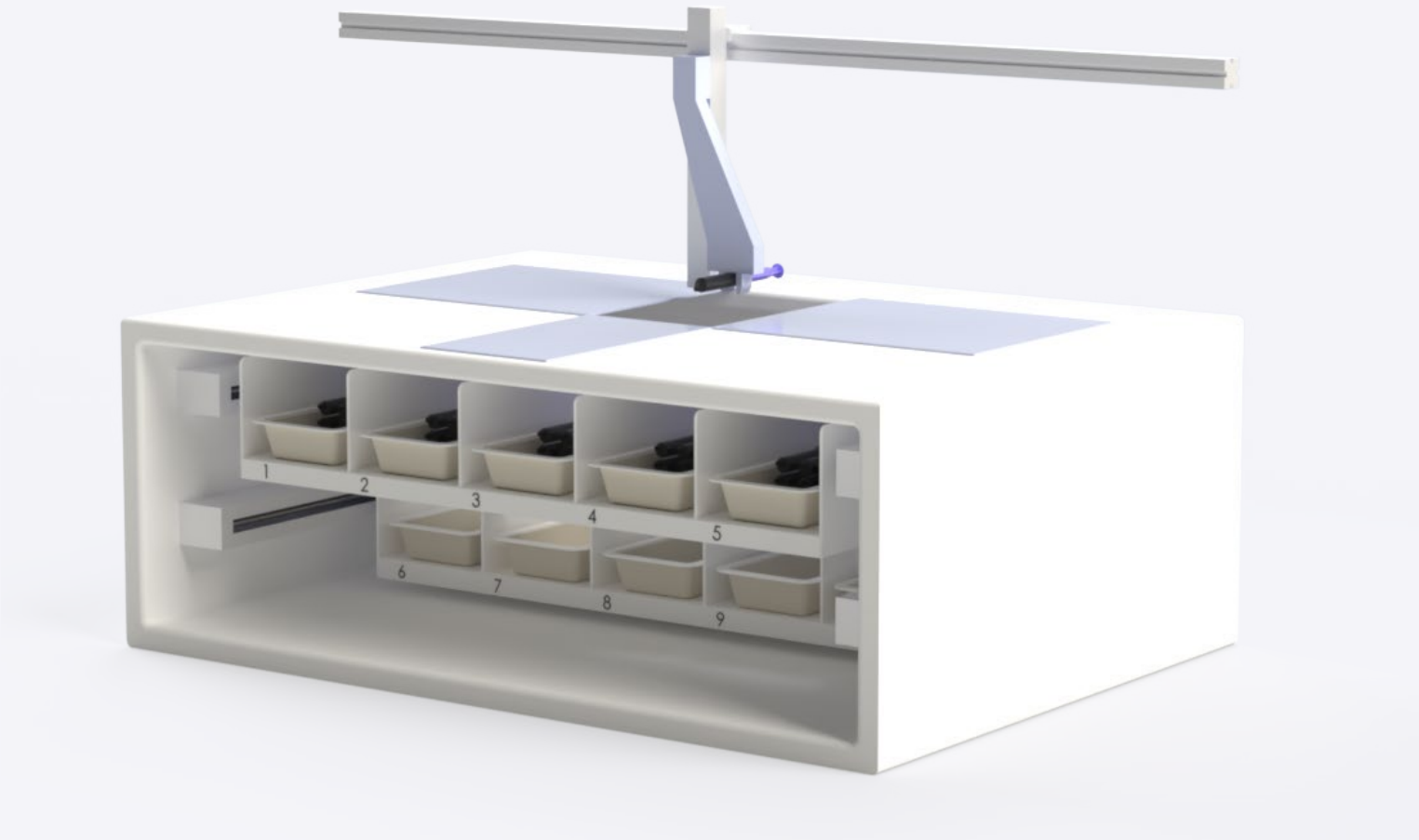

Designing an Output Module for Neollie B.V.

How can an output module be designed to safely and efficiently deliver cooled, well-organised syringes to nurses, while seamlessly integrating into the workflow of the NICU environment at Erasmus MC?

MASTER THESIS

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Ubi cura, ibi vita

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I am grateful for this opportunity and hope this thesis inspires future developments in medical design. Enjoy!

Valérie

Executive Summary

The Neonatal Intensive Care Unit (NICU) of Erasmus MC Sophia Children's Hospital is currently facing a shortage of nursing staff, resulting in temporary ward closures and increased workload pressure. At the same time, NICU patients require highly specialized care, in which nutrition plays a crucial role in growth, recovery, and survival. Breast milk, often enriched with fortifiers, must be prepared daily in precise quantities.
This process is currently performed manually and is both time-intensive and error-sensitive, placing significant responsibility on nursing staff.

Neollie is developing the Neo machine to automate the preparation of fortified breast milk syringes. A first prototype has demonstrated the technical feasibility of automating the filling process. The current development phase focuses on preparing the system for real hospital implementation, where strict spatial, hygienic, and safety requirements apply.

Within this context, patients and the nurses who prepare their nutrition represent the core stakeholder groups of this project. Patients define the ultimate quality and safety requirements, while nurses define the operational, usability, and workflow-related requirements.

The Neo system consists of multiple interacting subsystems. Through system analysis, a design gap was identified at the intersection of technology and human interaction. As an Integrated Product Designer, this thesis therefore focuses on the design of the output module: the stage responsible for delivering up to 120 patient-specific syringes per day in a cooled, organised, and workflow-compatible manner.

The central research question guiding this thesis is: How can the output stage of the Neo system be designed to deliver cooled and well-organised syringes to nurses in a way that is safe, efficient, and seamlessly integrated into the workflow of the NICU environment?
This question is addressed through four sub-questions focusing on cooling, organisation, user interaction, and implementation constraints.

Through ideation, co-creation sessions, consultations with Neollie, and iterative design development, the DualDrop mechanism emerged as the most promising concept. The system combines horizontally moving drawers with a controlled dropping mechanism that positions each syringe in the correct tray and patient-specific compartment.

To validate both technical feasibility and user alignment, three prototypes were developed and tested with NICU nurses. These prototypes generated qualitative insights into workflow integration, usability, safety perception, and trust.
The final DualDrop output module was subsequently developed in detail, including sensor integration, material selection, production considerations, and implementation strategy.

The result is a design proposal that integrates technology, human factors, and clinical constraints, contributing to a safer, more efficient, and scalable approach to neonatal nutrition preparation.

Table of Contents

Key terms and abbreviations

EMC	Erasmus Medical Center
NICU	Neonatal Intensive Care Unit: A specialized hospital unit that provides intensive care for premature infants and newborns with serious medical conditions, such as breathing difficulties, infections, low birth weight, or congenital disorders.
PICU	Pediatric Intensive Care Unit: This unit treats critically ill children, typically from infancy through adolescence, who require specialized care for severe illnesses, injuries, or after major surgeries.
Pediatric ward	Hospital unit dedicated to the care and treatment of children, typically from infancy to adolescence, who are admitted for various medical conditions.
Patients	Infants and children admitted to the NICU, PICU, or pediatric ward who are receiving medical care.
BMF	Breast Milk Fortifier
LCT	Long-Chain Triglyceride
Infant formula	Formula milk
Milk	Breast or formula milk before any other substances are added.
Fortifiers	Powdered supplements that provide extra nutrients and can be mixed into the milk.
Feed	Breast milk or formula supplemented with additional substances, such as fortifiers.
Neo	The name of the robot of Neollie B.V.

1

Introduction

This chapter presents the motivation, objectives, and methodological approach of the graduation project. It discusses the relevance of a human-centered perspective within Integrated Product Design, the collaboration with Neollie B.V., and the project's intended contribution to nursing practice.

1.1 Project Motivation

This thesis presents the development of the DualDrop output module for the Neo system, a robotic solution designed to safely and efficiently deliver cooled, patient-specific breast milk syringes to nurses within the complex workflow of the NICU.

This project presents an ideal opportunity, as it brings together the three pillars of Integrated Product Design: people, business, and technology.

Within the field of Integrated Product Design, the technological perspective tends to dominate, while the user perspective is treated as secondary. There is often an assumption that once the technical system functions properly, the design challenge is solved. This view is incomplete. A successful design must also take into account how people experience and interpret the product: does it truly work in practice as intended, and is it understood and used in the way the designer envisioned?

Neollie B.V. is a start-up developing an automated system to support nurses in the preparation of infant feeding within neonatal care. What makes this assignment particularly engaging is the central role of the user in this context. Nurses are not simply passive operators of a technical system; their work, needs, and responsibilities directly shape how the robot must function. Being able to focus more strongly on this human perspective is both a challenge and a valuable learning opportunity for me.
It is meaningful to envision a future where healthcare staff are freed from repetitive, time-consuming tasks and can instead dedicate those valuable hours to direct patient care. If design can contribute to reducing their workload and improving the quality of time spent with patients, it can create a genuine impact beyond technical efficiency.

The scale of the Mother Milk Preparation Robot also adds to this motivation. Unlike the smaller products I have worked on before, this is a large and complex system. It demands a different approach to prototyping and visual communication, pushing me to translate ideas into tangible, convincing representations at a scale I have not tackled before.

Finally, this project marks an important milestone in my personal and professional development. It is the final step in my studies, and I aim to approach it with ambition and a positive mindset. By applying the triple diamond methodology and independently managing the design process, I want to strengthen my confidence as a designer. Completing this project will not only conclude my education but also prepare me to enter the professional field as a full-fledged Industrial Designer.

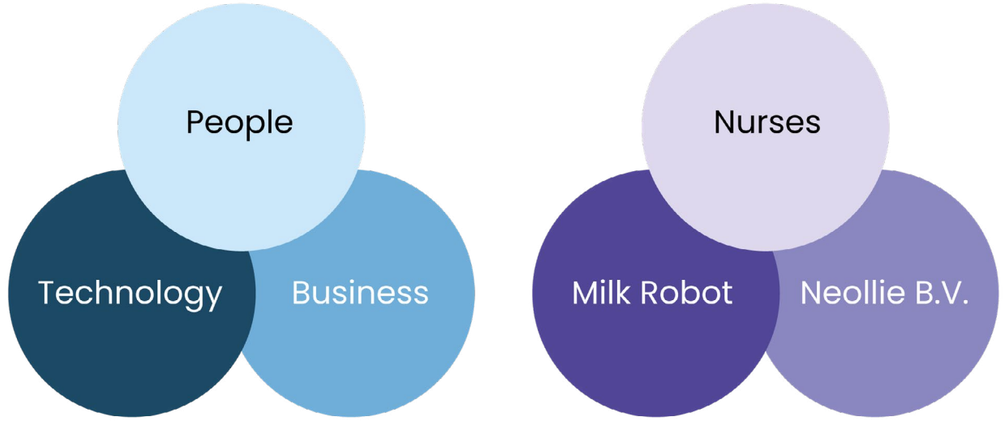


Figure 1: Three pillars of Integrated Product Design

1.2 The Initial Project Aim

The primary aim of the project of Neollie B.V. is to design a robotic system that relieves nurses from a simple, repetitive, and error-prone task that is generally regarded as unpleasant. Currently, the shortage of nurses is so acute that parts of the pediatric ward cannot be used to their full capacity. By reducing the burden of routine preparation tasks, a robot has the potential to free up time and energy, allowing nurses to concentrate on patient care where it is needed most.

Neollie B.V. is a young startup with a strong technical foundation. The team is composed mainly of electrical, mechanical, and software engineers, which makes the involvement of an Industrial Design Engineer particularly valuable. My role is to bring in the human perspective in this project, ensuring that the design of this project not only functions technically but is also meaningful, safe, and practical within the real context of the hospital environment.

1.3 Methodology Overview

The aim of this graduation project is to further develop their robot so that it can reliably prepare feeds for multiple patients throughout the day, while supporting nurses with a process that is safe, efficient, and straightforward to use. To achieve this a structured approach is needed that allows for exploration of nursing workflows, alignment with hospital routines, and testing of both the technical and user-facing aspects of the system. For this reason, the project follows an adapted version of the Triple Diamond framework.

The Triple Diamond is a design model that structures projects into phases of discovery, definition, and validation (Marin-Garcia et al., 2020). In this project, the model is adjusted so that user research and technical development receive equal attention. The first phase focuses on understanding existing practices through a literature review, field observations and interviews, and the analysis of the current prototype of the machine. Extending the discovery phase in this way is important, because neonatal feeding is not only defined by written protocols but also by the practical routines of nurses on the ward. Particular attention is given to how nurses will interact with the robot in key steps such as loading containers, setting nutritional parameters, and collecting prepared syringes.

The second phase focuses on generating and refining design concepts. Early scenarios, sketches, and partial prototypes are used to test ideas that support mechanical scalability and reduce the risk of errors in daily use. Both Neollie B.V. and the nurses are directly involved in these iterations, as evaluators but also as contributors who provide feedback that shapes the design.

In the third phase, concepts are tested and evaluated in more detail. Insights from these tests are translated into concrete design principles and recommendations for Neollie B.V. and Erasmus MC. Alongside technical performance and hygiene, attention is given to long-term aspects such as usability, maintenance, and the integration of the robot into the hospital setting.
This approach combines principles of Integrated Product Design with user-centered methods, balancing the human, technical, and contextual dimensions throughout the project. By adapting the Triple Diamond to emphasize discovery, iteration, and real-world integration, the project increases the chances that the robot will not only be technically viable but also genuinely useful for nurses and sustainable in the hospital environment.

