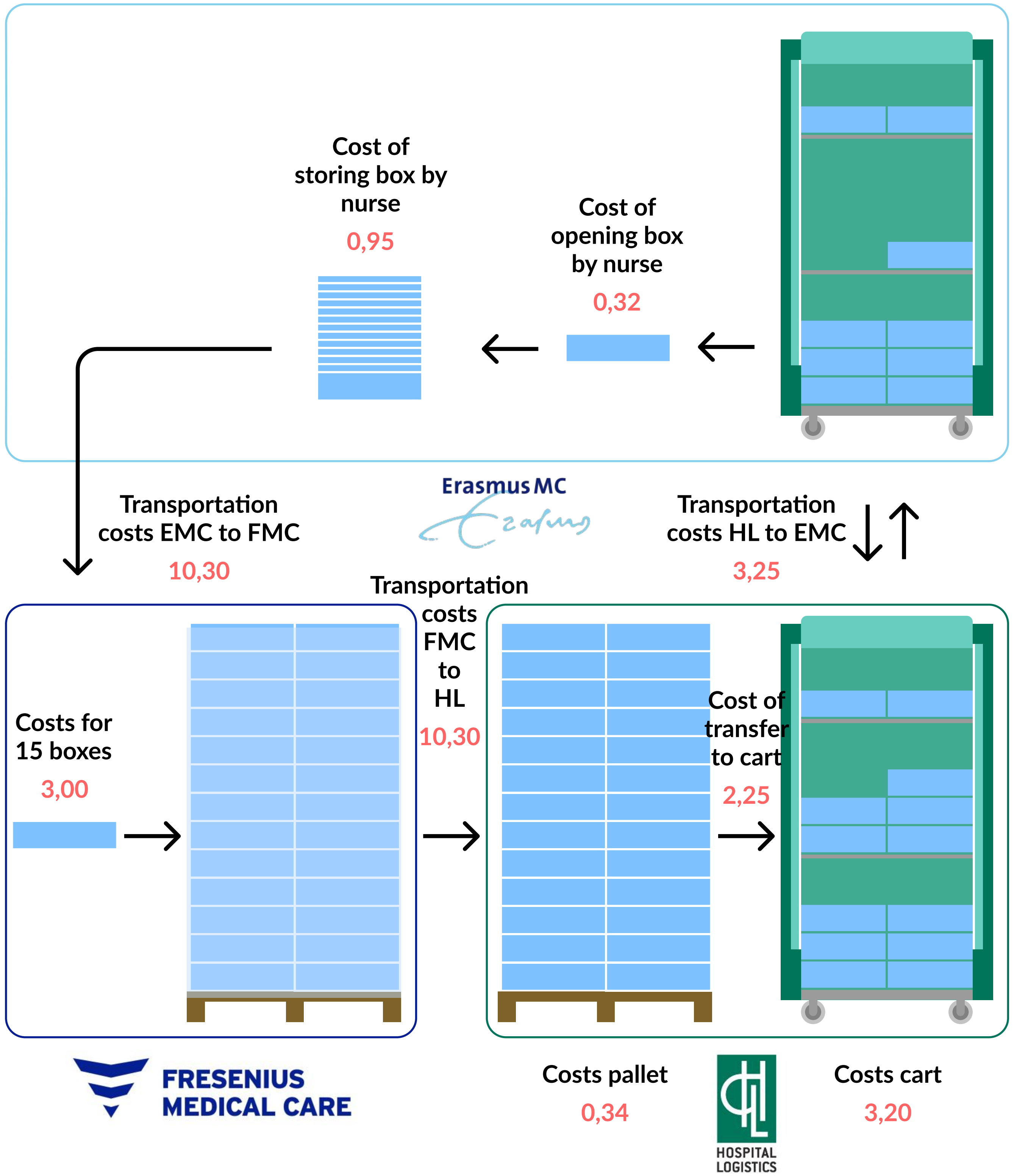


Figure 79: Cost analysis of scenario 1: paper box



Totaal: € 50,46

Figure 80: Cost analysis of scenario 2: hybrid paper box and reusable box



Totaal: € 33,91

Figure 81: Cost analysis of scenario 3: reusable box in current system

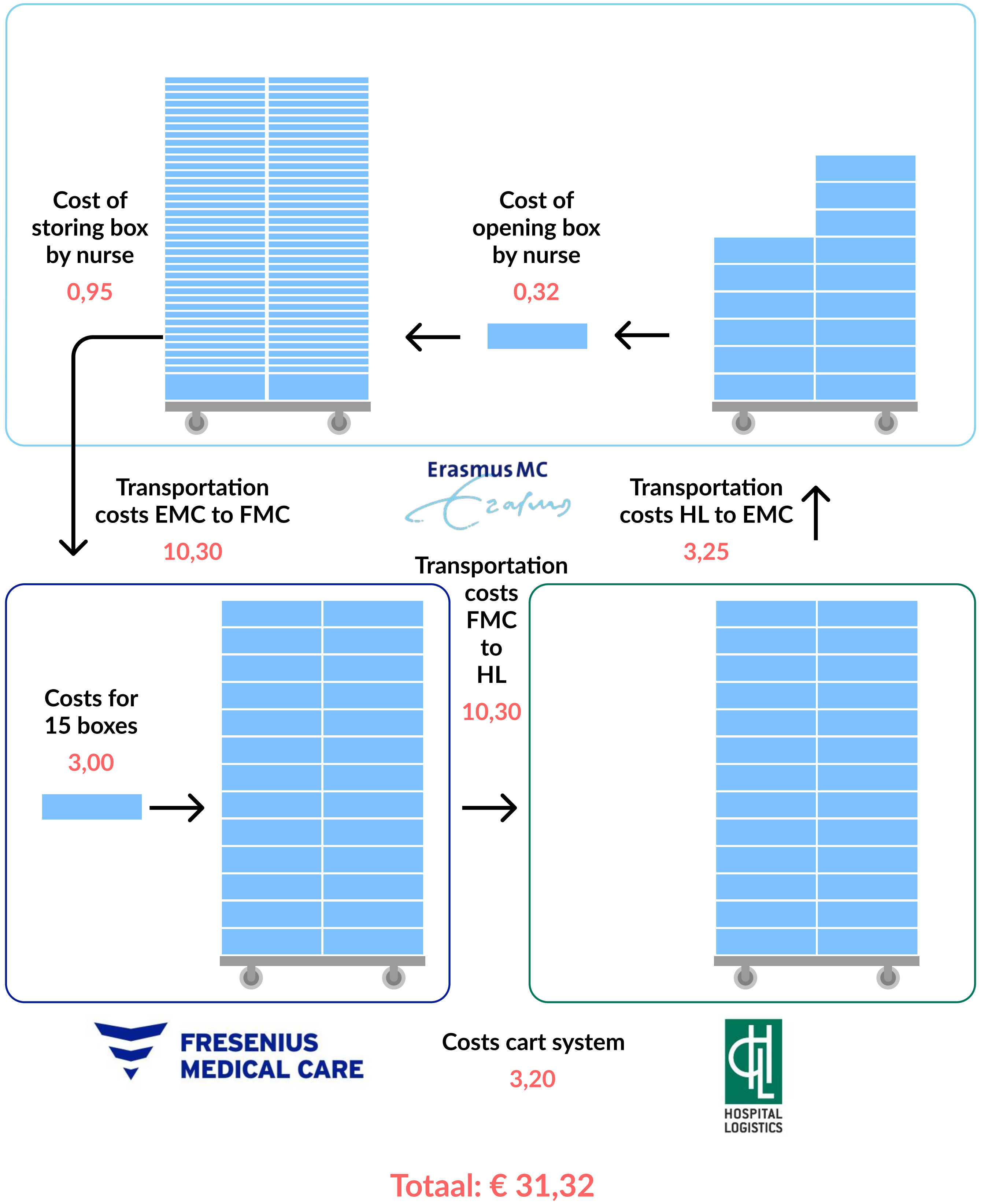


Figure 82: Cost analysis of scenario 4: reusable transport system

4.4.4 Choice of Ideas

As concluded from the cost analysis, scenario 3 and 4 are cheaper then scenario 1 and 2. Together with eliminating ideas from the PMI method, two concepts have been chosen from each of the scenarios 3 and 4. The four concepts that will be focussed on can be seen in Figure 83.

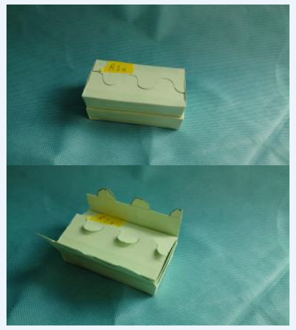
Nr.	Picture	Based on	+ ~ -	v ~ x
R1a			+Sealable +Stackable +Nestable +Already used in hospital	V
R4			+Stackable +Foldable +Already used in other industries ~Top one needs lid?	V
S4			+More efficient then current cart +No need for stacking +Drawers can be taken out -Lifting from high and low	V
S5			+Compact when empty +Works with multiple types of boxes +Customised amount per order ~Lid for on top? -Could be too little surface, chance of tipping over?	V

Figure 83: Concept choices of scenario 3 and 4

4.5 Design concepts

4.5.1 Design Requirements

From the collected information in Chapters 2.4, 4.2 and 4.3, design requirements have been developed iteratively.

In order to choose the final concept, these requirements have been worked out and are shown in Figure 84. The requirements are further explained in the following paragraphs together with the scoring of the four concepts.

Main requirement	Sub requirement	Explanation requirement
Protecting bags	Closed off	No bag should be able to get out or get damaged during transportation
	Strength	Needs to hold 12 other boxes with 24 bags, around 168 kg
	Sealable	Must have sealable element, visible when opened, not reclosable (if protection bag gives the sealing element it is not necessary for the box)
Liftable	Handles	Has two handles for lifting
	Weight	Must nog be heavier than 14 kg when filled
Stackable	Structure	Gives bags structure, for bags are not stackable
	Format	Must have fixed dimensions: Euronorm format
	Transferable	Must transfer to cart easily, one person should be able to stack them, from floor to head height
	Supporting	The top should allow supporting the bottom of the next box (ledges, lid)
Time-saving	Time	Less time required for opening and disposing of the box compared to current paper box: 39 sec
	Actions	Fewer actions needed for opening and disposing of the box compared to current paper box: 9 actions
Space-saving	Storage pre-emptying	Does take less space when storing compared to how it is transported
	Storage post-emptying	Does take 50% less space when storing (stacked/ folded) compared to how it is transported

Figure 84: Design requirements for the redesign

4.5.2 The Four Concepts

In Chapter 4.4.4, four concepts were chosen to proceed with. The four concepts are shown in Figure 85. For easier communication, the concepts R1a, R4, S4 and S5 have been given a name.

Box with lid (R1a): The first concept is a box with a lid that can be stacked and when empty can be nested within each other.

Foldable crate (R4): The second concept is a crate that can be stacked and folded when empty.

Drawer cart (S4): The third concept is a drawer cart system where the boxes do not need to be stacked on top of each other. The trays can be removed from the cart as a drawer.

Dolly cart (S5): The fourth concept is a dolly cart system. In this system, boxes or crates are stacked on a dolly. The choice of the box or crate comes from which of the first two concepts proves best.

The first two concepts, the box with lid and the crate, are designed in scenario three (Figure 74) where boxes are used in the current system, using pallets and the current cart.

The last two concepts, the drawer cart and the dolly cart, are designed in scenario four (Figure 75) where a new system needs to be set up without pallets and a new cart system.

4.5.3 Assessing the Concepts

This section of the report assesses the four concepts for each requirement. Physical existing products of the concepts already used in other parts of the hospital have been used for testing the concepts. These can be seen in Figure 85. The dolly cart concept has been simulated with the box with lid concept and foldable crate concept on top of a different dolly system used for bread crates.

For the sake of clarity, the requirements are explained first. This is done per main requirement. It explains how each sub-requirement was established. Then the four concepts are assessed against them.

In assessing the concepts, it occurs with some requirements that all concepts score equally well. This is due to the fact that these requirements have already been filtered on earlier in the PMI method in Chapter 4.4.2.

Figure 85: The four design concepts and their physical existing products

Main requirement	Sub requirement	Explanation requirement
Protecting bags	Closed off	No bag should be able to get out or get damaged during transportation
	Strength	Needs to hold 12 other boxes with 24 bags, around 168 kg
	Sealable	Must have sealable element, visible when opened, not reclosable (if protection bag gives the sealing element it is not necessary for the box)

Figure 86: Design requirements: Protecting bags

4.5.3.1 Protecting Bags

As can be read in Chapter 4.1, one of the functions of a box is to protect its contents. Therefore, the first requirement is to protect the dialysis bags, divided into the sub-requirements, read in Figure 86.

Closed off: This requirement comes from the fact that it should not be possible to puncture the bag or affect the medication from the outside. Also, the bag should be protected against being taken out or changed.

The reasoning for the grading can be read in Figure 87. The pictures of the physical products can be seen in Figure 88.

Concept	Reasoning	Score
Box with lid	Can be fully closed off with its own lid.	++
Foldable crate	Can be closed off by placing the next crate on top. The top crate will need a lid to be closed off.	-
Drawer cart	The trays are closed of by the trays above but there is a slight gab. The top tray will need a lid to be closed off.	-
Dolly cart	Box with lid: can be closed off with its own lid. Foldable crate: Can be closed off by placing the next crate on top. The top crate will need a lid to be closed off.	++ -

Figure 87: Reasoning of requirements: Protecting bags

Box with lid | Foldable crate | Drawer cart | Dolly cart

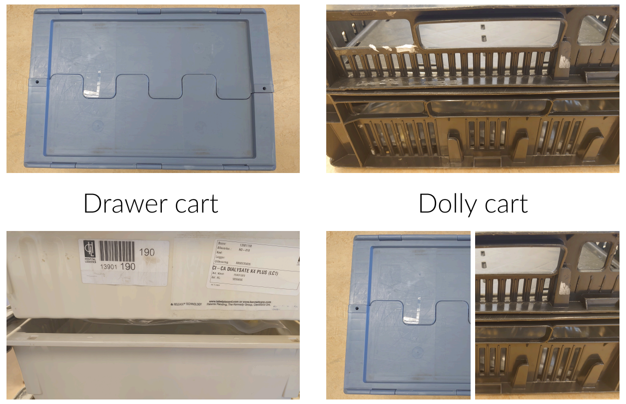


Figure 88: All four physical products closed off

Strength: As the boxes are stackable, they should be able to hold each other. Assuming the current situation on the pallet, the bottom box of the stack should be able to hold 12 boxes on top. Based on the maximum box weight (explained in the next paragraph 4.5.3.2) of 14 kg, the bottom box should be able to hold 168 kg.

The reasoning for the grading can be read in Figure 89. The data sheets of specifications have been used.

Concept	Reasoning	Score
Box with lid	Stacking capacity: 200 kg	++
Foldable crate	Stacking capacity: 400 kg (Euro Pool System, 2023).	++
Drawer cart	Not applicable because no stacking is needed.	N/A
Dolly cart	The box with lid and the foldable crate have the same grading.	++

Figure 89: Reasoning of requirements: Strength

Sealable: As explained in Chapter 2.4.4, it is important that the medication cannot be tampered with. Theft and forgery should also be prevented. This is done by sealing the packaging. For the concepts, the box itself should be sealable or the seal should be transferred to the protection bags.

In Figure 90 one of the holes for the seals for the box with lid concept can be seen as this is the only concept with a seal on the box. The reasoning for the grading can be read in Figure 91.

Figure 90: Hole for the seal for the box with lid concept

Concept	Reasoning	Score
Box with lid	Is sealable with a plastic seal trough a hole on two sides.	++
Foldable crate	Seal should be transferred to the protection bag.	-
Drawer cart	Seal should be transferred to the protection bag.	-
Dolly cart	Box with lid: is sealable with a plastic seal trough a hole on two sides. Foldable crate: seal should be transferred to the protection bag.	++ -

Figure 91: Reasoning of requirements: Sealable

Main requirement	Sub requirement	Explanation requirement
Liftable	Handles	Has two handles for lifting
	Weight	Must nog be heavier than 14 kg when filled

Figure 92: Design requirements: Liftable

4.5.3.2 Liftable

The box needs to be liftable by personnel, like the logistics workers and nurses. This requirement is divided into two sub requirements, see Figure 92.

Handles: The box must be able to be lifted. To ensure this, handles are important. These are also important for handling and being able to rotate the box properly for stacking. As the boxes are heavy, it is also useful that the handles are comfortably usable for all hand sizes and do not hurt your hands with sharp edges.

The reasoning for the grading can be read in Figure 93. The pictures of the handles of the physical products can be seen in Figure 94.

Concept	Reasoning	Score
Box with lid	Has handles but they are not as comfortable for all hand sizes because of the small cavity.	+
Foldable crate	Has handles and is comfortably usable for all hand sizes	++
Drawer cart	Has no handles on de trays, only on the cart itself	-
Dolly cart	Box with lid: Has handles but not as comfortable. Foldable crate: Has handles and is comfortably usable.	+ ++

Figure 93: Reasoning of requirements: Handles

Box with lid | Foldable crate | Drawer cart | Dolly cart

Figure 94: The handles of all four concepts

Weight: Again, the box must be able to be lifted. To ensure this, the boxes should not be too heavy. In Europe, there are standards and guidelines for lifting heavy objects (Ministerie van Sociale Zaken en Werkgelegenheid, 2024). The lifting index calculation tool (Federatie Nederlandse Vakbeweging, n.d.) was filled in for the box of dialysis bags with the heaviest conditions of lifting from the ground to overhead. This showed a maximum lifting weight of 14 kg. This means that the box minus the weight of the two full bags should not be more than 3.5 kg.

The reasoning for the grading can be read in Figure 95. The data sheets of specifications have been used. All four concepts score the same.

Concept	Reasoning	Score
Box with lid	Weight is 2,35 kg which is less than 3,5.	++
Foldable crate	Weight is 1,54 kg which is less than 3,5.	++
Drawer cart	Weight is 1,57 kg which is less than 3,5.	++
Dolly cart	Weight is 2,35 or 1,54 kg which are both less than 3,5.	++

Figure 95: Reasoning of requirements: Weight

Main requirement	Sub requirement	Explanation requirement
Stackable	Structure	Gives bags structure, for bags are not stackable
	Format	Must have fixed dimensions: Euronorm format
	Transferable	Must transfer to cart easily, one person should be able to stack them, from floor to head height
	Supporting	The top should allow supporting the bottom of the next box (ledges, lid)

Figure 96: Design requirements: Stackable

4.5.3.3 Stackable

The boxes must be stackable on top of each other for transport and easy storage. It is also important for the transfer to be easily stackable. Sub requirements have been created for this, see Figure 96.

Structure: To make the bags stackable, the packaging around them must provide structure since the bags themselves have no structure and cannot stack themselves.

Because in Chapter 4.4.2 this requirement was already taken into account, concepts without structure were already eliminated. This means that the four chosen concepts were already concluded that they give structure. Therefore all four concepts score the same.

Format: To ensure that the boxes can be transported in the global transport system, the boxes must have fixed dimensions. These dimensions must be in Euronorm format so that they fit on the pallets and carts used in the current system. For a new transport system, it must also be in this format so that it can be transported with other Euronorm-packaged cargo. As the current paper boxes are designed in a quarter of a Europallet (600 by 400 mm), the bags are design accordingly. The new concepts should fit the bags without the need of redesigning them.

The physical boxes and carts have been measured but also the data sheets of specifications have been used. The boxes, crates and trays are all based on the Euronorm of 600 by 400 mm, a quarter Europallet. They all fit within the pallets, carts and dollies envisioned in the situations of this report. Also the current bags fit in them so no redesign is needed.

As they all have the same dimensions, all four concepts score the same.

Transferable: As mentioned earlier, stackability is also important when transferring. You should be able to do this easily. There are several factors that influence this. If, when stacking, the box has to be placed with a specific rotation and movement, this is more difficult than if the box can be placed in several ways and from several sides. Also if, for example, the box has to be stacked very precisely, the transfer is more difficult.

The reasoning for the grading can be read in Figure 97. The pictures of the transferring elements of the physical products can be seen in Figure 98.

Concept	Reasoning	Score
Box with lid	Easy stacking because of lid with guided indent without the need for specific placement. As it can only be put in from the front of the cart, it requires more effort.	+
Foldable crate	Hard stacking because there is no lid and it needs to fit perfectly on the ledge. As it can only be put in from the front of the cart, it requires more effort.	-
Drawer cart	No stacking needed but tray slides on the rails. Inserting from the front in rails requires more effort.	+
Dolly cart	Stacking is similar for both the box and crate but the stacking can be done all around the dolly, making it easier then the cart.	+ ++

Figure 97: Reasoning of requirements: Transferable

Figure 98: Transfering elements of all four concepts

Supporting: When stacking, the bottom box should support the top box. This can be done by stacking on the lid or the edges.

The reasoning for the grading can be read in Figure 99. The pictures of the supporting of the physical products can be seen in Figure 100.

Concept	Reasoning	Score
Box with lid	The top box is supported by the lid of the bottom box. Because of the indent they do not slide off each other.	++
Foldable crate	The top crate is supported by the edges of the bottom crate. Because the bottom of the crates has a ledge that fits in the top of the edge, the crates stay in place and they do not slide off each other.	++
Drawer cart	The trays are not supporting each other because they do not stack. The trays get support from the to edge that slides into the rail.	+
Dolly cart	Both the box and crate are supported, either by the lid or ledge. They both do not slide off each other.	++

Figure 99: Reasoning of requirements: Supporting

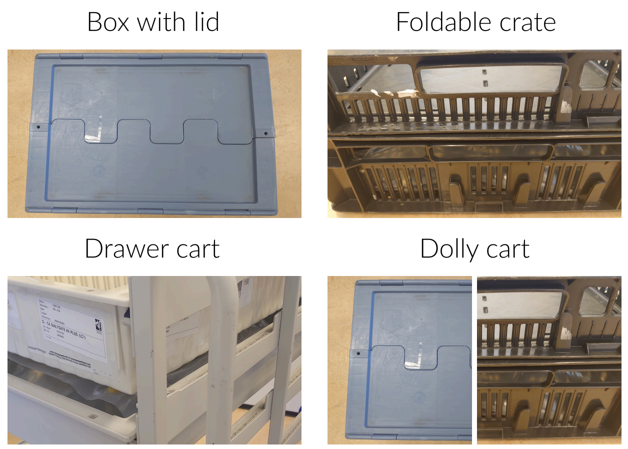


Figure 100: Supporting elements of all four concepts

Main requirement	Sub requirement	Explanation requirement
Time-saving	Time	Less time required for opening and disposing of the box compared to current paper box: 39 sec
	Actions	Fewer actions needed for opening and disposing of the box compared to current paper box: 9 actions

Figure 101: Design requirements: Time-saving

4.5.3.4 Time-saving

One of the things nurses barely have is time. And since the use of the current paper box is time-consuming and takes many actions, the redesign should save on time and the number of actions. In Figure 101, the requirements of the reduction in time and actions can be seen.