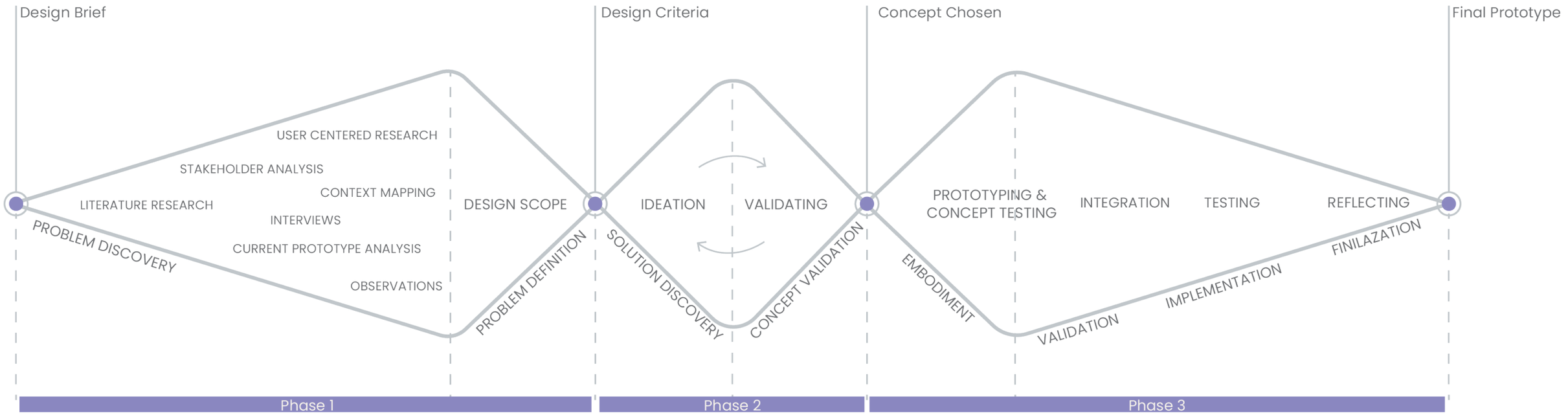


Figure 2: Adapted Triple Diamond Methodology

2 Background

This chapter provides the background context for the graduation project. It introduces Neollie B.V., the NICU environment at Erasmus MC Sophia Children's Hospital, and the clinical importance of human milk preparation for premature infants.

2.1 About Neollie

Neollie B.V. is a Dutch startup dedicated to improving neonatal care by automating the preparation of infant feeds. Today, feeding practices in hospitals are still largely manual and depend heavily on nursing staff. This creates several challenges: preparing breast milk with fortifiers is time-consuming, requires highly precise dosing for premature infants, and is vulnerable to human error. These difficulties are compounded by the shortage of qualified nurses, which places additional pressure on healthcare systems and reduces the time staff can spend directly with patients.

To address this, Neollie is developing Neo, a modular robotic system designed for neonatal intensive care units (NICU). The system measures, mixes, and prepares feeds in a consistent and traceable way, with the aim of reducing repetitive nursing tasks, ensuring accuracy, and improving overall efficiency and patient safety. By automating such routine processes, Neollie not only seeks to ease the workload of nurses but also to prepare hospitals for the expected shortage of healthcare staff.

The first prototype of Neo demonstrated that the basic principle of automating feed preparation is feasible. This version integrated technologies for precise dosing, controlled handling, mixing, and heating, and successfully prepared feeds by combining breast milk with fortifiers according to medical prescriptions. Building on these foundations, Neollie is now focusing on scaling the system into a market-ready solution that can meet the complex requirements of everyday neonatal care.

2.2 Erasmus MC

The project takes place in the Neonatal Intensive Care Unit (NICU) of Sophia Children's Hospital, part of Erasmus Medical Center, which is currently undergoing large-scale renovations. The ambition is to have the milk-preparation robot ready for use *before* 2032 so that it can already integrate into the current NICU workflow, while at the same time being designed to fit seamlessly into the renewed hospital environment of 2032 (Erasmus MC, n.d.-a). As the exact location of the robot within the new hospital has not yet been determined, the design process retains considerable freedom.

One important boundary condition is the overall size: the robot may not exceed the length or width of a standard hospital bed, as beds can always pass through the corridors. In addition, the height must remain within the clearance of hospital doors. These practical constraints provide clear guidelines for the physical design, ensuring that the robot will remain compatible with the hospital environment once implemented in 2032.

Criteria:
• The robot may not exceed the length or width of a standard hospital bed (2500x1500x2000)

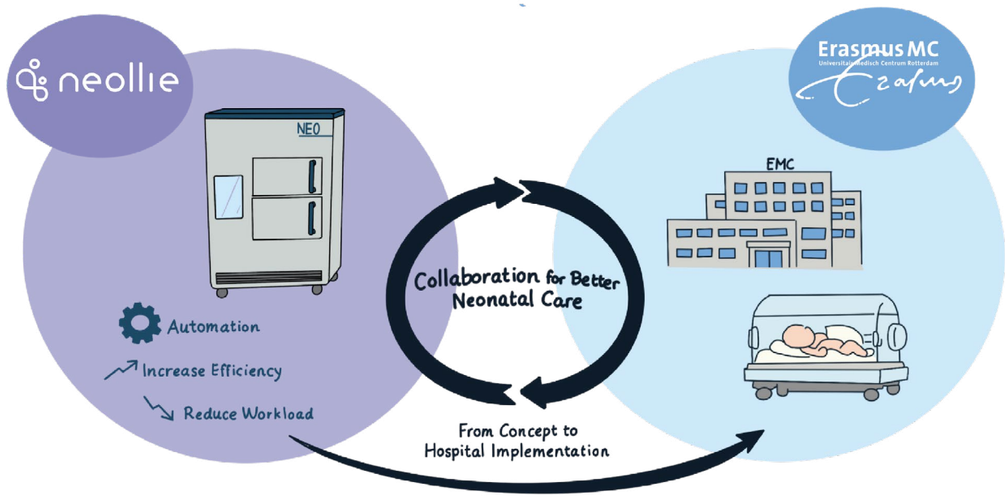


Figure 3: Collaboration for better Neonatal Care

2.3 NICU

The Neonatal Intensive Care Unit (NICU) at Erasmus MC-Sophia Children's Hospital provides specialized care for the most vulnerable newborns. In the Netherlands, deliveries before 32 weeks of pregnancy or with a birth weight under 1250 grams must take place in a hospital with a NICU facility (ICT&health, 2020). At Sophia, approximately 600 critically ill or extremely premature infants are admitted each year, requiring continuous intensive monitoring and treatment (Erasmus MC, n.d.-b). These infants often rely on advanced medical technologies. Their care is guided by the Newborn Individualized Developmental Care and Assessment Program (NIDCAP), which emphasizes individualized, developmentally supportive care to optimize long-term outcomes and quality of life (Erasmus MC, n.d.-c).

Nutrition plays a central role in this context, as breast milk enriched with human milk fortifiers provides essential nutrients to support growth and development in premature infants. Proper preparation of these feeds is critical, since errors in dosage or hygiene can have severe consequences, such as an increased risk of infection. Yet, the task is time-consuming and contributes to the already high workload of nurses, who must balance procedures with direct caregiving.

At the same time, the NICU faces broader systemic challenges. Staff shortages have increasingly forced Dutch hospitals to close beds or restrict admissions (NOS, 2019; Erasmus MC, 2024). At Sophia, this means that although the NICU could theoretically accommodate more patients, current staffing levels limit the number of babies that can be treated simultaneously, currently limited to 10 patients. This structural pressure highlights the need to develop innovations that reduce repetitive nursing tasks while maintaining patient safety.

Beyond the medical and organisational aspects, the NICU is also a highly emotional environment for parents. Feeding is often one of the very few tangible ways in which parents feel they can actively contribute to their child's recovery (De Ruiter, 2025), and this makes the preparation and administration of milk deeply meaningful. At the same time, studies show that the NICU can be a stressful place for parents, with feelings of limited control and reliance on professional staff shaping their daily experience (Alphenaar, 2019). Acknowledging this parental perspective is important, since it highlights why nurses play such a central role in bridging medical protocols and parental trust, and why any design for feed preparation must safeguard this trust while easing the workload of staff.

Criteria:
- The machine shall have the capacity to handle up to 10 patients.

Figure 4: Entrance Hall Sophia Kinderziekenhuis

Figure 5: Incubator in the NICU ward

2.4 The Nutritional and Clinical Importance of Human Breast Milk

Human Breast Milk

According to the World Health Organization (WHO), exclusive breastfeeding during the first 6 months after birth provides the infant with the most optimal start for life (World Health Organization, 2003). The WHO additionally states that the nutrient composition of human milk is essential for the growth, development, and health of infants, and that breastfeeding is an unparalleled way of feeding (Petersohn et al., 2024).
Breast milk also supports the development of the immune system. It enhances the immature immunologic defences of the neonate and provides protection against infections and other harmful agents.

The complex composition of the human breast milk, containing proteins, carbohydrates, fats, vitamins, minerals, and bioactive substances, offers not only nourishment but also immune and developmental support (van Veldhuizen-Staasen & Kleintjes, 2008).

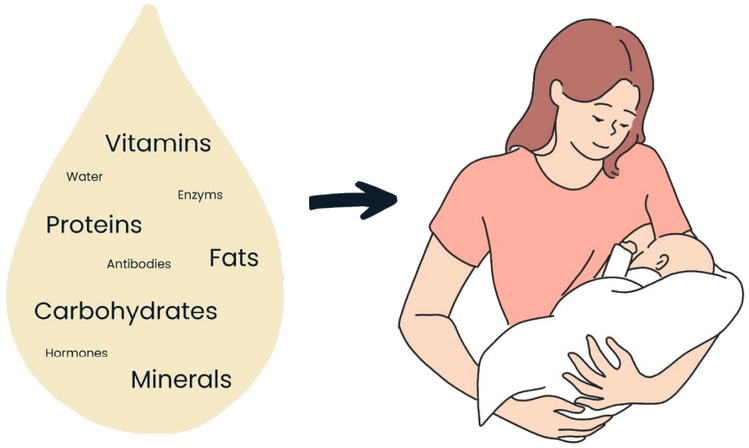


Figure 6: Composition of Human Breast Milk

Human Milk for Premature Infants

In a healthy situation, the infant feeds directly from the mother's breast. However, for premature infants, this is often not possible, as they may lack the strength or coordination to feed independently. In such cases, breast milk is expressed and collected in containers and placed into syringes for later use. During observations in the NICU kitchen, significant variation in bottle volumes was noted, which reflects both the differences in maternal milk production and the natural variability in milk composition. Each mother produces milk with a unique nutritional profile that changes over time, throughout the day, and across lactation stages (van Veldhuizen-Staasen & Kleintjes, 2008).

For preterm infants, breast milk is even more crucial. Preterm infants often require more nutrients than breast milk alone can provide, supplements such as Breast Milk Fortifier (BMF) and Long-Chain Triglycerides (LCT) are added. These fortifiers increase the caloric and nutritional density by providing additional proteins, fats, and micronutrients.

When a mother's own milk is insufficient or unavailable, donor milk or specialised formula may be used, to which BMF and LCT are also added. Only a small amount (4%-6%) is mixed into the milk (Hak et al.,2024). After mixing, the prepared milk is placed into syringes so that it can be hung at the bedside and administered to the infant via tube feeding. The preparation of these specialised feeds currently takes place manually in the NICU kitchen.

In contrast to human breast milk, infant formula has a standardised and consistent composition, which simplifies storage, preparation, and dosage. Formula can be prepared in fixed volumes with predefined nutritional values, making it inherently more suitable for straightforward automation. If formula feeding alone were sufficient for premature infants, the preparation process could be significantly simplified. However, due to the clinical preference for human breast milk and the need for patient-specific fortification, the feeding process in the NICU remains inherently complex and variable.

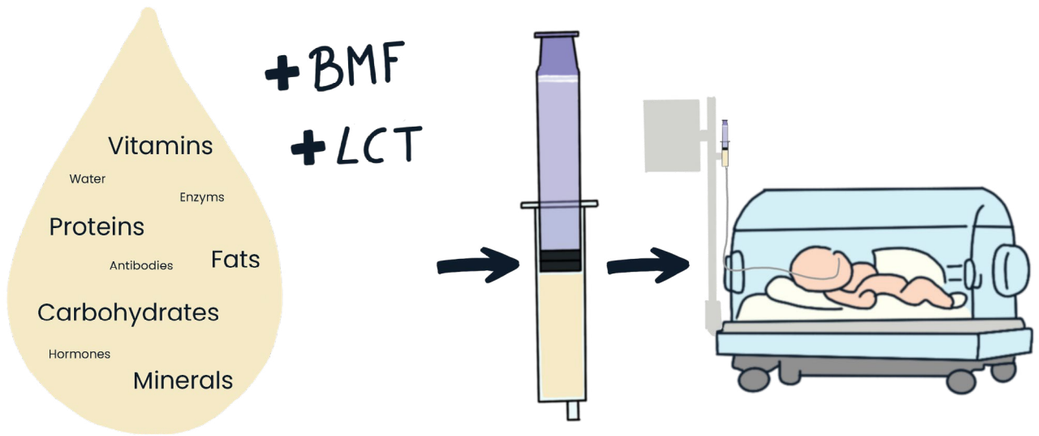


Figure 7: BMF and LCT added to Breast Milk

Temperature and Storage

Once prepared, the milk must be stored under the correct conditions. According to the protocols of Erasmus MC (Erasmus MC, n.d.-d), expressed breast milk can be kept refrigerated for up to 24 hours, while frozen milk can be stored for a longer period. Milk from the same mother, but expressed at slightly different times, may be combined before freezing, provided it remains within the safety timeframes. The storage guidelines for breast milk are shown in Table 1.

Before feeding, milk is ideally warmed gradually to body temperature using an au bain-marie system near the infant's bed. The use of microwaves is discouraged, as this can damage the nutrients and alter the milk's structure (Ito et al., 2025). In the initial prototype of Neollie, the warming process was integrated into the system; however, in the current design vision, warming is conceived as a bedside activity, independent of the robotic platform, and therefore falls outside the scope of this project.

Figure 8: Au bain-marie system near infant's bed

Table 1: Breast milk storage guidelines (Eglash, Simon, & The Academy of Breastfeeding Medicine, 2017)

Storage conditions	Room temperature (20°C)	Refrigerator (5°C)	(Deep) freezer (-15°C / -20°C)	After warming
Fresh breast milk	5-10 hours	5 days	12 months	1 hour
Thawed breast milk	1 hour	24 hours		1 hour

Feeding Frequency

The feeding frequency depends on the infant's postmenstrual age (PMA) and birth weight.
For infants with a PMA < 32 weeks and/or < 1750 grams, the feeding schedule typically consists of 12 feedings per 24 hours.

For infants with a PMA ≥ 32 weeks and ≥ 1750 grams, this decreases to 8 feedings per 24 hours.
In other words, the infants are fed about 8 to 12 times every 24 hours (N3 Recommendation, 2024).

In clinical practice, smaller and more immature infants who require 12 feedings per day are often provided with smaller-volume syringefeedings, typically using 20 mL syringes.
In contrast, more mature infants receiving 8 feedings per day generally tolerate larger feeding volumes and are therefore commonly fed using 60 mL syringes.

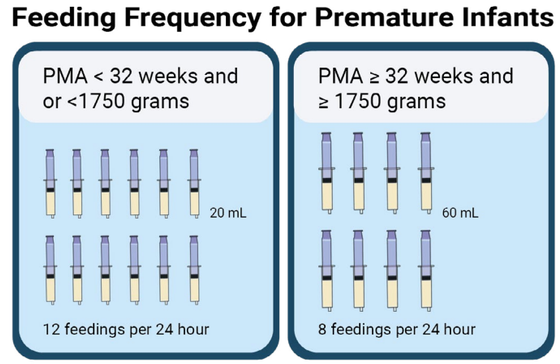


Figure 9: Feeding Frequency for Premature Infants

Hygiene and Contamination

Given the extreme vulnerability of neonatal intensive-care patients, rigorous hygiene and contamination control are absolutely essential. At Erasmus MC's Neonatal Intensive Care Unit, breast milk and donor milk preparations are subject to strict safety protocols. As noted in their nutrition policy document, donor milk is pasteurized and thoroughly screened to prevent disease transmission, reflecting the highest safety standards (Erasmus MC, n.d.-e). It is clear that any mechanical system developed for feeding preparation, such as the Neo robot, must incorporate equivalent hygiene safeguards. Should milk or syringes become contaminated, the consequences can rapidly become life-threatening for these infants.

Criteria:
- The system shall be able to handle 8 to 12 syringes per patient per day.
- The system shall be able to handle 2 different syringe volumes (20 mL and 60 mL).
- Syringes shall be stored in a cooled environment at 3–5 °C.
- No contamination shall occur.

Take-away

- Breast milk remains the optimal form of nutrition for both healthy and premature infants.
However, for preterm babies, additional fortification is often required to meet their specific developmental needs.
- The composition of human breast milk is not constant; therefore, the required amounts of added fortifiers may vary.
- The infants are fed between 8 - 12 times per day.
- The preparation, storage, and delivery of these feeds demand a high degree of precision and hygiene.

3 User Centered Research

This chapter outlines the user-centered research. It analyzes the current NICU feeding workflow, highlights key challenges and opportunities for automation, and presents the future vision for Neo. A stakeholder analysis further clarifies the needs of the primary groups involved.

3.1 Current Workflow Analysis

To understand how Neo can meaningfully support nurses in their daily practice, it is necessary to first examine the existing feeding workflow and identify its primary challenges.

Previous research conducted by four Erasmus University students has described the current workflow at NICU at Erasmus MC in detail, outlining both its strengths and the difficulties it poses for nursing staff. Their work shows that feed preparation is a highly time-consuming activity, sensitive to error, and emotionally demanding due to the vulnerability of the patients and the value of the breast milk itself. At the same time, their findings suggest that automation holds clear potential to ease the workload, improve accuracy, and strengthen safety, provided it is integrated into existing routines and supported by appropriate accountability structures (De Ruiter, 2025; Guetbach, 2025; Van Riel, 2025; Schutter, 2025).

In addition, the Robottler minor group of TU Delft contributed to this body of work by producing a structured overview of the workflow, which illustrates the numerous interdependent steps and the extensive number of checks required shown in Figure 10. The Robottler group was a student project team from a minor programme, and their work provided the initial foundation and inspiration for the development of the Neo machine. Their report emphasizes how repetitive manual handling dominates the process and concludes that automation could relieve part of this burden, allowing nurses to devote more time to clinical care (Hak et al.,2024).

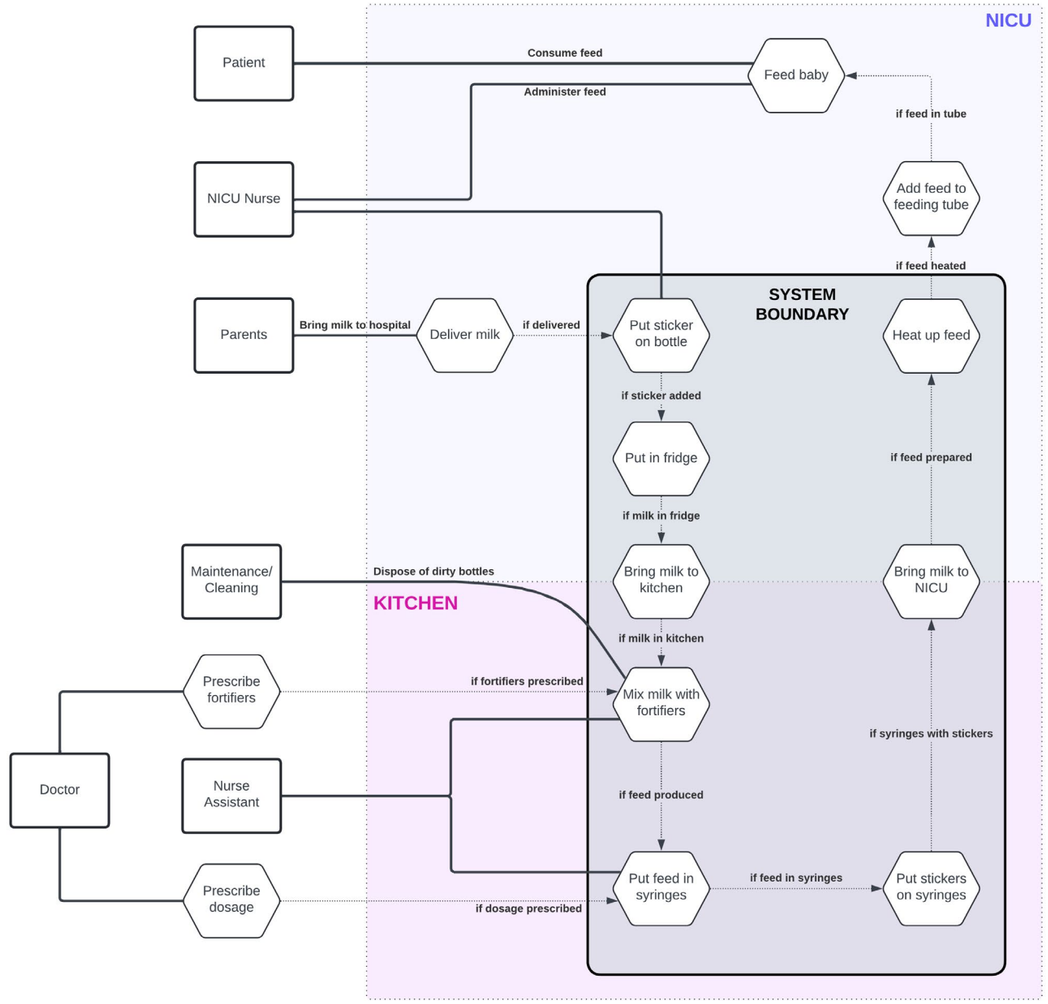


Figure 10: Overview of the current workflow at NICU at Erasmus MC (Hak et al., 2024)

These findings were further supported by direct observations carried out at the NICU of Erasmus MC. During the observations, nurses prepared feeds in pairs, seated opposite each other to allow for continuous double-checking, which they themselves described as essential for safety. This approach ensures correct patient–syringe matching by placing syringes in patient-specific trays, thereby preventing confusion between syringes belonging to different patients.

The observations were unplanned, as they coincided with a meeting with Dr. Tom Ouwehand, neonatologist at the Sophia Children's Hospital, which created an opportunity to witness the process in an ordinary, unscripted setting. During this visit with Dr. Tom Ouwehand to the NICU kitchen, it was observed that the feeding preparation process is highly sensitive to interruptions. The nurses were briefly distracted by our presence, which disrupted their routine and required them to double-check with each other for which infant the feed was being prepared. This moment underlined how dependent the process is on concentration and how easily errors could occur when that focus is interrupted (see Figure 11 for an impression of the kitchen environment).

Figure 11: NICU Kitchen Erasmus MC

The observed workflow consists of several distinct stages: collecting the milk, measuring and adding prescribed fortifiers, mixing the bottles, filling the syringes, collect syringes in trays, and finally distributing the syringes.

According to nurses, the full cycle of collection, preparation, filling, and distribution takes around four hours per day. Approximately two hours are devoted to preparation, which is always carried out by two nurses working together. Figure 12 is an illustration of the observation. This is a simplified version of Figure 10. Here, the emphasis is on preparing breast milk with nutrients, and the period immediately before and after.

This preparation stage represents the area where the Neo robot could make the most significant impact. By automating the filling and dosing processes, the robot would remove one of the most time-consuming elements of the workflow. In practice, this could free up around two hours per day for two nurses, time that could instead be directed toward patient care and bedside attention, an aspect that nurses consistently identify as the most valuable part of their work (Schutter, 2025).

Criteria:
• The machine must store syringes per patient

Take-away

- Two nurses spend approximately two hours per day preparing feeds.
- The preparation of feeds is highly error-sensitive and requires continuous double-checking.
- Nurses consider the repetitive task of filling syringes less meaningful, as they value direct attention and care for patients much more.

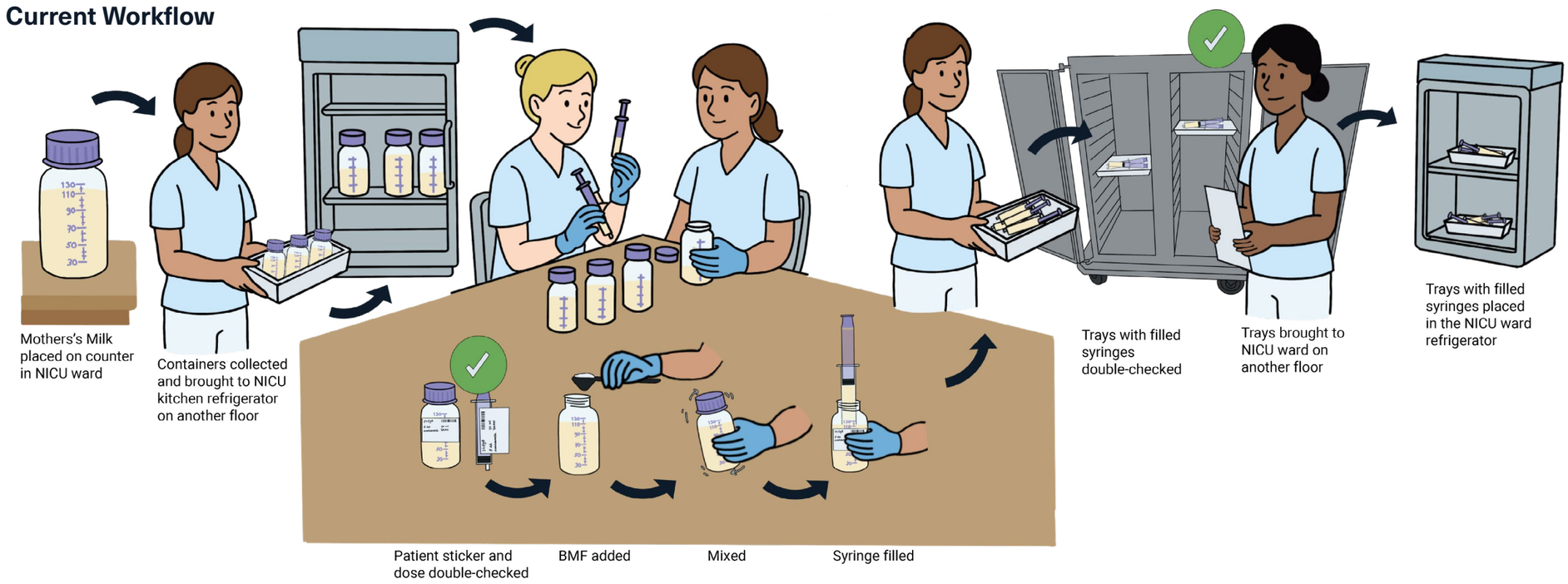


Figure 12: Current workflow in NICU kitchen illustrated

3.2 Future Vision

The long-term vision for the Neo system is that it will take over the repetitive and error-prone aspects of feed preparation. According to discussions with Neollie, the intended use scenario is that the robot will be filled in the morning, activated, and will prepare all syringes within approximately two to three hours. Once ready, nurses can collect the syringes and place them into the NICU ward refrigerators, as illustrated in Figure 13. *(Disclaimer: The Neo shown in the figure is a playful illustration and does not represent the final design of the system).*

At present, the robot is expected to be placed in the hospital kitchen. However, depending on how the Erasmus MC facilities will be organised after the ongoing renovations, it may be considered to place the system in another restricted-access space dedicated to nurses. Determining the exact location of Neo within the hospital is therefore important for its integration in 2032, although it is not expected to fundamentally alter the design as long as sufficient space is available.