To know whether the concepts are an improvement on the current paper box, the use of the concepts was recorded and timed. These have been compared with the recording and timing of the current paper box. The action of taking out the bags is not considered as this is the same for all concepts. Both the time and actions can be seen in the user scenarios in Figure 107 on pages 82 and 83.

Time: Thus, the nurses barely have time. That time is also costly for the hospital because of the nurses' salaries. Besides, their time is also precious because the nurses can better spend that time on their patients who need very intensive care.

The reasoning for the grading can be read in Figure 102. All concepts score the same. They all are an significant improvement in time over the current paper box.

Concept	Reasoning	Score
Box with lid	Use time is 12 seconds.	++
Foldable crate	Use time is 16 seconds.	++
Drawer cart	Use time is 6 seconds.	++
Dolly cart	Use time is 12 or 16 seconds.	++

Figure 102: Reasoning of requirements: Time

Actions: To reduce time, it is also helpful to reduce the number of actions. This also to make the process easier and gives nurses more peace of mind to put their energy more into patient care.

The reasoning for the grading can be read in Figure 103. All concepts score the same. They all are an significant reduction in actions compared to the current paper box.

Concept	Reasoning	Score
Box with lid	Using takes 3 actions.	++
Foldable crate	Using takes 4 actions.	++
Drawer cart	Using takes 2 actions.	++
Dolly cart	Using takes 3 or 4 actions.	++

Figure 103: Reasoning of requirements: Actions

Main requirement	Sub requirement	Explanation requirement
Space-saving	Storage pre-emptying	Does take less space when storing compared to how it is transported
	Storage post-emptying	Does take 50% less space when storing (stacked/ folded) compared to how it is transported

Figure 104: Design requirements: Space-saving

4.5.3.5 Space-saving

To make transport and storage more efficient, it is important to make boxes and carts save space. Hospitals have limited space to store things and, as at Erasmus MC, some of the carts are even stored in the basement because there is little space in the ICU itself. Figure 104 shows the sub requirements.

Storage pre-emptying: It is important that, prior to emptying the boxes, the redesign does not take up more space compared to how it is transported. The first two concepts use the pallets and carts used in the current system. The last two concepts will have a new cart system so this new system should not take up more space than the current cart.

The reasoning for the grading can be read in Figure 105. All concepts take up the same space when stored compared to the transporting.

Concept	Reasoning	Score
Box with lid	Does take the same space as when transported as the pallets and carts are the limiting factor.	+
Foldable crate	Does take the same space as when transported as the pallets and carts are the limiting factor.	+
Drawer cart	Does take the same space as when transported as the carts are the limiting factors	+
Dolly cart	Does take the same space as when transported as the dollies are the limiting factors	+

Figure 105: Reasoning of requirements: Storage pre-emptying

Storage post-emptying: Besides saving space in pre-emptying, it is also important to save space in storing the empty systems post-emptying. In the current system with paper boxes, storage falls under: the box being thrown into the paper container after being flattened, after which it is collected by PreZero, and the empty carts being stored in the basement to be collected by Hospital Logistics.

As reusable boxes are used in the newly envisioned systems, the storage of paper waste is eliminated. However, storage is still needed to store the reusable boxes before they are collected by Hospital Logistics and then returned to Fresenius Medical Care.

The reasoning for the grading can be read in Figure 106. The comparison of the pre- and post-emptying of the systems, compared to the amount of bags fitting, can be seen in Figure 108 on page 84.

Concept	Reasoning	Score
Box with lid	Does not reduce space, the boxes can be nested but the cart is the limiting factor.	--
Foldable crate	Does not reduce space, the crates can be folded but the cart is the limiting factor.	--
Drawer cart	Does not reduce space, the trays stay in the cart which is the limiting factor.	--
Dolly cart	Does reduce space for both the boxes and crates as they can be nested or folded and stacked on the also stackable dollies.	++

Figure 106: Reasoning of requirements: Storage post-emptying

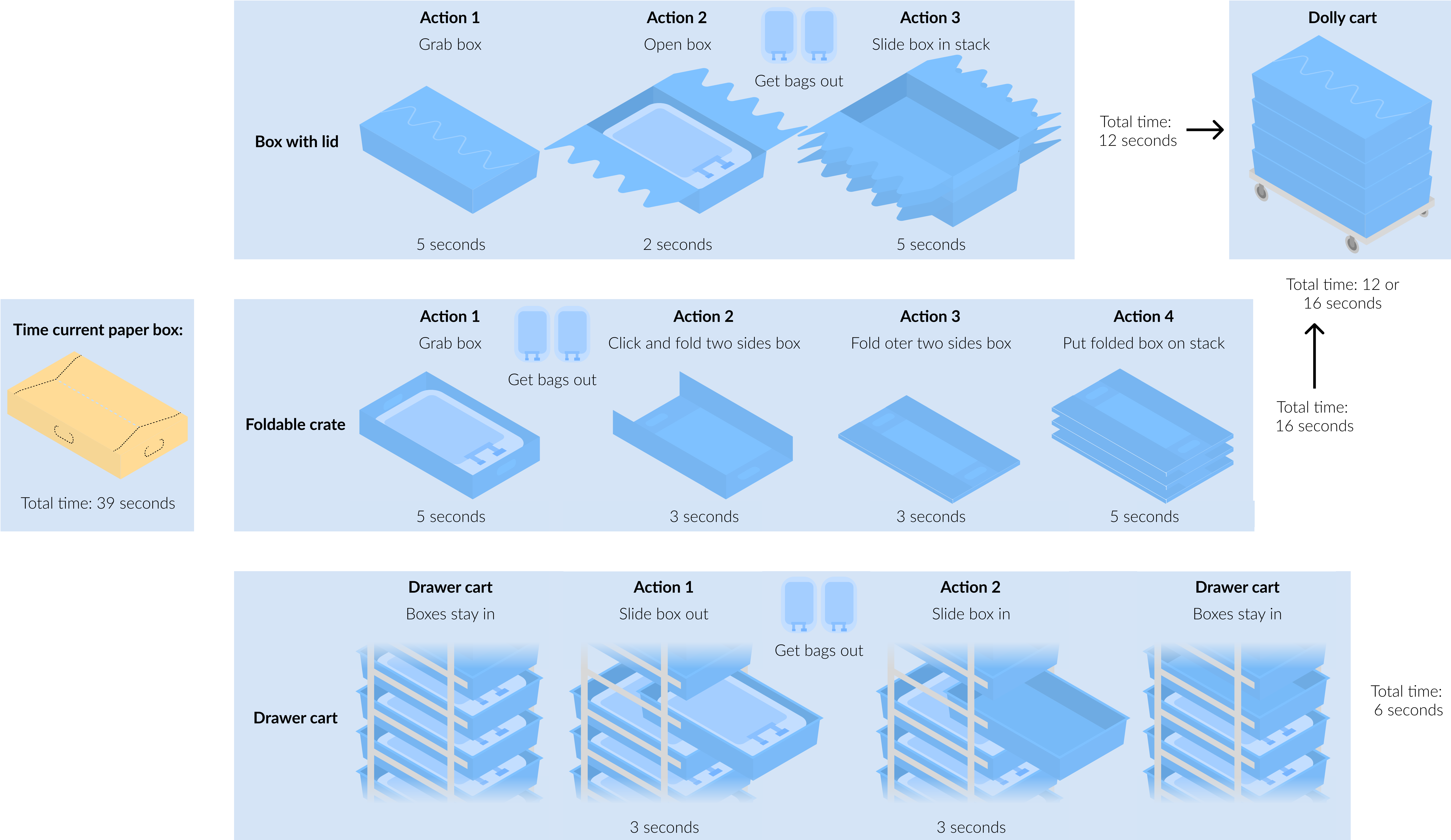


Figure 107: User scenarios with time and actions *of all four concepts*

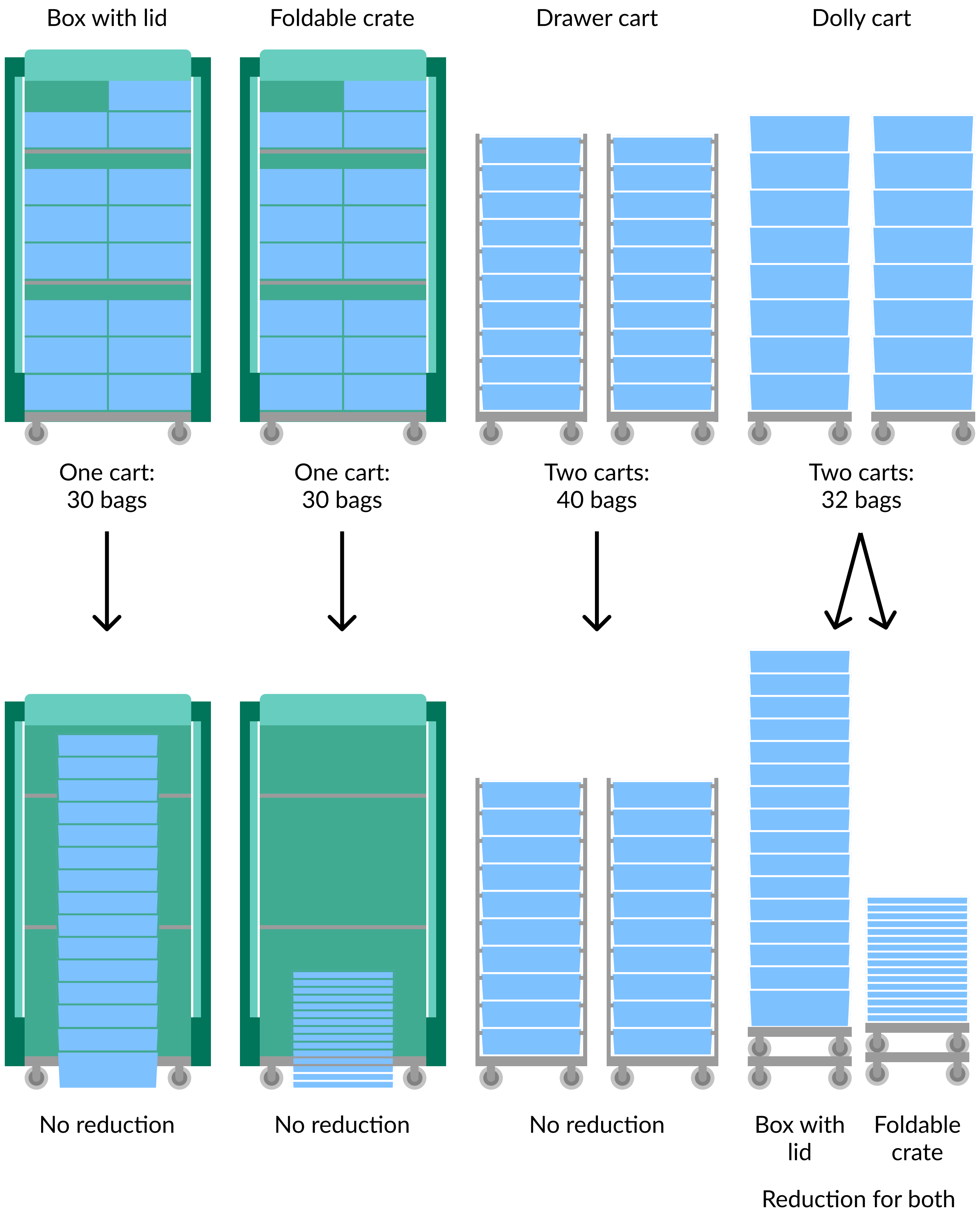


Figure 108: Comparison of pre- and post-emptying of all four concepts compared to the amount of bags fitting

4.5.4 Harris Profile

As described earlier in Chapter 4.5.1, the requirements were used to choose which concept would be selected. The choice was made using a Harris profile (Van Boeijen et al., 2014).