Insights from De Ruiter's research further clarify the decision to restrict use of the machine to nursing staff. While parents generally expressed trust in their own ability, they also emphasized a lack of trust in other parents when it comes to using shared equipment. One respondent explained: "I would like to be more involved. I think I could do it, but I wouldn't trust the other parents with it. Just look at how messy the shared coffee machine gets." (De Ruiter, 2025). This perception of trust and responsibility strongly informed Neollie's choice to design Neo as a system operated exclusively by nurses.

Conclusion

The purpose of the robot is threefold: to give nurses more time for direct patient care, to ensure precise and hygienic preparation of feeds, and to reduce the risk of errors.

Take-away

- Parents generally trust themselves but do not trust other parents to use a shared machine.
- Neo is expected to be placed in the Sophia Children's Hospital kitchen by 2032, though it would be beneficial if the design also fits into the current kitchen, in case the system is implemented earlier.

Future Vision Workflow

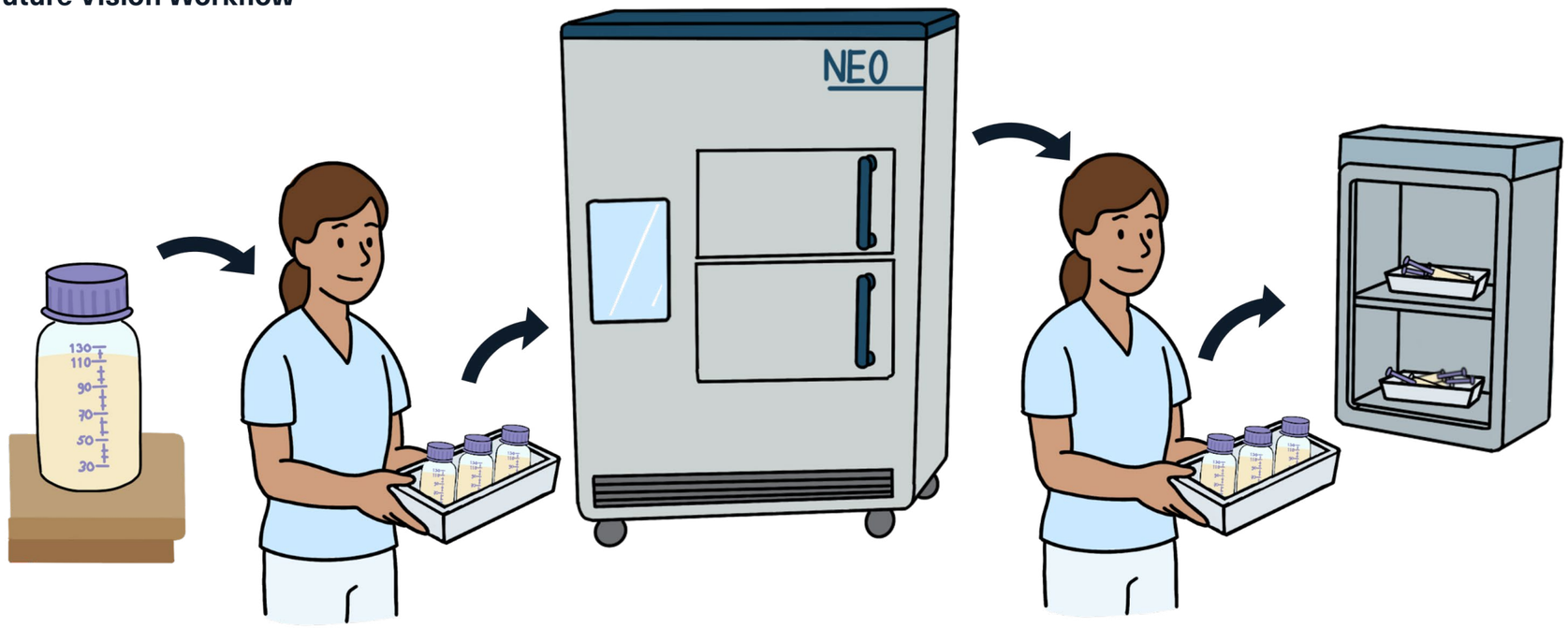
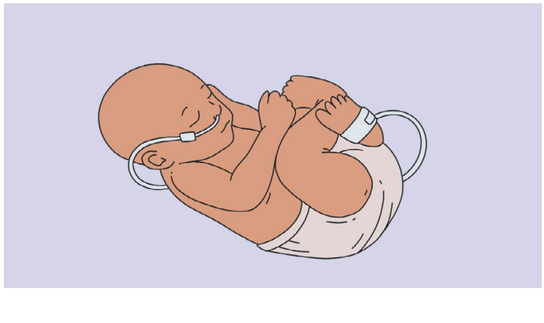


Figure 13: Future vision workflow NICU kitchen

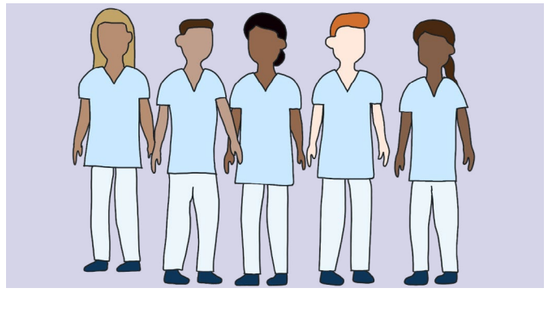
3.3 Stakeholder Analysis

The stakeholders involved in this project can be categorized into three categories. Primary stakeholders are those who are directly affected by or interacting most closely with the robot. Secondary stakeholders engage indirectly with the robot or are indirectly affected by its performance. Tertiary stakeholders do not directly interact but may still influence or set requirements for the robot's design and use. A complete stakeholder map is shown in Figure 14. This stakeholder Analysis was performed by the Robottlers team (Hak et al., 2024). The two most critical stakeholder groups, patients and nurses, are discussed, while all other stakeholders are elaborated in Appendix A.



Patients

The patients, the infants admitted to the NICU, are the ultimate recipients of the feeds prepared by the robot. They are therefore classified as primary stakeholders. Their health and safety are directly dependent on the quality of the feeds, including correct dosage, appropriate mixing of fortifiers, accurate temperature control, and strict avoidance of contamination. In this sense, the robot's effectiveness will have a direct impact on clinical outcomes. From a design perspective, their interest translates into reliability, consistency, and adherence to the highest medical standards during preparation.



Nurses

Nurses at the Sophia Children's Hospital represent the second group of primary stakeholders. They are responsible not only for patient care but also for preparing and administering feeds in the current workflow. By interacting with the robot, nurses play a central role in its day-to-day operation. Their main interest lies in reducing the time and effort required for feed preparation so that more attention can be directed toward patient care. Additionally, they require a system that is intuitive, safe to operate, and seamlessly integrated into their workflow.

Although parents are not classified as primary stakeholders, they remain an important group to consider. Neollie has emphasized that the robot will be operated exclusively by nurses, not by parents. This choice reflects both workflow and safety considerations. Previous research on the NICU feeding process indicates that parents generally place strong trust in nurses to prepare feeds correctly, and they have confidence in their own actions. However, they are less inclined to trust the actions of other parents (De Ruiter, 2025; Guetbach, 2025).

In addition, Neollie's current plan is to locate the robot within the hospital kitchen, an area where parents do not have access. This spatial arrangement reinforces the idea that the robot is part of the professional medical workflow rather than something parents would interact with directly. From a design perspective, it is therefore essential to recognize that parents' needs are primarily indirect. Further details on the secondary and tertiary stakeholders are provided in Appendix A.

Conclusion

The patients and the nurses who prepare the patients food are the two stakeholder groups represent the core focus of the design.
Patients define the ultimate quality requirements, while nurses define the operational and usability requirements.

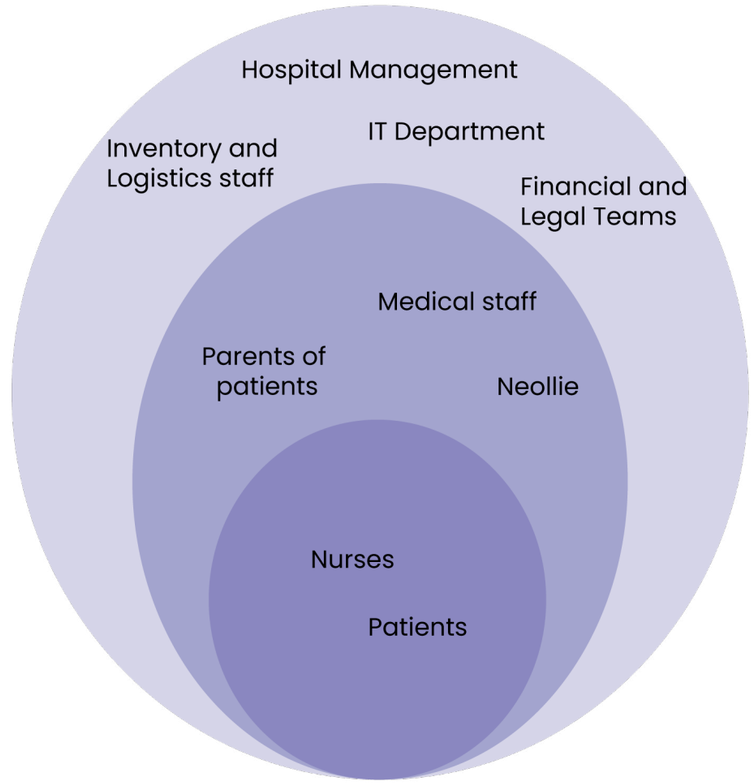


Figure 14: Stakeholder Map

4 Understanding Neo

This chapter provides a technical understanding of the Neo milk-preparation robot by reviewing its first and second prototypes. It explains the system's workflow, inputs and outputs, and the chain of subsystems involved in feed preparation. Through a structured assessment of these subsystems, key design gaps are identified, leading to the selection of the output stage as the primary focus for further development in this project.

4.1 NEO 1

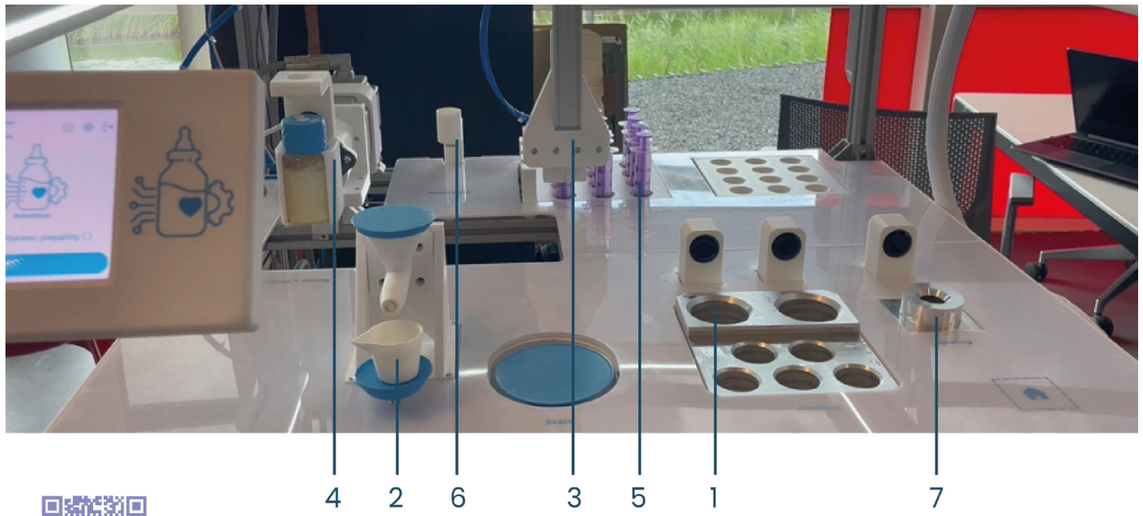
In the domestic domain, devices for preparing infant formula are capable of dosing powder and water, heating liquids to the desired temperature, and delivering consistent volumes with minimal user intervention. These systems demonstrate how automation can reduce manual workload while improving consistency in preparation processes.

However, translating these functionalities to a clinical environment such as a Neonatal Intensive Care Unit (NICU) introduces substantially higher requirements. In contrast to domestic use, NICU feeding preparation involves strict hygienic standards, traceability, precise nutritional dosing, and the handling of patient-specific prescriptions. In addition, the process must be reliable, reproducible, and seamlessly integrated into existing clinical workflows. As a result, a significant technological step is required to move from automated preparation in a home setting to a safe and scalable solution for clinical use.

Neollie aims to address this challenge through the development of the Neo milk-preparation robot. The system builds on advanced technologies such as precise weighing and dosing, controlled mixing, integration of nutritional supplements, temperature-controlled storage, and robotic handling. By combining these technologies into a single system, Neo seeks to automate the complex preparation of feeding in the NICU while maintaining the required standards of safety and reliability.

To explore the feasibility of this approach, Neollie developed an initial technology demonstrator, which serves as the starting point for this project (see Figure 15).

This early prototype validated the basic feasibility of the system: a single container of breast milk could be processed, filled, and prepared into one syringe as output. In doing so, the essential principle of the Neo concept was confirmed, demonstrating the robot's potential for future clinical application. However, the system is still far from a finished product and requires substantial further development before it can be implemented in a hospital setting.



Scan QR-code for a video of Neo 1

Figure 15: Neo 1

The process within the prototype follows a sequential workflow:
1. The milk container is manually placed into the Peltier-cooled storage unit.
2. The fortifier powder is weighed and deposited into a small container, which is then manually poured into the milk container.
3. A robotic arm transfers the container to the mixing system.
4. The mixing system mixes the milk and the added powders.
5. In parallel, the arm collected a syringe and attached it to the container using a custom-designed blue connector cap developed by Neollie. Once attached, the container was inverted so that the milk could flow into the syringe by gravity, aided by a pulling motion.
6. The filled syringe is weighed to verify the correct volume.
7. Finally, the syringe is placed into the heating compartment for manual retrieval.

The current limitations of Neo 1 are evident. While the robotic arm itself is capable of executing multiple tasks sequentially and can support parallel subprocesses, the overall system architecture is not designed to enable truly parallel operation. As a result, the system can handle only one container at a time. In addition, the fortifier powders must still be measured and manually added to the milk container by the nurse. The process is time-consuming and limits workflow efficiency. Furthermore, the user interface is minimal and does not support efficient operation, while the overall prototype is physically wide and open, making it impractical for use in a clinical environment.

The vision for Neo 2 is to move beyond this proof-of-principle and start addressing issues of scalability and workflow integration. Instead of validating only basic functionality, the next version should demonstrate how multiple containers and syringes can be processed simultaneously, how user interaction can be improved, and how the connection between subsystems can be made more reliable and efficient.

Conclusion

To conclude, Neo 1 demonstrated that the essential subsystems of Neo could be connected into a functioning process. Although the prototype was preliminary, it demonstrated that milk could be processed through a sequence of steps, including input, mixing, filling, checking, and cooled storage. This was achieved primarily through the use of a robotic arm, which acted as a link between the different subsystems by physically transferring components from one stage to the next.
For the second prototype, it remains an open question whether this same method of transport will be retained or whether alternative mechanisms will be introduced.

Figure 16: Custom-designed blue connector cap

Take-away

- Custom-fabricated components, such as the connector cap (Step 5 / Figure 16), would require additional regulatory approval before clinical use. As Neollie aims to minimise involvement in complex regulatory processes associated with non-standard medical parts, this should be taken into account as an important design constraint.

4.2 NEO 2

This paragraph reviews the current state of the Neo robot, acknowledging that since the start of this project, further adaptations have already been made to the Neo prototype. It outlines opportunities for continued development from a design perspective. The discussion begins with a general overview of Neo's inputs and outputs, followed by a more detailed consideration of its subsystems.

The Black Box

From an abstract perspective, the Neo robot can be conceptualised as a "black box," into which a diverse set of inputs is introduced and from which controlled outputs are generated. Inputs include BMF powder, LCT powder, formula powder, stickers, breast milk containers with caps, empty containers with caps, 120 syringes of 60 mL, 120 syringes of 20 mL, 120 syringe caps, water, and electricity. The quantity of breast milk provided is calibrated precisely to match the feeding requirements of each infant. Although this volume varies on a case-by-case basis, the machine is capable of processing a maximum of two containers per infant.

These inputs enter Neo's black box, where they are handled through a sequence of subsystems. The system's outputs consist of empty containers and ten trays, each containing twelve syringes filled with either 20 mL or 60 mL, depending on the infant's medical prescription. An overview of this is presented in Figure 17.

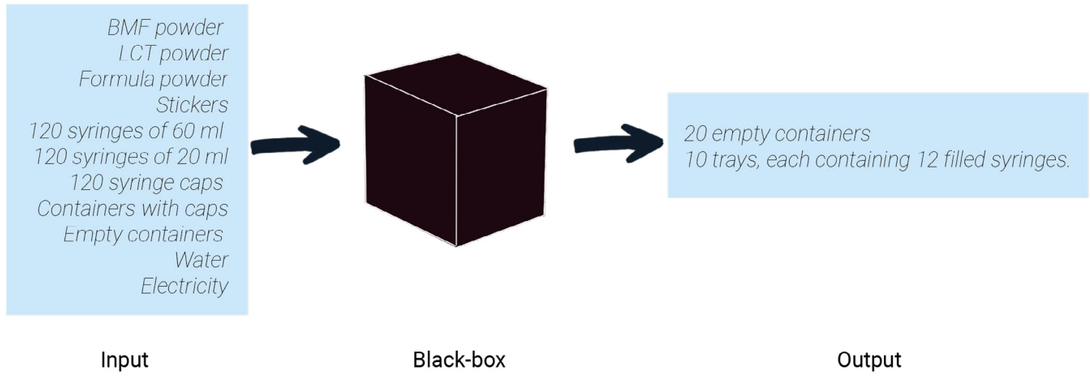


Figure 17: Neo as a 'Black-Box'

Subsystems

Looking inside the black box, the Neo system is organised as a chain of subsystems, each performing a distinct function. Each subsystem receives its own inputs, processes them, and passes on outputs to the next stage. As illustrated in Figure 18, the process begins with the placement of a milk container into a cooled system (1), followed by identification via scanning (2). The cap is removed (3), fortifiers are dosed into the container (4), and the cap is re-attached before the container is mixed (5). Meanwhile, a label is applied to a syringe (6). The syringe is then filled with milk (7), cleaned to prevent cross-contamination (8), oriented correctly due to its off-centered tip (9), capped (10), and weighed for verification (11). Finally, the syringe is placed into cooling storage (12).

Assessment of Subsystems

To identify design gaps, an assessment of Neo's subsystems was conducted using documentation provided by Neollie. Each subsystem has been evaluated according to its current state, using the framework of Technology Readiness Levels (TRLs). In addition, the degree of complexity of the problem, the relevance of the subsystem from both a technical and design perspective, and the suitability of the topic as a graduation project have been considered.

The assessment was subsequently validated in consultation with G. Hak and C. Huijbregts of Neollie.

The full analysis is included in Appendix B. Overall, three directions emerged as most promising for further exploration: the input subsystem, which can be subdivided into two approaches namely the input of the milk containers and the input of the stock; the output subsystem, which could either be linked to input or addressed independently; and the cooling subsystem, which plays a critical role in both input and output. Cooling is relevant at the moment containers are placed into the system, as well as at the final stage when filled syringes are stored. Although this suggests a possible connection between input and output cooling, it is not necessarily the case: the milk container cooling unit could be positioned on one side of the machine, and the syringe cooling on the other, depending on the final system layout.

Re-examining the inputs and outputs (Figure 17) highlights several open questions. These include how to efficiently supply the stock of the large number of syringes required daily (120 in total), how nurses will interact with the machine when placing milk containers, how cooling will be managed throughout the in- and output process, and how the nurses will interact with the large amount of syringes as output.

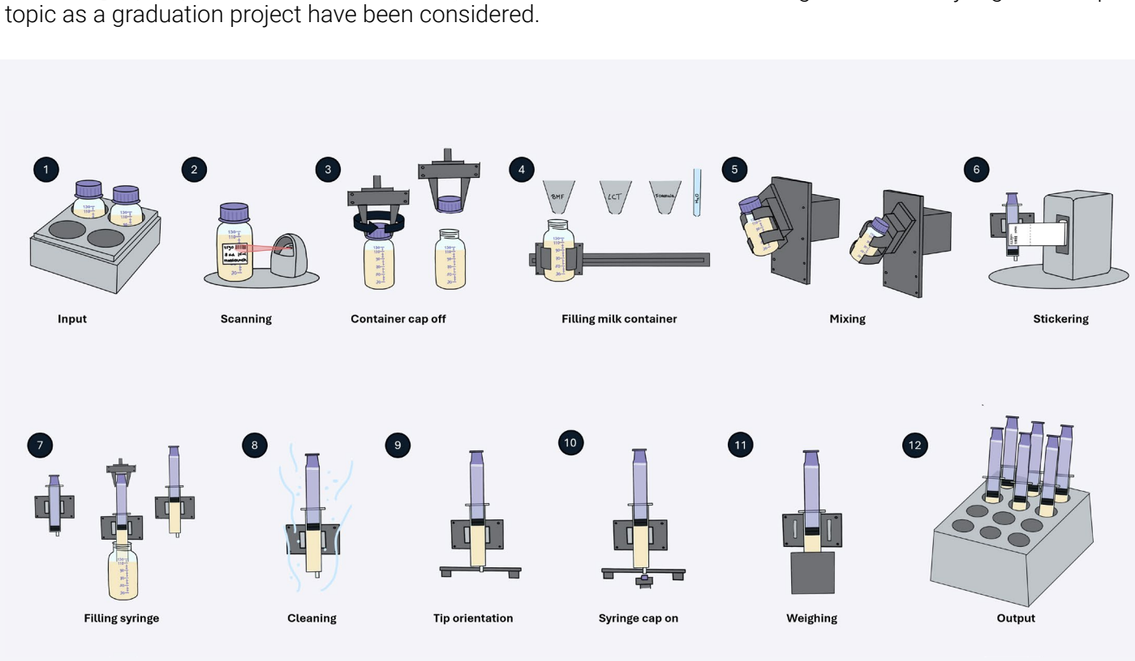


Figure 18: Process Neo Prototype 2

Because infants require different feeding volumes, the system's output consists of syringes in two sizes: 20 mL and 60 mL. Particularly, the larger 60 mL syringes, measuring approximately 25 cm in length when filled, present specific design challenges in terms of handling, storage, and tray organisation. As these syringes are collected directly by nurses, their usability and presentation become key considerations in the design of the output.

Certain aspects, such as the recognition and loading of syringes into the machine as stock, can be approached as mechanical challenges. Research on AI-assisted recognition of medical products (Chen et al., 2012) demonstrates promising solutions that, when combined with robotic arms, could support the positioning of syringes within the system. Similarly, placing containers into the machine does not appear to be the most significant challenge. By contrast, the output stage, particularly the organisation, cooling, and presentation of syringes, emerges as a more complex design problem, and therefore the most relevant focus for this graduation project.

Conclusion

The assessment shows that the greatest design gap lies in the output stage of Neo. While many subsystems have been proven individually, the way in which 120 syringes of varying sizes are cooled, organized, and presented to nurses remains unresolved. This makes the output subsystem not only the most technically and logistically demanding, but also the most meaningful area for design intervention.

Figure 19: Syringe grap position

Key insight

- During the assessment of the subsystems, it became evident that the syringe partially enters the breast milk container. Although the syringe is cleaned after this subsystem, Neollie assumes that residual milk may remain. To prevent cross-contamination, this insight led to the decision that the machine may grasp the syringe at only one designated location: directly below the syringe flange, as shown in Figure 19.

Criteria:
• The machine may grasp the syringe at only one designated location: directly below the syringe flange.

5

Design Scope

This chapter defines the project scope by focusing on the output stage of the Neo system. It presents the central research question, sub-research questions, and a program of criteria's that will guide the further development of the design.

5.1 Design Scope

Scope definition

The starting point of this project is the identified design gap in the output stage of the Neo system. To ensure the project remains feasible within the six-month graduation period, the scope has been clearly defined and delimited.

The scope of this project focuses on the output phase of the Neo robot. In this phase, syringes, once weighed, are kept cool during the waiting period and organised per infant. The cooling function is based on an existing and proven principle. This principle will not be technically developed or physically implemented within this project, but it will be theoretically substantiated and considered in the design decisions. The design must ensure that the output is delivered to nurses in an efficient and user-friendly manner, while fitting seamlessly into the current NICU workflow and meeting the spatial and hygienic requirements of the hospital.

Scope delimination

In consultation with Neollie, it was agreed that the cooling principle will be based on a refrigeration cycle, comparable to that of a conventional refrigerator. This cycle produces a cooled liquid that can be circulated through the system. Although this has not yet been tested, the decision was made to adopt this principle because such systems are available "off the shelf" and therefore do not require additional development or certification.

Previous prototypes employed Peltier elements; however, these proved inefficient at maintaining stable cooling. Peltier systems are generally less effective when higher cooling capacity is required and are therefore uncommon in industrial applications. For these reasons, the assumption for this project is that a refrigeration-cycle-based system will be used.

This assumption allows the project to focus on the human interaction and design aspects of the output stage. Nevertheless, practical considerations such as the circulation of cooled liquid through tubing are acknowledged to ensure that the design remains realistic for future clinical implementation.

Research Question

How can the output stage of the Neo system be designed to deliver cooled and well-organized syringes to nurses in a way that is safe, efficient, and seamlessly integrated into the workflow of the NICU environment?

Research Sub-Question

Cooling

Which existing cooling principle is most suitable to keep syringes at a stable temperature during the waiting period, and how should these principles be considered in the design?

Organization

How can syringes be grouped and presented so that each infant's feedings are clearly separated and mix-ups are prevented?

User interaction

How can the output stage be aligned with the daily nursing workflow in the NICU, ensuring that trays fit existing storage solutions and enable a safe and user-friendly hand-over to nurses?

Constraints

What spatial, hygienic, and regulatory requirements must the output design meet in order to be implemented in the NICU of Erasmus MC?

5.2 Program of Requirements

Before the design process could begin, a comprehensive list of design requirements was established. Part of these requirements had already been defined by Neollie. The MoSCoW method was used to structure them, distinguishing between Must, Should, Could, and Won't have criteria. To achieve a successful design outcome, all Must requirements must be fulfilled. Should requirements are important and should be addressed when feasible, while Could requirements are considered desirable but not essential. The Won't have criteria fall outside the current project scope; they may become relevant in future development stages, but are intentionally excluded from this iteration of the design.

As the design process is inherently non-linear, additional requirements and wishes emerged throughout the project. These were identified following user testing, observations, and the development of a deeper understanding of how the final prototype should look and function. The overview of requirements therefore reflects both initially defined criteria and insights gained during the iterative design process.

In addition, Neo must comply with specific hospital regulations in order to be implemented within Erasmus MC. These include spatial, hygienic, and operational requirements set by the hospital itself. Furthermore, several user-related needs and preferences were derived from previous research from the four thesis reports conducted by Erasmus University students, and were validated through discussions with NICU nurses.