Some of the requirements are the same for all four concepts because these requirements were used to eliminate the previous concept ideas, see Chapter 4.4. The reasoning for the grading in Chapter 4.5.3 indicates whether the concepts have the same rating.

Only the requirements that differ were included in the final selection using the Harris profile. The requirements that differ and the grading can be seen in the Harris profiles in Figure 109.

For the dolly cart concept, the grading of the box with lid was used, because it scored better than the foldable crate.

After weighing the requirements, the Harris profile shows that the dolly cart concept is the best concept.

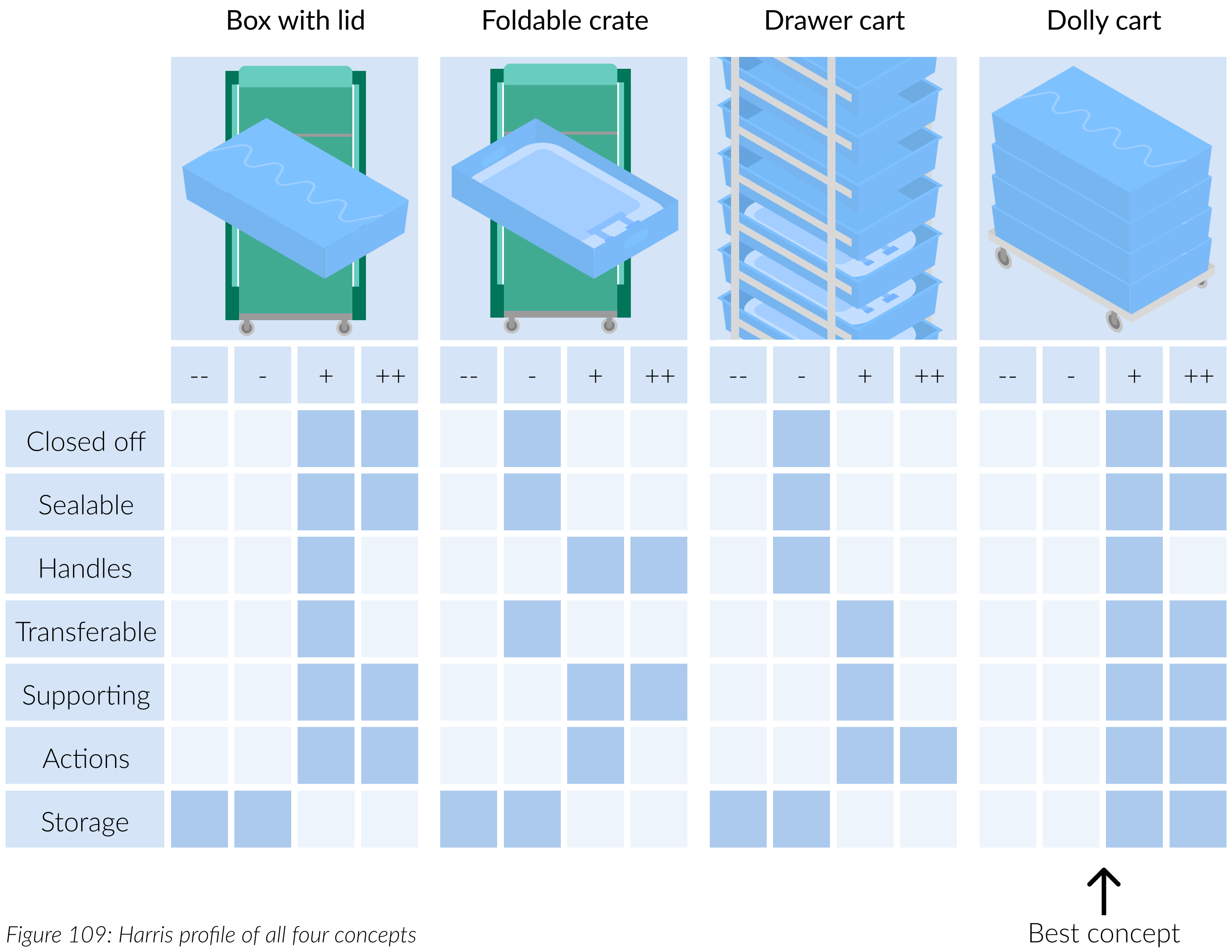


Figure 109: Harris profile of all four concepts

4.6 Final Concept Evaluation

4.6.1 System Explanation

In Figure 110 the pictures of the physical box (Multifunctionele Bakken, n.d.) can be seen. Note that this box (290 mm) is a higher version of the box that was chosen (190 mm) to be used in the system. The bottom dimension is for both versions the same (610 by 400 mm). While going over the requirements the most important features can be read in Figure 111.

In Figure 112 the new envisioned system surrounding the final concept can be seen.

First starting at Fresenius Medical Care, the production of the medication is the same. In this system, The production line needs to be altered to feed the bags in the reusable boxes instead of being packaged in paper boxes. The boxes then need to be stacked on dollies and transported to their destinations.

Before going to the EMC, this destination is Hospital Logistics first, similar to the current situation. The dollies are only stored here as transferring to carts is not needed anymore, saving time and money for HL. The dollies are transported to the EMC by the smaller and cleaner transport, as in the current situation.

Because of the limited space at the ICU, the dollies are stored in the basement and brought up to the storage room while being exchanged with the empty dollies. When the dollies are in the unit, the nurses will grab the bags out of the boxes when needed. The new use scenario of the box with lid can be seen in Figure 107 (pages 82 and 83), Chapter 4.5.3. The nurses do not need to dispose of the boxes in the paper waste bin anymore. Now the boxes are nested in each other on a dolly and the remaining dollies are stacked onto each other. Both types are taken down by logistics personnel and stored in the basement.

Different to the current system, the boxes are thus not collected by PreZero but need to be returned to Fresenius Medical Care, via Hospital Logistics. When they return to FMC, the boxes need to be monitored for defects or contamination and disposed of or cleaned accordingly. If the boxes are good to go they can be used again for the next cycle.

To be able to track and monitor the boxes, each box has clear labels. This system makes it possible to keep track of how many times the boxes have been used. This also gives the opportunity to know if a box is gone missing when it has not gotten back to FMC in due time. The label also holds the function of keeping information. When scanned, the user can see what for example the contents or destination is.

Figure 110: Pictures of final concept: Dolly cart with box with lid

Main requirement	Sub requirement	Explanation features for final concept
Protecting bags	Closed off	Can be fully closed off with its own lid.
	Strength	Stacking capacity of 200 kg which is more than 168 kg.
	Sealable	Is sealable with a plastic seal trough a hole on two sides.
Liftable	Handles	Has handles but they are not as comfortable for all hand sizes because of the small cavity.
	Weight	Weight is 2,35 kg which is less than 3,5.
Stackable	Structure	Gives fixed structure, does not slide of because of indent in lid.
	Format	Quarter of Europallet format (610 by 400 mm). Two bags fit in box.
	Transferable	Easy stacking because of lid with guided indent without the need for specific placement. Stacking can be done all around the cart, making it easier then the cart.
	Supporting	The top box is supported by the lid of the bottom box. Because of the indent they do not slide off each other.
Time-saving	Time	Use time is 12 seconds which is less then 39 seconds.
	Actions	Using takes 3 actions which is less then 9 actions.
Space-saving	Storage pre-emptying	Does take the same space as when transported as the dollies are the limiting factors.
	Storage post-emptying	Does reduce space as the boxes can be nested on the stackable dollies, taking up to 75% less space.

Figure 111: Features of final concept described per requirement

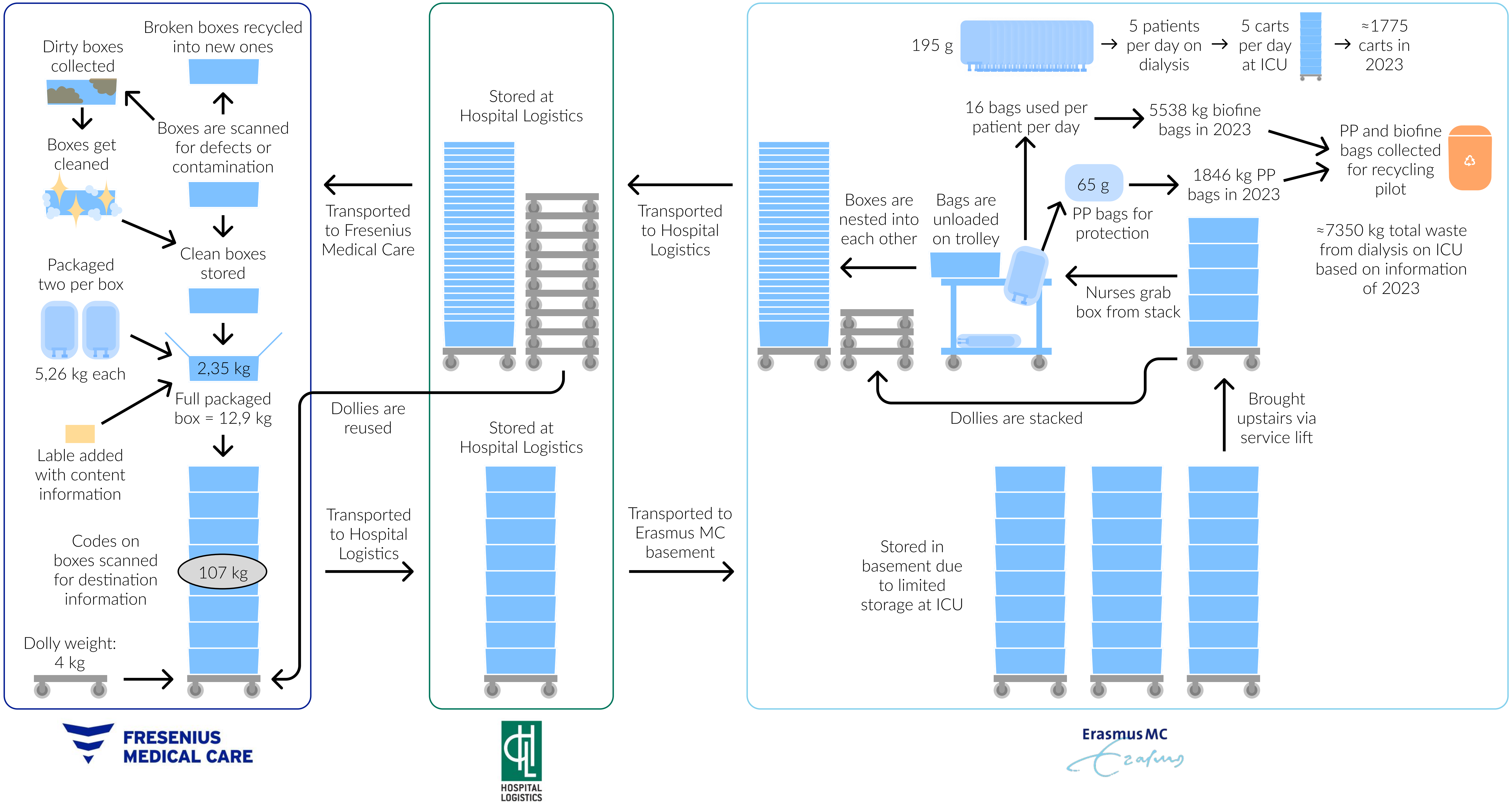


Figure 112: The new system of the final concept

4.6.2 Feasibility

The feasibility of the proposed redesign is clear from its compatibility with existing practices and its potential to provide significant long-term benefits. Similar reusable systems are already used for smaller medicine packaging and in pharmacies, demonstrating that such an approach is feasible within the healthcare industry. Moreover, reusable systems are common in other industries, meaning that this redesign does not mean reinventing the wheel, but rather adapting proven solutions to a new context. As the cost analysis shows, this system is also more cost-effective in the long run than single-use packaging.

However, the main challenge lies in the complexity and reduced flexibility of healthcare logistics, as well as the strict regulations and guidelines surrounding medicine packaging. These barriers may hinder the adoption of reusable medication systems, but this redesign aims to serve as an eye-opener and demonstrate that change is possible. Ensuring that patient safety is not compromised is, of course, a fundamental requirement when implementing any new system.

4.6.3 Desirability

The desirability of this redesign lies in its ability to meet the values and needs of various stakeholders while aligning with Erasmus MC's sustainability goals to reduce waste and impact on the environment.

For the Hospital Logistics staff, the redesign simplifies processes by eliminating the need to transfer boxes of dialysis bags from pallets to carts, reducing workload.

Nurses also benefit, as the new system saves precious time that can be better spent providing critical care to patients, improving efficiency and the overall quality of patient care. In addition, the hospital as a whole produces less waste and requires less storage space, contributing to a more streamlined and sustainable operation.

For Fresenius Medical Care, the redesign supports global sustainability goals while providing a competitive advantage as a more environmentally friendly provider of medical care.

Finally, the environment itself is an important stakeholder, as reducing waste and environmental impact contributes to a healthier planet. And a healthier planet, in turn, means fewer people will be dependent on the already overwhelmed healthcare system.

4.6.4 Viability

The viability of this redesign is supported by the fact that it is based on existing practices from other industries, such as the fruit and vegetable sector, which also operate under regulations but still successfully use reusable systems. In the long run, this approach provides financial benefits for all parties involved, as the cost savings from reusability outweigh the costs associated with single-use packaging. Moreover, the redesign has the potential to save significant amounts of paper, contributing to both environmental and economic sustainability.

However, the ultimate success of this project depends on Fresenius Medical Care, as they are responsible for implementation. A key challenge remains the current strict regulations on medical packaging. Policymakers should assess whether these regulations are too restrictive and explore ways to facilitate the adoption of reusable packaging within the healthcare sector.

For this redesign to succeed in the long term, cooperation between the EMC, Fresenius Medical Care and policymakers is crucial. The responsibility now lies with these stakeholders to drive the necessary changes and realise the potential of this sustainable innovation.

Project Evaluation

5

This final chapter looks back at the overall project. First, the chapter summarises what was discussed in the report and recommendations follow. Finally, it concludes with a project reflection and personal reflection.

5.1 Conclusion

As the negative impact on the environment of healthcare in the Netherlands is significant, the purpose of this project was to make healthcare in the Erasmus MC more sustainable by contributing to the achievement of the Green Deal's goals of reducing used resources, waste and CO2 emissions.

This was done by mapping the flow of waste and identifying hotspots within. The Material Flow Analysis revealed that almost half of the waste produced in the ICU consists of many different plastics. More than a quarter is paper waste and almost a quarter is glass. One of the packaging, the box of dialysis bags, causes 20% of the total waste in the ICU.

This box was chosen as the focal point for a redesign to reduce waste. With the Reuse strategy, a reusable box system concept was designed. This system does not only reduce waste and CO2 emissions. It has also improved in usability by logistics staff and nurses. For the nurses, it takes less essential time that can be better spent on patient care.

As dialysis is a common procedure in medical care, switching to reusable boxes may have even more impact when this system is extended to other hospitals and healthcare facilities, even outside the Netherlands.

This project acts as an eye-opener to all stakeholders in the industry and politics to show that things can also be done differently. Why exactly do we have all these rules and guidelines? And why do we let the sometimes unnecessarily strict rules hinder new ideas for sustainability?

5.2 Recommendations

To build on this project, several recommendations are proposed for different stakeholders.

Further research on medicine packaging is essential to refine the findings. Short pilot projects could be carried out to weigh empty medicine containers more accurately to distribute material weights more precisely and identify specific materials used. Ideally, this should be done in collaboration with the drug manufacturers themselves. These insights will provide a better basis for evaluating environmental impact and designing sustainable alternatives.

When focusing on other redesign projects from the results, it is advisable to focus on making glass products like vials and ampules more circular using the R strategies. Standardisation of packaging with plastic can also be looked at so that fewer different types of plastic are used. Also, with a lot of packaging, it is important to look at the possibility of separating the different materials as they are often permanently attached to each other.

Looking at redesigning the paper box to a reusable system, it is recommended to do more user testing by purchasing a whole dolly system with multiple boxes and see where there are still areas of concern in the complete system. In addition, a Life Cycle Assessment comparing the current paper box to the proposed reusable system should be conducted to quantify the environmental and economic benefits.

For Fresenius Medical Care, it is recommended to prioritise the implementation of the reusable packaging system by addressing logistical challenges, such as storage and transportation requirements. By using examples from other industries, this process can be streamlined. By implementing this system, Fresenius can realise long-term cost savings, meet sustainability targets and gain a competitive advantage as a more environmentally conscious supplier.

For policymakers, it is crucial to review the existing regulations surrounding medicine packaging. Policymakers should work with the healthcare industry to evaluate whether these regulations are unnecessarily strict and hinder the adoption of reusable systems, and work with healthcare providers to develop guidelines that enable sustainable solutions without compromising patient safety.

For Erasmus MC, it is proposed to start implementation with small-scale pilot programmes together with Fresenius Medical Care to test the feasibility of the redesigned reusable packaging in practice. Collaboration with other hospitals may provide valuable insights into the wider applicability of the system.

Finally, future research should be expanded to investigate other components of healthcare waste and further optimise reusable packaging systems. Gathering input from other hospitals and stakeholders can strengthen the case for industry-wide adoption of sustainable packaging materials.

5.3 Reflection

During this project, I grew in many ways and I learned a lot. It went with ups and downs, but through all the experiences I managed to become stronger and more self-confident.

For the first time, I had the opportunity to participate in conducting a large research study. This was very overwhelming at first and took much more time than expected, mainly the preparation and finishing of all the data collected. When preparing, it was sometimes difficult to know if you were really prepared for everything and it was a difficult decision to start weighing, not knowing if everything would run smoothly. This is of course true with many projects and it never runs completely as you planned. Once we started weighing, things came up that we could still easily and quickly implement. But also afterwards, things came up that we wanted additional information on. Now that I have had the opportunity to do such a large study, I have a clearer idea of what I can take into account in future studies and I know that it never hurts to collect more information than is eventually necessary. This gives less work afterwards.

In the design process, it was sometimes very difficult to deal with all the strict rules and guidelines around medication and packaging. This sometimes limited the creative flow of designing and it was occasionally necessary to throw these rules out of the window, so to speak. The moment the rules could be let go of for a while, more out-of-the-box ideas emerged and in the end much more seemed possible than before. While designing within a system as complex as healthcare, it is good to be able to let go of reality and constraints at times and let your imagination take over.

Looking at my set learning objectives, I learnt a lot from examining medication packaging in practice. I got to walk along and see the full context around all kinds of medication. I have held many types of medication packaging in my hands while weighing. I also spoke to many experts and people in the field from whom I learnt a lot. It was very interesting to see that everyone has a different perspective on a project and therefore have their own remarks.

Because sustainability is very important to me, also in my personal life, I feel honoured to have been able to contribute to this already. I am very happy to have been able to work with like-minded people who also really care about the climate and our future. I hope when I find a job I also find myself among such fine and like-minded people.

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Appendix

Appendix A: Project Brief

DESIGN FOR our future

Personal Project Brief – IDE Master Graduation Project

Name student Silke Rijcks **Student number** 4,666,690

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Redesigning medicine packaging to be more sustainable for the Intensive Care Unit at Erasmus Medical Centre

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)

Healthcare in the Netherlands is responsible for 7% carbon footprint, 4% waste and 13% resource use. In recognition of this, healthcare institutions signed the Green Deal Sustainable Healthcare, with targets for a 30% CO2 reduction and a 25% reduction in residual waste by 2026 compared to 2018 and 2016 respectively, and ultimately full climate neutrality and circularity by 2050. (Green Deal Duurzame Zorg 3.0, n.d.)

The focus of my graduation project is the Intensive Care Unit (ICU) at Erasmus Medical Centre. Hunfeld et al. (2022) conducted a Material Flow Analysis of the ICU department. This showed a "black box" surrounding medication and its packaging while being a significant part of the environmental impact (see Figure 1). I want to find out what this "black box" consists of and how much is related to the packaging.

Stakeholders in this challenge include the Erasmus Medical Centre which wants to raise awareness of and implement sustainability practices, manufacturers that need to be compelled to make changes, hospital staff directly involved in product use and waste management, product suppliers crucial for transportation, and most importantly, the environment as a key stakeholder.

This project not only provides opportunities for more sustainable healthcare, in line with hospital goals but also catalyses broader sector-wide change. By identifying hotspots at the ICU, I aim to redesign the packaging to ensure sustainable practices. Nevertheless, challenges are abundant, including the possible need for higher initial investment, huge regulation around medical packaging and fixed habits of the industry. Balancing these factors will be the main way to achieve lasting positive change in the healthcare sector's environmental footprint.