In summary, only the requirements and wishes directly relevant to the defined project scope have been included in this design phase.

Must Have Criteria

#	Requirement	How/Why
M1	Be able to handle up to 10 patients.	The NICU department will have 10 patients.
M2	Be able to handle 8 to 12 syringes per patient.	Feeding takes place (at most) 12 times per day. 8 times 60 mL or 12 times 20 mL.
M3	Be able to handle 2 different syringe volumes. (20 ml and 60 ml)	Nutritional requirements vary from patient to patient.
M4	Syringes must be physically separated per patient.	To prevent mix-ups and ensure patient safety.
M5	The output must clearly indicate for which infant each group of syringes is intended.	To prevent identification errors.
M6	Syringes must be stored in a cooled environment between 4–6 °C.	To comply with breast milk storage requirements
M7	The system must continuously monitor and report internal temperature.	To detect deviations and ensure safe storage conditions.
M8	The system must be compatible with the currently used white trays and trolley.	To ensure seamless workflow integration.
M9	Robotic movements and mechanical parts must be physically shielded during operation.	To prevent accidental contact.
M10	The access door must remain locked during active operation.	To prevent interference and maintain cooling stability. And to prevent accidents.
M11	All milk-contact-related components must be cleanable within 24 hours.	In accordance with hospital hygiene regulations.
M12	Surfaces must withstand cleaning with water and alcohol-based disinfectants.	In accordance with hospital hygiene regulations.
M13	The system must be operable while wearing medical gloves.	To integrate into NICU hygiene practices.
M14	The system must report operational status and fault conditions clearly.	To prevent unnoticed errors.
M15	The robotic handling system must minimise physical contact with the syringe and, if contact is required, it may only occur on predefined non-critical areas that do not come into contact with milk.	To prevent contamination risks and ensure hygienic integrity of the feeding process.
M16	Critical components must be modular and replaceable without full system disassembly.	To minimise downtime and support repairability.
M17	Materials must be moisture-resistant and corrosion-resistant.	Due to condensation in cooled environments.
M18	The system must fit within the maximum allocated hospital dimensions (2500 × 1500 × 2000 mm for total machine).	Then it will always fit throughout the entire hospital. These are the max volumes for the total robot so the design of the output module must be smaller.
M19	Controlled user access must be implemented.	To ensure traceability and prevent unauthorized use.

Should Have Criteria

#	Requirement	How/Why
S1	The output module should be positioned at an ergonomically validated height	To prevent injuries in the long term
S2	Trays should be easily graspable and removable without force.	To reduce workload and handling errors.
S3	The system should align with existing NICU workflow routines.	To prevent disruption and resistance to adoption.

Could Have Criteria

#	Requirement	How/Why
C1	The system could allow flexible batch timing	For more adjustment options and upscaling possibilities

Won´t Have Criteria

#	Requirement	How/Why
W1	Heat up the feed to a variable temperature.	Is done by device next to the infants incubator
W2	Be operatable by untrained user, such as parents	For safety reasons not desired
W3	Have a self-cleaning function.	Too complex for this graduation project but a good future criteria.

6 Concept Creation

This chapter translates the defined design scope into concrete concept directions for the Neo output subsystem. Starting from a system level perspective, the complete syringe journey is analysed to ensure alignment between mechanical functionality and nursing workflow. Based on technical analysis, stakeholder input, co-creation, interviews, and structured ideation methods, solution principles are generated and evaluated.

6.1 Product Journey

In order to create a meaningful concept, it is essential not only to zoom in on specific details but also to zoom out and understand the system as a whole. The design process therefore begins with a broader perspective, examining the product journey, in this case, the syringe, as it moves through the Neo system.

This overview, shown in Figure 20, helps to re-establish a clear understanding of the context before focusing again on the individual components and their respective design requirements.

In this process, both the technical and human-experience dimensions must be considered. Balancing these two perspectives, mechanical functionality and user interaction, is central to achieving a design that serves the needs of both the machine and the nursing staff. This intersection of technology and human experience forms one of the most compelling aspects of this project.

The final step within Neo's 'black box' is the weighing of the filled syringe. This moment marks the starting point for the design phase of this graduation project. From there, several key questions arise: how can the syringe be transferred or positioned within the cooling system? How should the cooling system open and operate? And how can its design not only fit the mechanical constraints but also align with the nursing workflow?

Ultimately, the prepared syringes are collected by nurses, placed into a cooled trolley, and transported to the NICU ward. Understanding this complete flow, from weighing to placement in the NICU fridge, ensures that the final concept integrates seamlessly into both the mechanical system and the hospital environment.

Now that the overall system has been explored from a broader perspective, the focus can shift back to the details. By zooming in on the sub-research questions, the next phase aims to translate this understanding into concrete design directions.

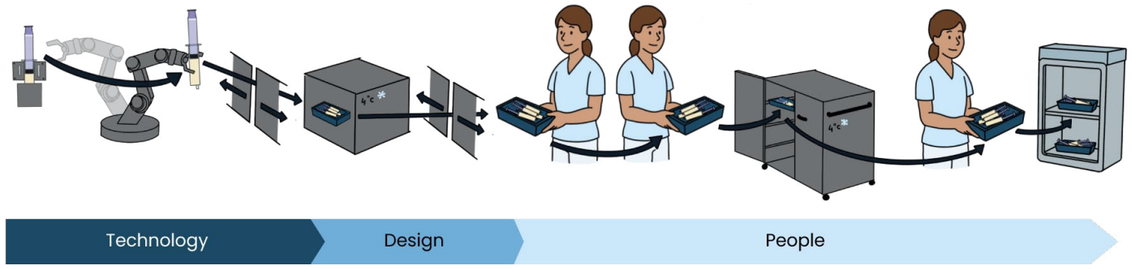


Figure 20: Product Journey Syringe

6.2 Exploration of the Sub-research questions

There are several possible approaches to achieving cooling within a system or environment. The project scope has been defined around the use of a refrigeration cycle system instead. This type of system has not yet been tested within Neo, but the decision to adopt it as a baseline has already been made.

Cooling System Analysis

In the book Fysische Transportverschijnselen: Denken in balansen by van den Akker and Mudde (2023), the refrigeration cycle system is explained in a simplified and conceptual manner.

A refrigerator functions through a vapor-compression refrigeration cycle, in which a refrigerant continuously circulates and changes state to transfer heat. The compressor compresses the refrigerant gas, raising its temperature and pressure. This hot gas moves through the condenser coils, usually copper tubing with aluminium fins, where it releases heat to the surrounding air and condenses into a liquid.

The high-pressure liquid then passes through an expansion valve or capillary tube, where the sudden drop in pressure causes cooling. The refrigerant, now a cold mixture, enters the evaporator, a coil system inside the refrigerator made of copper or aluminium. There, it absorbs heat from the air inside, evaporates back into a gas, and cools the interior. The gas then returns to the compressor, repeating the cycle.
Applying this system within the Neo design requires consideration of several practical and spatial factors.

Cooling

Which existing cooling principle is most suitable to keep syringes at a stable temperature during the waiting period, and how should these principles be considered in the design?

The refrigeration cycle relies on a network of tubes through which the refrigerant circulates. In this design, these pipes, would be integrated into the walls of the cooling compartment. The broader refrigeration unit, including the compressor and condenser, remains outside the project scope and is assumed to function as a prefabricated, closed system (Figure 21). However, the spatial arrangement of these components must also be taken into account. The way in which this system is implemented in the final design is explained in Chapter 6, Embodiment Design.

Criteria:
• Refrigerant tubing must be integrated into the walls of the cooling compartment.

Key Take-away

● The cooling subsystem imposes direct spatial constraints on the compartment design.

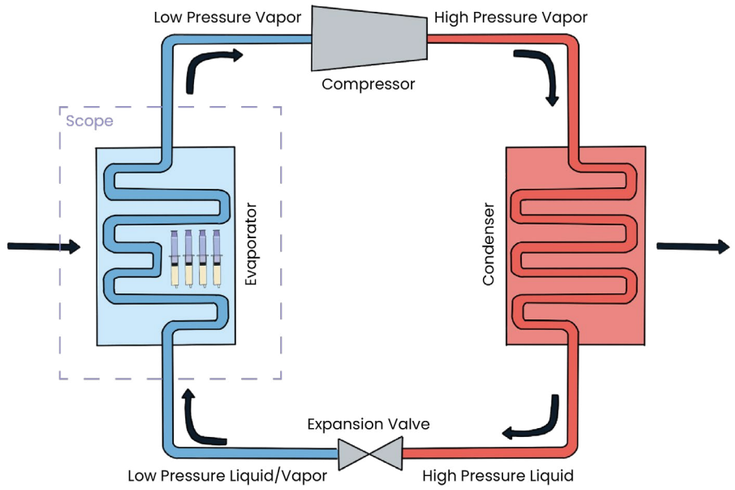


Figure 21: Refrigeration Cycle System - Scope

Co-creation Session

To explore potential design directions for the Neo output system, a co-creation session was organised with the aim of generating a broad range of ideas within a short period of time. The session was intended to provide fresh insights and explore diverse perspectives to inform early-stage concept development.

The session took place at the Living Lab of Erasmus MC and involved three Master's students from the Integrated Product Design programme. All participants had prior experience working on projects within Erasmus MC and were therefore familiar with the hospital context, although none were clinical professionals. A structured session plan was developed and facilitated to guide the workshop, while allowing active participation of the designer. A detailed description of the setup and method can be found in Appendix C.

During the session, participants engaged in a series of creative exercises focused on user interaction, workflow integration, and practical usability. The outcomes resulted in multiple preliminary concept clusters that supported early-stage ideation (see Appendix C for a complete overview of the generated ideas and visual material).

A limitation of this session is the absence of healthcare professionals, which may have reduced the practical applicability of some ideas. This became evident in later stages of the project, where interviews revealed that current clinical practice relies on standard white trays. This insight ultimately guided the layout decisions in the final design. The integration into the clinical workflow is further discussed in the following section.

Organization

How can syringes be grouped and presented so that each infant's feedings are clearly separated and mix-ups are prevented?

Figure 22: Co-creation session Ideation

Key Take-away

● Concept exploration confirmed the importance of workflow-compatible output organisation.

Figure 23: Co-creation session Clustering

Interview

To gain a deeper understanding of the current feeding workflow, an exploratory interview was conducted with two NICU nurses at Erasmus MC. Both participants were responsible for preparing infant feeds and were interviewed during their routine work in the NICU kitchen. Conducting the interview in this context allowed for direct observation of the workflow and provided insights into practical challenges and daily practices.

The interview was qualitative and exploratory in nature, aiming to gather initial insights into the preparation process, workflow integration, and requirements for the Neo output system. A semi-structured approach was used, allowing flexibility to follow up on observations and spontaneous events during the session.

The key insights derived from this interview are: At Erasmus MC, nurses use standardised white trays to organise and transport filled syringes. These trays fit within existing trolleys and refrigerators and are fully integrated into the current workflow. As this practice was consistently observed and confirmed, the trays were taken as a fixed starting point in the design.

Figure 24: White plastic tray with 20 mL syringes

Figure 25: Tray fits perfectly in trolley

User interaction

How can the output stage be aligned with the daily nursing workflow in the NICU, ensuring that trays fit existing storage solutions and enable a safe and user-friendly hand-over to nurses?

Hygiene is of utmost importance, and cross-contamination must be strictly avoided. Existing cleaning protocols, such as daily cleaning of refrigerators and cleaning trays after each use, must be maintained.

Nurses expressed concern about having to continuously monitor the machine. The system should therefore support autonomy and reduce workload, rather than increase it.

A verification mechanism is preferred, as nurses currently check each other's work. A similar function should be incorporated into the system.

Large syringes (60 mL) are used infrequently (approximately six to eight times per day) and could remain a manual task if needed.

This interview involved two nurses, reflecting the standard working situation in which feeds are prepared in pairs. As the study was qualitative and exploratory, the findings provide indicative insights rather than statistically representative conclusions.

A limitation of this study is the small sample size and the lack of variation in participants (e.g., experience levels or different shifts). Therefore, results should be interpreted as exploratory. A detailed overview of the interview, including notes and observations, is provided in Appendix D.

Criteria:
- The output subsystem must accommodate standardised white NICU trays.
- The design must support strict hygiene and frequent cleaning.

Key Take-away

- Nurses use these white trays and report being satisfied with them, as they do not rust, fit appropriately in the trolley, and in the NICU refrigeration units.

Technical Consultation

Understanding Neollie's current perspective on the composition and interaction of Neo's subsystems is essential to ensure that the design aligns with the company's overall development strategy. For this reason, a technical consultation was conducted with G. Hak from Neollie.

During the interview with the nurses in the NICU kitchen, it became clear that the availability of breast milk varies considerably. When insufficient milk is available, nurses label the syringes and place them in trays, but leave them unfilled until later. In contrast, Neollie has decided that, within the automated system, syringes should not be prepared at all when there is not enough milk supplied for a specific infant. In such cases, the system will issue a notification. Likewise, excessive milk input is undesirable, as the goal is to minimise waste and ensure that only the prescribed amount of milk is used for each patient. These considerations primarily affect the front-end logic of the system and therefore fall outside the scope of this design project.

From a mechanical standpoint, Neollie expressed a preference for Cartesian robotic arms, which they currently employ in development. These arms are more compact, space-efficient, and easier to program compared to articulated robotic arms with six degrees of freedom. Although the latter could technically be used, the company prioritises simplicity, maintainability, and reliability.

Criteria:
- The robotic system shall utilize a Cartesian robotic arm architecture.
- The number of electrical motors shall be minimized, with pneumatic actuation preferred where feasible.
- All robotic movements and mechanical components shall be physically shielded to prevent human interaction during operation.