→ space available for images / figures on next page

introduction (continued): space for images

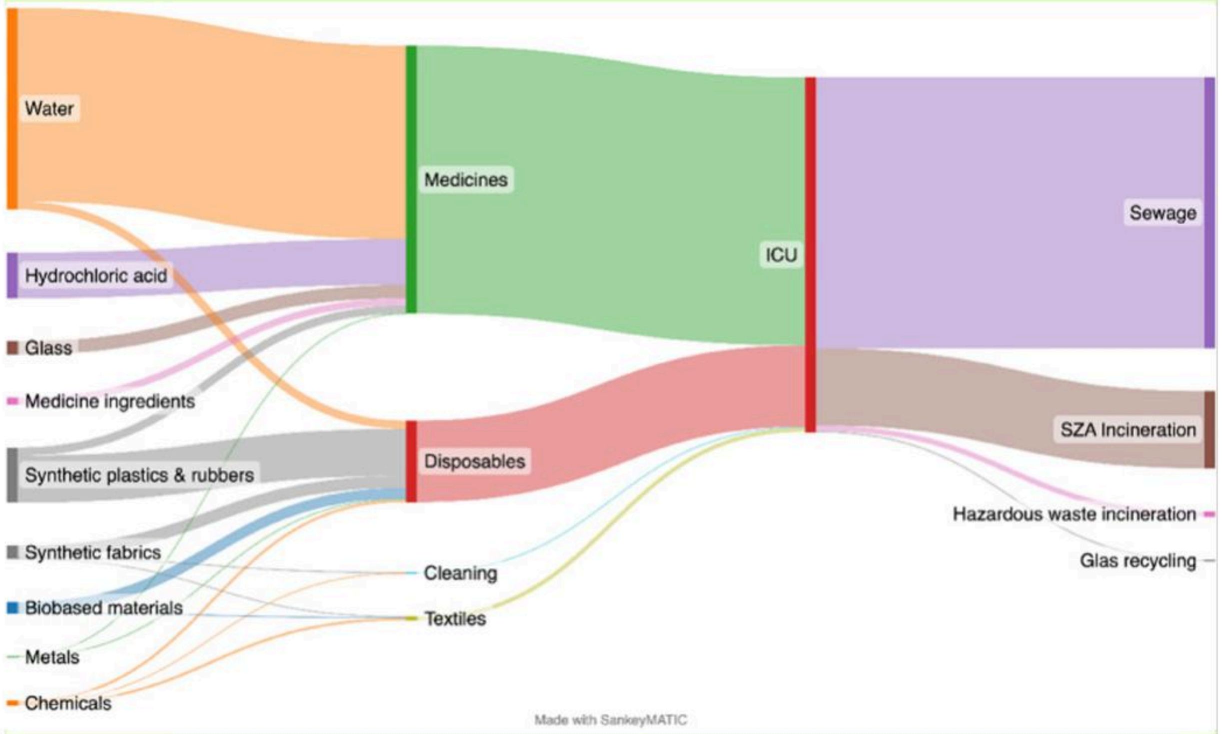


image / figure 1 Mass Flow Analysis from the ICU at the EMC, showing the big flow of medication. (Hunfeld et al.,2022)

image / figure 2 Portion of the medication packaging waste of one day at one of the depots of the ICU of the EMC.

DESIGN FOR our future

TU Delft

Personal Project Brief – IDE Master Graduation Project

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 problems to be tackled are the large amount of materials used and waste created related to medication use. A conducted LCA regarding morphine shows that 46% of the impact of the medication is from packaging (McAlister et al., 2016). Another complication is the immediate incineration of waste because it is not properly separated or categorised as medical waste because it still contains medication. Moreover, products are thrown away if they are prepared but unused or over the expiry date. I see the following opportunities:
Recycling, especially with plastic packaging, seems suitable because it is clean and homogeneous in material. However, this requires packaging and materials designed to be separated and processed.
Reduction of excessive or oversized packaging, or refusing packaging use.
Introducing more circular economy practices, such as reuse or repurposing. This however raises questions about maintaining sterility and safety or the energy costs associated with cleaning.

Despite these possibilities, care must be taken to avoid negatively affecting patient care. Usability remains a critical factor and changes should not unnecessarily consume precious time. It is essential to ensure that the proposed changes are in line with the overarching goal of sustainability without compromising the quality and efficiency of healthcare.

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:

Investigate the medication packaging flow at the ICU, determine which packaging or packaging types have the greatest negative environmental impact and create (re)designs that are more sustainable.

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)

The project starts by orienting in the field of healthcare and learning what happens at the ICU through desktop and literature research, and field research by tagging along with the pharmacists and talking to experts.

Together with a PhD candidate, we will be mapping the packaging waste of medication. This will be done by measuring the mass and materials of the packaging with medication, equivalent to last year's medication used. We will ask the producers of the medication for information about the weight of the medication itself and the materials used in the packaging.
With this mapping, we will calculate the impact on the environment and find hotspots and possibly other interesting points.

After the midterm, I will be focusing on making several redesigns for these hotspots and packages. To come up with improvements, Cradle2Cradle and Circular economy principles will be used and LCAs can be conducted on the redesigns to prove the positive impact created. I want to make prototypes of the final 3 concepts to demonstrate to producers and suppliers how to make more sustainable products, reducing materials use, waste and climate impact.

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	12 Feb 2024
Mid-term evaluation	23 Apr 2024
Green light meeting	5 Jul 2024
Graduation ceremony	9 Aug 2014

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	25
Number of project days per week	4,0

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)

I want to tackle this project because I have a passion for sustainability and want to make a positive impact. My parents, both working in healthcare, taught me how important this sector is. However, because the impact of healthcare is so significant, I don't want this important care to come at the expense of others. I am shocked at how much waste is created by this sector.

Hospitals are just recently starting to become aware of the problems and they want to do something about it. This is where I would like to help and show my skills. In my electives, I have chosen many courses about sustainability, and I would like to apply this knowledge to a real project. I have already done a project for sustainable food packaging and now I want to apply this to medication packaging.

In my studies, I had to do my bachelor's thesis and other projects during covid. This limited me a lot because a lot was done individually and a lot of research about context was done online and with desktop research. With this project, I want to learn to collaborate more with other disciplines and do more context research in practice.

Appendix B: Form

Wegen IC

LET OP: GETALLEN REGISTREREN ALS XX.YY (KOMMA'S WORDEN VERWIJDERD DOOR SYSTEEM)

* Vereist

Totaal

Voordat je gewichten invoert, controleer eerst of de match juist is in het bronbestand.
1. scan de GS1 (QR-code), zoek vergelijkbare GTIN (of selecteer handmatig)
2. vergelijk naam, sterkte en farmaceutische vorm
3. Indien relevante gegevens in databestand missen (zoals RVG) en die wel op verpakking staan, noteer dit bij overige opmerkingen later in bestand

1. Match? en gecheckt? *

○ Ja

2. Voer hier het Zi-nummer in van het artikel *

Voer uw antwoord in

3. Totaalgewicht in grammen (zoveel mogelijk getallen na de nul als mogelijk met weegschaal) *

Het gaat hierbij om het totaalgewicht van de secundaire verpakkingen inclusief alle producten en primaire verpakking.

De waarde moet een getal zijn

Volgende

Secundaire verpakkingen

Haal nu de primaire verpakkingen uit de secundaire verpakkingen

4. Is er een secundaire verpakking? *

○ Nee

○ Niet aanwezig

● Ja, 1 of meer

5. Gewicht secundaire verpakking 1 (de grootste/hoofdverpakking/ omverpakking) in grammen. *

De waarde moet een getal zijn

6. Materiaal secundaire verpakking 1 *

Voer uw antwoord in

7. Soort secundaire verpakking 1 *

(doos, lichtdicht zakje, gripzakje, etc..)

Voer uw antwoord in

8. Aantal primaire verpakkingen in secundaire verpakking *

De waarde moet een getal zijn

9. Hoe is de hoofdverpakking geseald? *

○ Plastic sticker

○ Papieren sticker

○ Plastic scheurstrip

○ Perforatie in verpakking (drukpunt)

○ Geen

○ Andere

10. Zitten er **papieren** stickers op de hoofdverpakking? *

Selecteer uw antwoord

11. Overige opmerkingen secundaire verpakking 1?

(zoals bijvoorbeeld recycle label, of als er een **taalsticker** opzit)

Voer uw antwoord in

12. Is er een tweede secundaire verpakking? *

○ Ja

● Nee

Terug Volgende

Accessoires

13. Zijn er accessoires?
naald, solvens, silica zakje, etc.

- ( ) Nee
- (•) Ja

14. Gewicht accessoire 1 (indien meer de grootste eerst) in grammen. *

De waarde moet een getal zijn

15. Omschrijving accessoire 1 (wat is het?) *

Voer uw antwoord in

16. Materiaal accessoire 1 *

Voer uw antwoord in

17. Is er een tweede accessoire? *

- ( ) Nee
- ( ) Ja

Terug | Volgende

Bijsluiter

14. Totaal gewicht van de bijsluiters (in grammen, inclusief stickers en wrappers) *
zoveel mogelijk getallen na de nul als mogelijk met weegschaal

De waarde moet een getal zijn

15. Bijzonderheden bijsluiter *
je kan meerdere kiezen

- [ ] nee (los in verpakking)
- [ ] Plastic wrapper
- [ ] Papieren wrapper
- [ ] Plastic sticker
- [ ] Papieren sticker

16. Overige opmerkingen
i.e.: is papier FSC-certified (licht toe), of zitten er meerdere bijsluiters (andere of dezelfde talen) in een verpakking, zoja hoeveel?

Voer uw antwoord in

Terug | Volgende

Primaire verpakking

Dit is de verpakking die direct in aanraking komt met het medicijn

17. Soort verpakking *

- (•) strip (blister)
- ( ) Strip met eigen QR code per pil (EAG/EAV)
- ( ) Flacon (S)
- ( ) Flacon (M)
- ( ) Flacon (L)
- ( ) Ampul (glas)
- ( ) Ampul (kunststof)
- ( ) Fles
- ( ) Tube
- ( ) Sachet
- ( ) Infusie Zak
- ( ) Spuit
- ( ) Pot
- ( ) Andere

18. Lengte strip (blister)/EAV in MM

Voer uw antwoord in

19. Breedte strip (blister)/EAV in MM

Voer uw antwoord in

20. Gewicht primaire verpakking in grammen: *

zoveel mogelijk getallen na de nul als mogelijk met weegschaal

De waarde moet een getal zijn

21. Materiaal primaire verpakking

Voer uw antwoord in

22. Hoeveelheid per verpakking *

Hoeveel stuks zitten er per primaire verpakking (Tablet of poeder:1, vloeistof de hoeveelheid in ml)

De waarde moet een getal zijn

23. Zitten er stickers op de primaire verpakking? *

- ◯ Nee
- ◯ Ja, 1 papier
- ◯ Ja, 2 papier
- ◯ Ja, 1 plastic
- ◯ Ja, 2 plastic
- ◯ Ja, 1 materiaal onbekend
- ◯ Ja, 2 materiaal onbekend
- ◯ Andere

24. Overige opmerkingen primaire verpakking

Voer uw antwoord in

Terug | Volgende

- ◯ Infusie zak
- ◉ Spuit
- ◯ Pot
- ◯ Andere

18. Soort spuit:

- ◯ BD 1ml
- ◯ BD 3ml
- ◯ BD 5ml
- ◯ BD 10ml
- ◯ BD 20ml
- ◯ BD 50ml
- ◯ Andere

Terug | Volgende

Geef nooit uw wachtwoord. Misbruik melden

Afsluitend

25. Fotonummer: *

Voer uw antwoord in

26. Overige opmerkingen

Laat leeg als er niks is

Voer uw antwoord in

Terug | Verzenden

Appendix C: Qualitative results

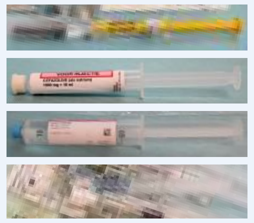
	Ampule	Vial	Infusion bag	Syringe	Blister	Sachet	Bottle
Example pictures							
Materials	Glass or plastic (PP or LDPE)	Glass or plastic (PP or LDPE), rubber, aluminium, plastic	Viaflo: PE/PP/PA, Biofine: PPCE/ SEBS/SIS/PP/PIP, PVC, PP, other mixed plastics	COCP, glass, rubber, PP	Bottom layer: aluminium or paper Top layer: PVC, PE, PVDC, OPA/alu or mix	Paper, aluminium, plastic (PE, PET, LDPE, EMC)	Glass, plastic (PE, LDPE, HDPE, PET, PP)
Joining	None	Mechanical	Coextrusion	Mechanical	Laminated	Laminated	Mechanical
Stickers	Plastic or paper	Plastic or paper	Paper	Plastic or paper	None	None	Plastic or paper
Secundairy packaging	Box	Box	Protection bag, box	Grip bag, blister packaging, box	Box	Box	Box
Accessories	Tray, green sign-off sheet, rubber band	Tray, green sign-off sheet, rubber band, filter, solvent	None	Silica bag	Silica bag, green sign-off sheet	None	Cup
Leaflet	Yes	Yes	Yes	Yes but prefilled from pharmacies not	Yes unless repackaged	Yes	Yes

Figure: Qualitative results per primary typology

	Box	Bag	Blister packaging
Example pictures			
Materials	Paper or cardboard	LDPE, PA/PP, MATT BOPP/ ALU/LDPE	Plastic, plastic/ medical paper, plastic/alu
Seals	Plastic, plastic/alu, paper, tape, perforated in box	Adhesive strip, grip line, melted	Heat seal lacquer, melted
Stickers	Label, repackaged, language	Label, refrigerated, opiates	None
Tray included	Sometimes	None	None

Figure: Qualitative results per secondary typology

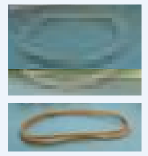
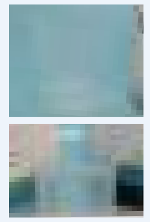
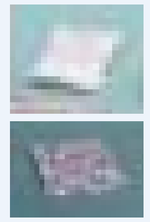
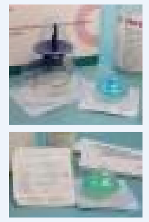
	Tray	Sign-off form opiates	Rubber band	Solvent	Cup	Silica bag	Filter
Example pictures							
Materials	Paper, hard plastic	Paper	Rubber	Glass, liquid solvent	Hard plastic (PP)	Silicon dioxide (silica), bags unknown	Filter: mix of plastics Packaging: plastic/ medical paper

Figure: Qualitative results per accessory typology

Appendix D: Brainstorm

Reuse

Binnen ziekenhuis
- omverpakte pillen of uit pill picker

Steuse doosjes

- info op QR code

Rethink?

? pill picker of om verpakken

waarom?

doosjes kleur coderen
of in drukken
↓
Swappable lable?

Buiten ziekenhuis
Is al systeem met dozen waar medicatie in wordt vervoerd

trays in herbruikbare dozen gestandaardiseerd

Dozen van dialyse zakken zijn groot en bevatten weinig zakken → reusable want kunnen worden ook hergebruikt?

Rethink

(pill picker?)

dispensers voor pillen?

Reduce

kleinere doosjes → meer per doosje?

! niet gestandaardiseerd?

op maat zods bij delivery

Transport → efficienter ~~kleiner~~

waarom pillen in blister in doosje?

waarom niet in pot?

Soms zit iets in doosje dat helemaal niet nodig is (kalium drank bv)

Refuse

pill picker systeem

doosjes worden soms snel weggegooid
- in ander bakje
- Doosjes mengen

! tray die in het doosje geïntegreerd zijn

Recycle

Scheiden doosjes al

Stickers → lijm?

Duidelijke instructies

! mono materiale
↓
Seals, Stickers van papier of in het doosje (amazone heeft papieren tape nu)

! inkt?

! coatings?

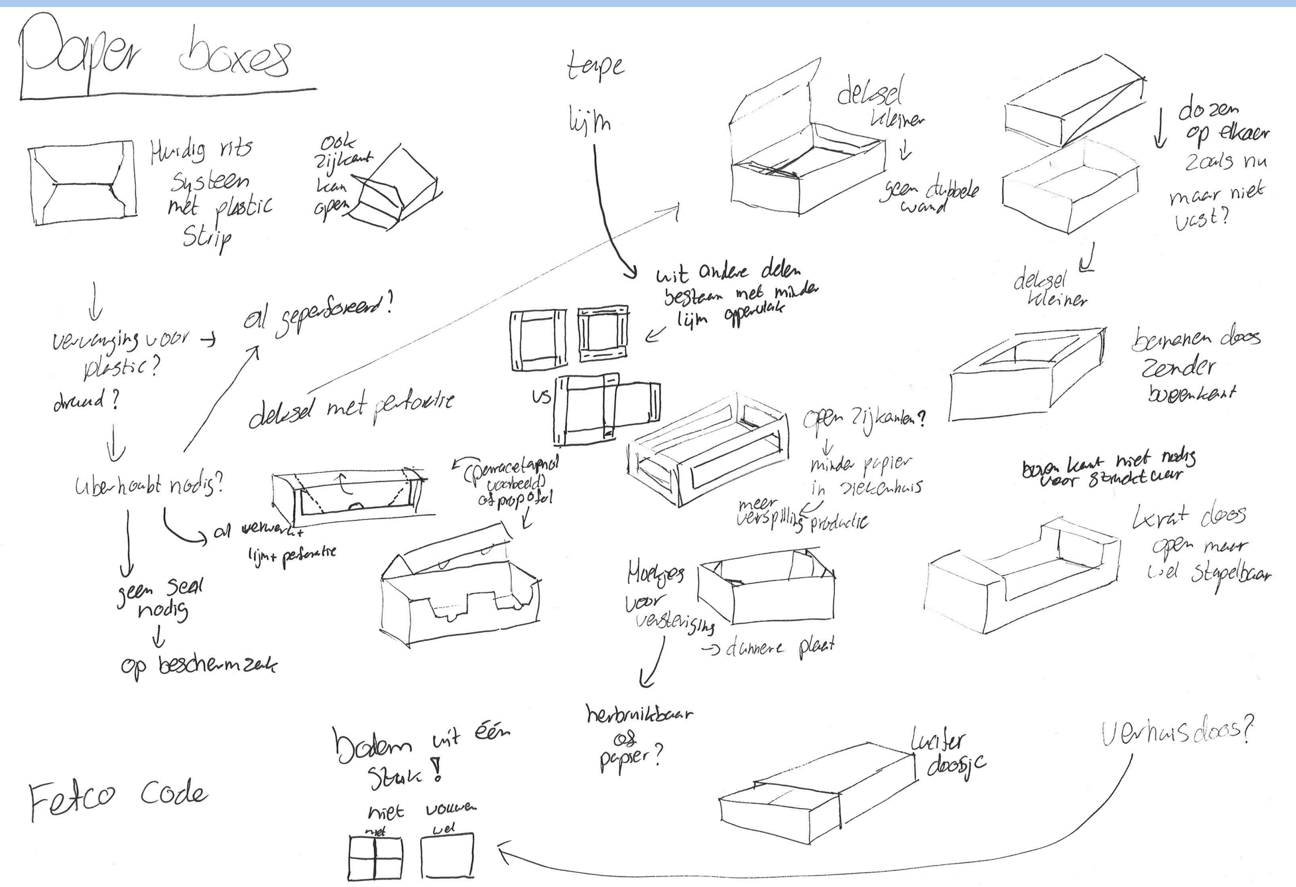
composting?