Constraints

What spatial, hygienic, and regulatory requirements must the output design meet in order to be implemented in the NICU of Erasmus MC?

In addition, Neollie aims to reduce the number of electrical motors wherever possible, favouring pneumatic actuation for specific movements. More generally, simplicity is preferred in the system design, as reducing the number of components is expected to improve reliability, maintainability, and robustness. At the same time, a balance must be maintained between simplicity and functional performance. At this stage, there is no finalised system layout or spatial overview of how the subsystems will be positioned within Neo. However, it was emphasised that the output subsystem is considered a high-priority component, meaning that its spatial and functional requirements may take precedence over other modules.

Finally, as a safety requirement, all robotic movements and mechanical parts must be physically shielded to prevent human interaction during operation. This is a standard condition in robotic system design and an important consideration for any design proposals involving user interaction.

Key Take-away

- Neollie prioritises compact, space-efficient, and easily programmable robotic solutions.
- Simplicity, maintainability, and reliability are key considerations in the selection of robotic architectures and actuation methods.
- The output subsystem is considered a critical component within the overall system architecture, meaning that its spatial and functional requirements may take precedence over other subsystems.

6.3 Ideation overview

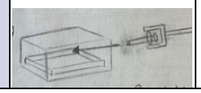
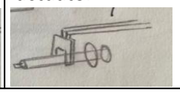
A key starting point in the ideation phase was the integration of the Neo output subsystem into the existing workflow of the NICU feeding kitchen. In order to ensure that the introduction of the Neo machine would not require additional organisational changes, the design was aligned as closely as possible with current nursing practices. This approach increases the likelihood of acceptance and lowers the threshold for implementation within the hospital environment.

Based on the workflow insights described in the previous section, all output concepts were developed around the use of the existing tray system currently applied in the NICU. This served as a fixed boundary condition throughout the ideation process.

This decision had direct implications for subsequent concept development, as ideas that depended on alternative logistical solutions, created in the cocreation session, were excluded early on. Instead, the ideation phase focused on exploring different ways of organising and accessing trays within a cooled compartment, while ensuring reliable syringe placement.

To systematically explore the solution space for the Neo output subsystem, a morphological overview was constructed. This method supported structured ideation by decomposing the subsystem into key functional elements and listing alternative solutions for each element. This overview formed the basis for three main concept directions: TopFill, CircuLade, and SlideGate. These concepts represent different strategies for automated syringe delivery within the defined physical constraints.

Table 2: Morphological Overview

SUB FUNCTION	SOLUTIONS	1	2	3	4	5
	Drop-off point	A fixed position	Various locations			
	Dropping mechanism	Slide	Dropping			
	Front Closure	Valve	Shutter up	Shutter down	Shutter to the side	Door(s)
	Closing of the cooling system	Horizontal slider	Valves that open upwards	Valves that open downwards	Rubber flaps	
	Movement mechanism	Rails	Linear Actuator	Gears	Belt mechanism	Spindle mechanism
	Syringe tilt mechanism	Fixed horizontal 	Pneumatic tilt actuator 			

6.4 Concept directions

This section provides a brief introduction to the three most promising concepts: TopFill, CircuLade, and SlideGate. Each concept is discussed concisely, while a more detailed explanation, including design iterations as well as their respective advantages and disadvantages, can be found in Appendix E.

TopFill Principle

The TopFill concept is based on a straightforward linear layout in which trays are positioned inside a cooled compartment and syringes are delivered vertically from above.
The main advantage of this approach is its simplicity: trays remain in fixed positions while a robotic mechanism releases syringes into the correct location. Only a limited opening is required during filling, which reduces cold air loss.

However, early evaluation revealed that a fully horizontal arrangement of many trays results in an impractically wide system. Since the trays have a width of approximately 18 cm, placing ten trays side-by-side would require nearly two metres of internal width. This is not ideal for usability and ergonomics within the constrained NICU kitchen environment. Therefore, further iterations focused on dividing trays across two drawer levels in order to reduce overall width while maintaining accessibility.

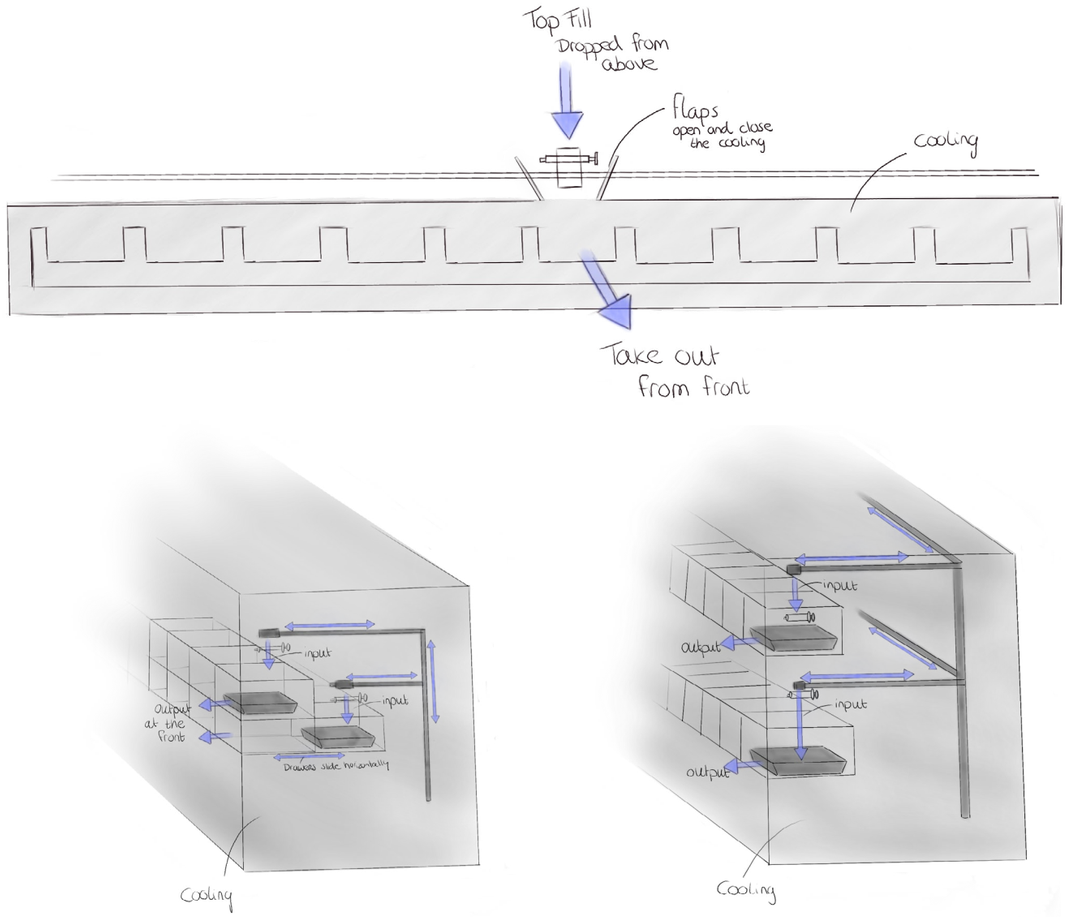


Figure 26: TopFill Ideation

CircuLade Principle

The CircuLade concept explored a rotating carousel configuration in which trays are positioned along a circular path. Through rotation, one tray at a time is brought underneath a fixed syringe drop-off point. This concept offered a compact organisational principle and a clear separation between filling and retrieval positions.

Nevertheless, the carousel approach introduced substantial mechanical complexity. Rotating components require accurate positioning, locking mechanisms, and additional actuation, while also increasing challenges related to cleaning and maintenance. Furthermore, trays could only be accessed sequentially, reducing efficiency and limiting user overview. As a result, CircuLade was considered less suitable for further development within the NICU context.

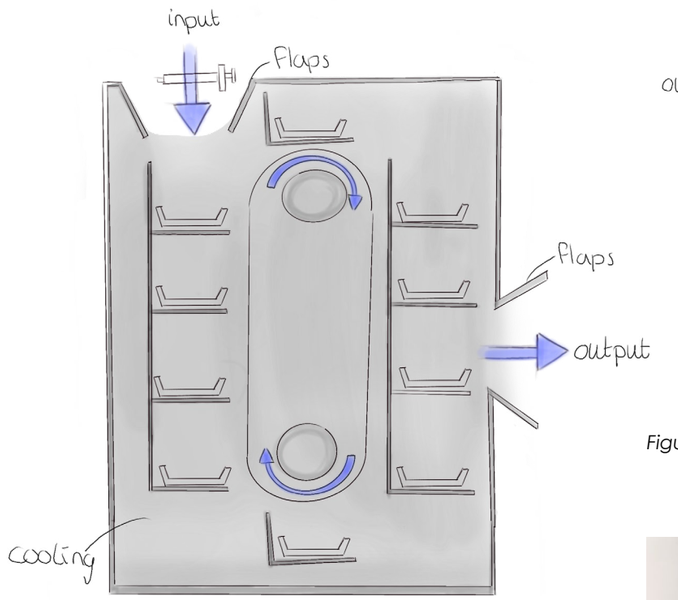


Figure 27: CircuLade Ideation

SlideGate Principle

The SlideGate concept aimed to avoid active syringe tilting by guiding syringes into the tray via a sloped path. In theory, this would simplify the dropping mechanism by using gravity rather than robotic rotation.

Physical testing, however, demonstrated that syringe geometry strongly affects reliability. Syringes frequently jammed within the guiding path and did not consistently settle into the correct final position. In addition, the guiding surface would come into contact with parts of the syringe that may have been exposed to breast milk, introducing hygienic concerns and increasing the required cleaning frequency. Due to its low robustness and contamination risk, SlideGate was excluded from further development.

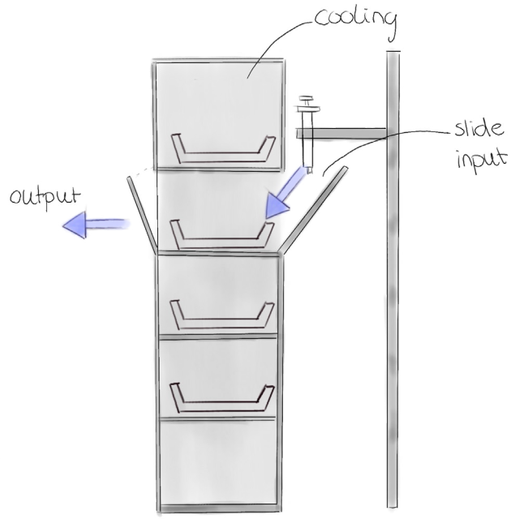


Figure 28: SlideGate Ideation

Figure 29: SlideGate lo-fi testing

6.5 Iteration and Concept Selection

Following the initial ideation phase, the different concept directions were evaluated by systematically comparing their advantages and disadvantages (see Appendix E). This comparison showed that while the TopFill concept offered a clear and mechanically simple starting point, it also revealed several limitations, which motivated further iteration.

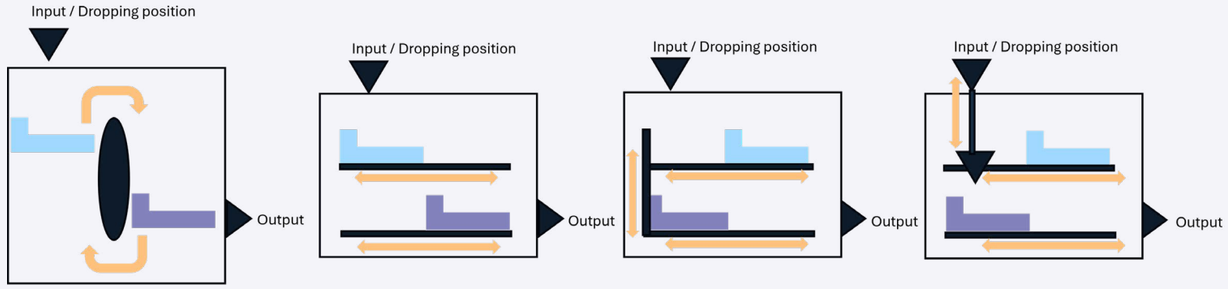
In contrast, the SlideGate concept was discarded at an early stage, as physical testing demonstrated unreliable syringe behaviour, including frequent jamming and increased risk of contamination.

The CircuLade concept initially appeared promising; however, its early configuration lacked efficient accessibility and overview, which required further iteration.

Based on these insights, an iteration phase was conducted in which the most promising principles were further developed into four distinct variants: CircuLade, DualSlide, LiftSlide, and DualDrop. These variants explored different distributions of movement between the drawer system and the dropping mechanism, with the aim of improving placement control, reducing mechanical complexity, and enhancing usability.

To assess the technical feasibility of these variants within Neo's modular system architecture, dedicated consultation sessions were held with engineers from Neollie (G. Hak, K. Sperczynski, and G. Tertelici). During these sessions, the concepts were critically evaluated with respect to robustness, integration, and manufacturability. In parallel, a weighted trade-off analysis was conducted to compare the concepts across key criteria such as reliability, cleanability, complexity, and spatial efficiency (Appendix E).

The combination of iterative development, expert evaluation, and structured comparison provided a comprehensive basis for decision-making. Based on these outcomes, the DualDrop concept was selected for further embodiment development. This concept achieves a balanced distribution of movement by combining horizontally accessible drawers with a vertically movable dropping mechanism. As a result, it enables controlled syringe placement with minimal drop height, while maintaining system simplicity and compatibility with the existing workflow.



1 CircuLade

Two rotating drawers move to a fixed dropping position. Compared to the other concepts, the mechanism is relatively complex and introduces a larger amount of unused internal space. The concept offers no distinct functional advantages while increasing mechanical effort and spatial inefficiency.