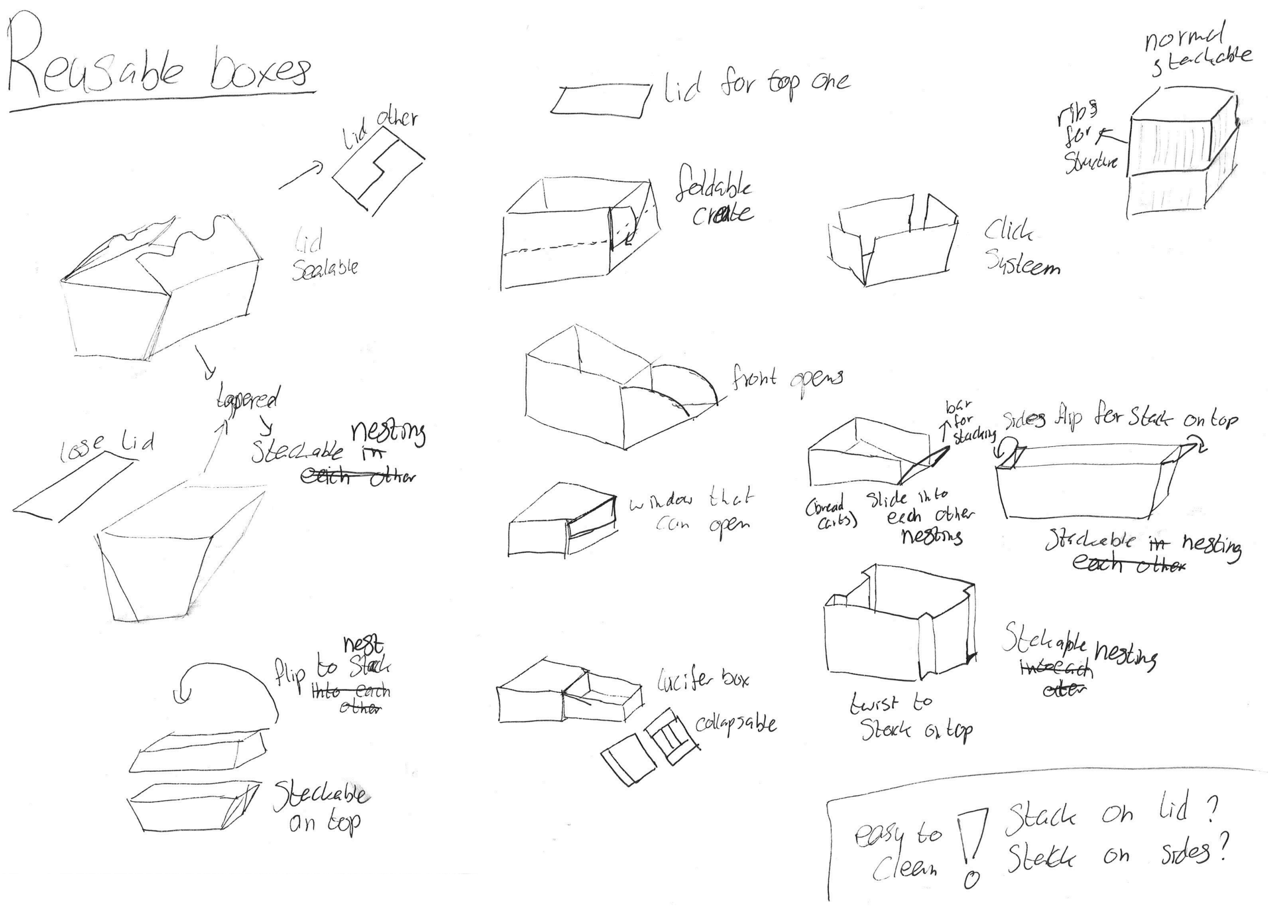
Recover

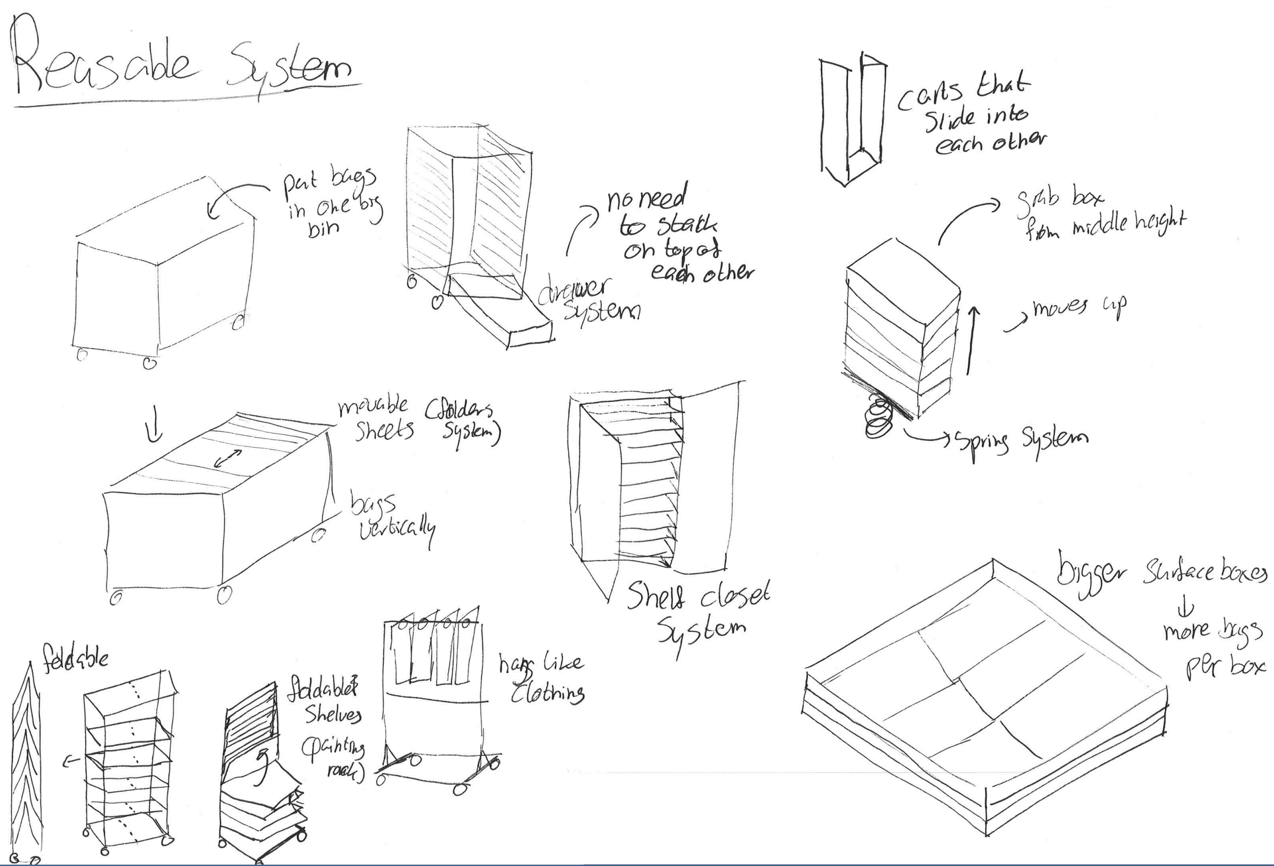
belangrijk dat er geen giftige stoffen vrij komen

Appendix E: Collage existing solutions

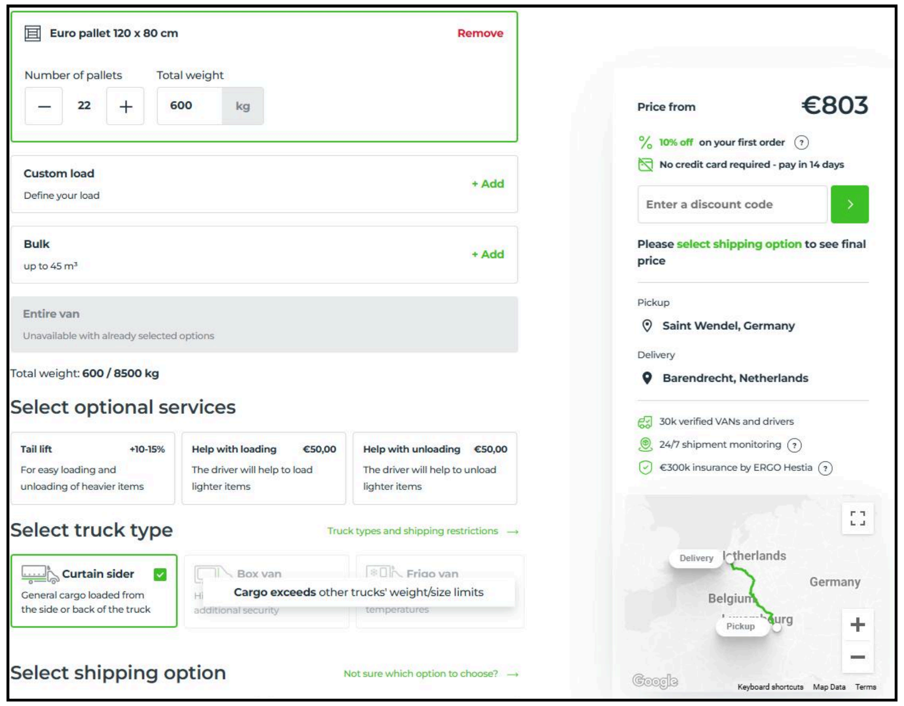
Appendix F: Idea sketches

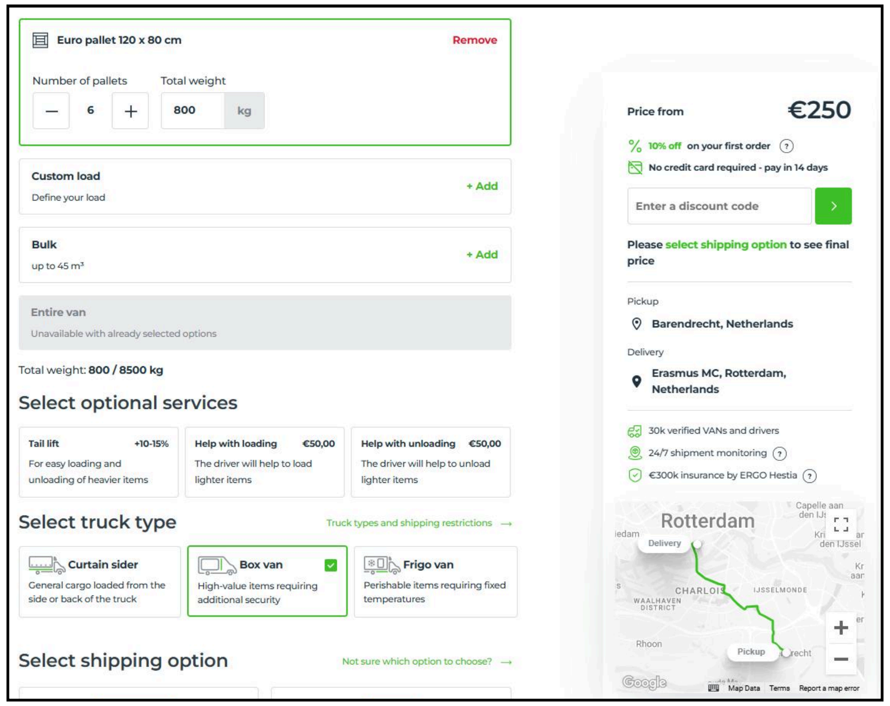


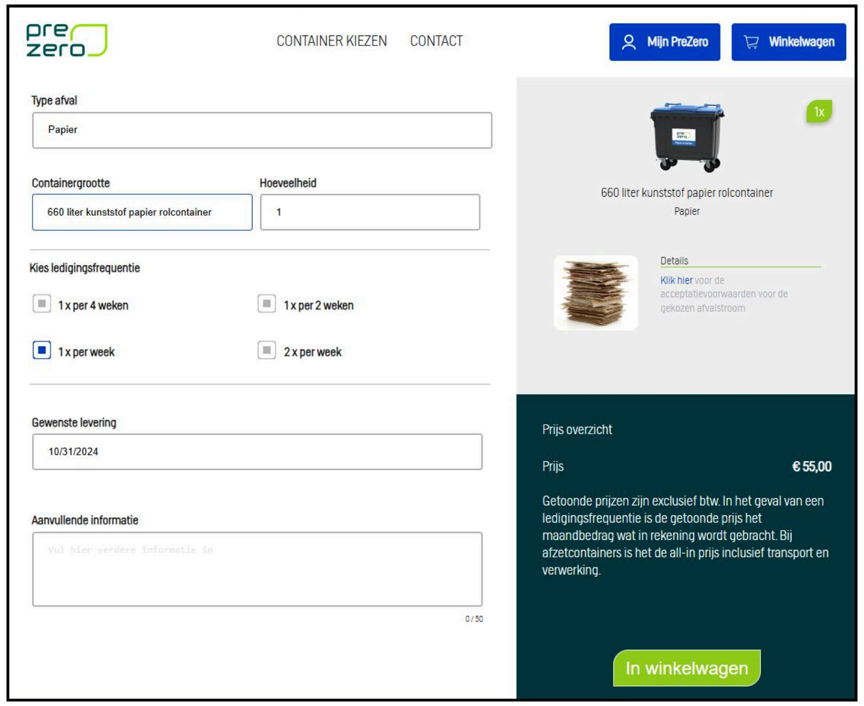




Appendix G: Cost Analysis







	beschrijving stappen	Situatie 1	beschrijving stappen	Situatie 2	beschrijving stappen	Situatie 3	beschrijving stappen	Situatie 4a
	papieren dozen	16.8	papieren dozen	16.8	herbruikbare boxen	3	herbruikbare boxen	3
	pallet	0.341428571	pallet	0.341428571	pallet	0.341428571	systeem	3.2
	T FMC naar HL	10.3	T FMC naar HL	10.3	T FMC naar HL	10.3	T FMC naar HL	10.3
	kar	3.2	kar	3.2	kar	3.2	T HL naar EMC	3.25
	omzetten	2.25	herbruikbare boxen	3	omzetten	2.25	openmaken box vpl	0.31625
	T HL naar EMC	3.25	openmaken doos lm	0.50625	T HL naar EMC	3.25	wegzetten box vpl	0.94875
	openmaken doos vpl	0.94875	omzetten	2.25	openmaken box vpl	0.31625	T EMC naar FMC	10.3
	klein maken doos vpl	3.1625	klein maken doos lm	1.6875	wegzetten box vpl	0.94875		
	papier afval afvoeren	7.857142857	papier afval afvoeren	7.857142857	T EMC naar FMC	10.3		
			T HL naar EMC	3.25				
			openmaken box vpl	0.31625				
			wegzetten box vpl	0.94875				
Kosten:		**48.10982143**		**50.45732143**		**33.90642857**		**31.315**
dozen		16.8		19.8		3		3
systeem		3.541428571		3.541428571		3.541428571		3.2
transport		13.55		13.55		23.85		23.85
gebruik		6.36125		4.02125		3.515		1.265
afvoer		7.857142857		7.857142857		0		0