2 DualSlide

Two horizontally sliding drawers combined with a fixed dropping position. The drawers can be easily removed for cleaning and the mechanism is relatively simple. However, syringes are always dropped from the same height; for the lower drawer this results in a larger drop distance, reducing placement reliability.

3 LiftSlide

Two horizontally sliding drawers that additionally move vertically to reach a fixed dropping position. While this configuration maintains a consistent drop height, it requires lifting the entire drawer, causing unwanted air movement and potential cold air loss. The transition from horizontal to vertical motion increases mechanical complexity and complicates cleaning.

4 DualDrop

Two horizontally sliding drawers combined with a vertically movable dropping mechanism. Syringes can be placed from a controlled minimal height, improving reliability and precision. Drawer actuation remains mechanically simple and trays can be removed for cleaning. The trade-off is the increased technical complexity within the dropping mechanism.

Figure 30: Iterations

7

Prototypes & User tests

Throughout the project, multiple prototypes were developed for different subsystems. These prototypes were tested and evaluated through user tests and interviews. The findings from these evaluations guided further refinement of the design and supported informed design choices.

7.1 Prototyping Approach

Within this project, prototyping is employed to evaluate the DualDrop concept in a physical context. By materialising the design, insight is gained into scale, proportions, and spatial integration within the Neo machine. This enables an assessment of design decisions in terms of practical feasibility, including movement ranges, accessibility, and the spatial coordination between components.

In addition, prototyping supports the validation of assumptions related to use and interaction. A physical prototype allows nurses to experience key actions, such as inserting and removing trays, rather than imagining them based on drawings or renderings. This hands-on interaction results in more concrete and actionable feedback, grounded in actual use rather than abstract interpretation.

Finally, the prototype functions as a communication tool within the multidisciplinary collaboration between the designer and Neollie. It provides a shared reference point for the designer and engineers, facilitating discussion, alignment, and iterative refinement of the concept based on test outcomes and user feedback.

To address both technical performance and user-centred considerations within the design process, three complementary prototypes were developed. Each prototype focused on a distinct aspect of the DualDrop concept, enabling targeted evaluation, testing, and refinement. Figure 31 provides an overview of these prototypes.

Prototype A:
Focused on the output interaction zone, with emphasis on ergonomics, accessibility, and workflow alignment. It allowed evaluation of how nurses insert and remove trays within the existing NICU context.

Prototype B:
Addressed the dropping mechanism, enabling testing of positioning accuracy, release behaviour, and the interaction between the X–Y mechanism and the drawers.

Prototype C:
Focused on user interaction and operational safety through a display-based test. This prototype evaluated whether nurses could independently and safely operate the machine, initiate the process, interpret status information, and recognize and respond appropriately to warnings and error messages. The aim was to assess clarity of the interface and the system's support for safe, autonomous use.

Together, these prototypes ensured that mechanical performance, workflow integration, and safe user interaction were developed and validated in parallel throughout the design process.

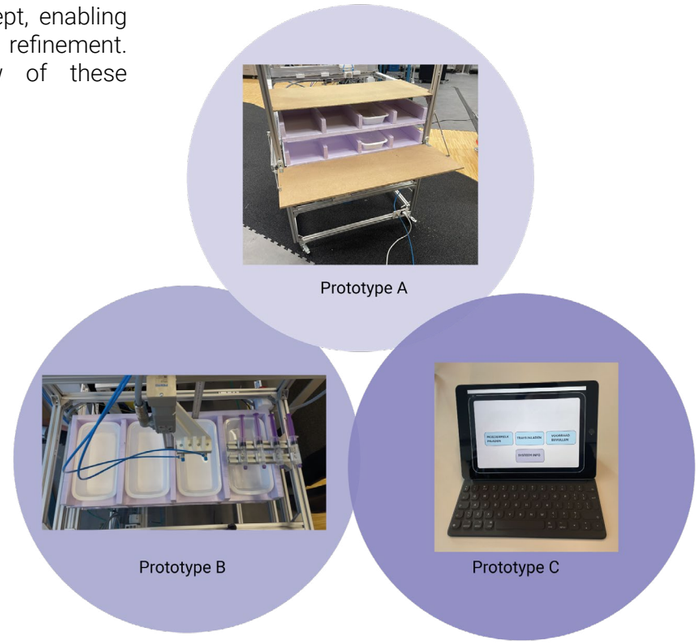


Figure 31: Prototype overview

7.2 Prototype A & User test

Protoype A

The first components to be prototyped were the drawers, which were produced in foam to enable low-fidelity prototyping and to quickly establish an understanding of the physical dimensions of the concept (Figure 32A). In this model, the drawer walls were designed to extend only slightly above the trays, in order to keep the configuration as compact as possible.

As shown in Figure 32B, the foam prototype initially extended beyond the existing frame currently used by Neollie. To ensure compatibility with this frame, one tray position per drawer was removed. As a result, the prototype now features a layout of two drawers with four trays each instead of 5 trays each. This adjustment was made deliberately to allow the prototype to fit within the available frame, enabling meaningful user testing and demonstration of the subsystem's functionality. The drawers are mounted on sliding rails similar to those used in standard drawer systems, allowing both drawers to be moved manually forwards and backwards.

Figure 32C illustrates the mechanical interface that holds the syringes and releases them at the correct position in the appropriate tray. In this prototype, the arm is able to hold and drop the syringe, moving only in the horizontal direction. This allows User Test A to provide a realistic representation of the interaction between the dropping mechanism and the drawer layout, although the system does not yet function fully as originally intended.

In addition, the enclosure of the subsystem (Figure 32D) was prototyped to clearly communicate the scope of the design during user testing. This boundary helps users understand which part of the system is under evaluation and allows for testing of how the enclosure is opened and accessed by the user. A forward-opening hinged flap was selected for the front interface, as it is intended to function as a work surface; this design choice will be evaluated during user testing.

Figure 32 A: Foam Drawers

Figure 32 B: Foam Drawers in Neo frame

Figure 32 C: Mechanism that holds syringe

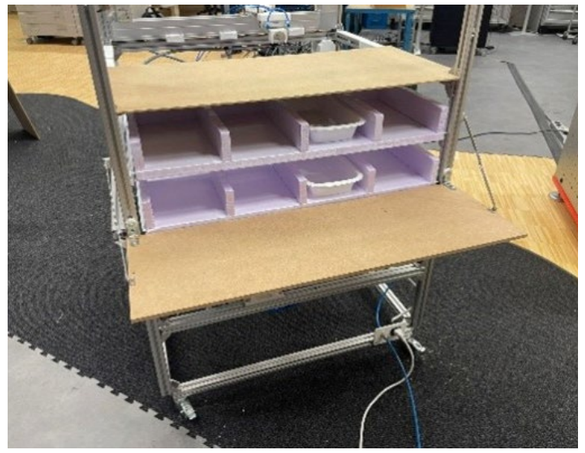


Figure 32 D: Enclosure

Evaluation Study Prototype A

This paragraph presents the evaluation study conducted with Prototype A of the DualDrop output module. The aim of this study was to obtain qualitative insights into user interaction, workflow alignment, and perceived safety and trust, rather than to quantitatively validate system performance. The prototype enabled nurses to physically interact with the system, allowing assumptions made during the design phase to be discussed and reflected upon in a realistic context.

Objective

The primary objective of this evaluation study was to assess how well the DualDrop output concept aligns with the daily nursing workflow in the NICU kitchen, and to what extent it supports a safe, intuitive, and trustworthy handover of prepared syringes. In particular, the study aimed to explore:

- How nurses interact with the output module in relation to existing tools such as trolleys and trays;
- How safety, control, and trust are perceived during use;
- How cleaning routines, logistics, and exceptional scenarios fit within current practices;
- Whether the design choices support Research Question 3, or require refinement.

Rather than functioning as a formal usability test, this study combined guided workflow walkthroughs, observation, and semi-structured interviews, and is therefore referred to as an evaluation study.

Research question

How can the output stage be aligned with the daily nursing workflow in the NICU, ensuring that trays fit existing storage solutions and enable a safe and user-friendly handover to nurses?

Method

A qualitative evaluation study was conducted with two NICU kitchen nurses at Erasmus MC. Both participants are directly involved in the preparation of infant feeds and represent the primary user group of the system. The study took place in the NICU during their regular workflow.

A semi-structured approach was applied, combining a guided workflow walkthrough, hands-on interaction with the prototype, and concurrent discussion. Due to time constraints, participants performed tasks while verbalising their thoughts, allowing observations and reflections to be collected simultaneously.

Data collection focused on qualitative insights, including observations, user feedback, and reflections on usability, workflow integration, and perceived safety. A detailed description of the method, tools, interview questions, and discussion is provided in Appendix F.

Key-findings

Table 3 summarizes the key findings, the corresponding design criteria, and the resulting design decisions carried forward into the embodiment phase.

Limitations

The evaluation involved two participants, limited by the availability of NICU nurses during the testing moment. As a result, the sample size was small and did not include variation in participant characteristics such as experience level or shift type.

In addition, the study was conducted using a functional prototype rather than a fully operational system. Certain aspects of the workflow, such as handling fully loaded trays, could therefore only be simulated. This may have influenced how participants perceived interaction, ergonomics, and workflow integration.

For these reasons, the findings should be interpreted as exploratory, providing indicative insights into user interaction and workflow alignment rather than generalizable conclusions.

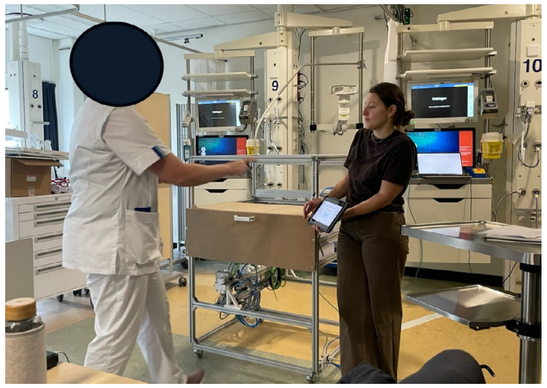


Figure 33: User test A

Table 3: Key findings test A

Topic	Finding	Design Implication
Safety, control & trust	A fixed and predictable layout inside the machine supports learning, checking, and confidence building. : for example, tray slot 1 should always correspond to the same patient bed, bed 1	Numbers have been added to the drawer compartments
	Nurses strongly prefer to retain stickers on the white trays for visual identification and double-checking during the transition to automation.	The system accommodates continued use of tray stickers and is designed to support gradual transition rather than immediate change.
	Trust in the robot is not immediate and must be earned through repeated correct operation. Double-checking by two nurses is considered essential in the current phase and should be supported rather than eliminated.	The workflow supports optional role separation (one nurse loads, another unloads), without eliminating existing verification habits.
Access, control & accountability	Card scanning was perceived positively as a way to ensure that only trained personnel operate the machine. Access control was associated with accountability rather than distrust. “If you are not trained yet, you are not allowed to work with it.” While the NICU kitchen itself is already a restricted space, card-based access was seen as valuable for traceability and safe use.	A card-scanner is integrated to restrict access to trained users and enable traceability of actions.
Workflow & Logistics	A fold-down workbench was considered unnecessary and potentially fragile, as trays are placed directly into the trolley.	The workbench concept was removed. The design aligns directly with existing trolley logistics.
	No strong preference was expressed for take-out height, provided trays can be removed safely and comfortably.	The take-out height is determined based on ergonomic accessibility and the overall Neo layout.
	Preparation every 24 hours or every 12 hours is acceptable. More frequent collection would reduce time savings.	The system supports batch preparation aligned with 24-hour or 12-hour workflows.
	Opinions on a viewing window differed: one participant appreciated visibility, another compared it to “staring into a washing machine.”	A subtle, darkened viewing window is integrated to allow limited visibility without making the process visually dominant.
Cleaning	White trays are preferred because they fit both trolley and refrigerator. Metal trays corroded and ceramic trays broke. White trays are reused.	The design is built around the existing white tray system.
	Trolleys are cleaned daily in a central facility. White trays are cleaned manually with water and a cloth (See Figure). Wiping the machine with water and a cloth is considered sufficient.	Surfaces in the machine are designed to be smooth, wipeable, and free of unnecessary grooves.

Figure 34: Cleaning wipes

7.3 Prototype B & Dropping mechanism test

Protoype B

This prototype represents the DualDrop mechanism, which positions and releases the syringes into the correct drawer and corresponding tray compartment. In contrast to Prototype A, this prototype is capable of both X- and Y-axis movement.

The configuration is shown in Figure 35A. For testing purposes, an additional module was added to the right side of the machine, as illustrated in the figure. This extension enables the system to pick up syringes automatically, rather than requiring manual handover. In this way, the test setup more closely resembles a realistic scenario in which the machine operates autonomously.

Figure 35B provides a detailed view of the gripping mechanism. The gripper consists of two movable jaws that can open and close, allowing it to handle both 20 mL and 60 mL syringes. These syringe types differ in length and diameter, which required a flexible gripping solution.

The control code for operating the machine was developed by G. Hak. During testing, adjustments were discussed and implemented directly, allowing immediate refinement of the system behavior.

Figure 35 A: DualDrop Mechanism test setup

Figure 35 B: Mechanism that holds syringe

Dropping Mechanism test

This section presents the dropping mechanism test conducted with Prototype B of the DualDrop output module. The aim of this study was to experimentally assess the feasibility and reliability of the syringe dropping mechanism. In contrast to Test A, which focused on workflow alignment and user perception, this test concentrated on the technical performance and physical constraints of the dropping process.

The test explored the reliability of syringe placement in the tray, the required wall height of the drawers to ensure safe containment, and whether syringes should be dropped from a fixed position or from multiple positions. Additionally, the study examined the maximum safe dropping height and the time required to fill one tray with twelve syringes.

Further details regarding the experimental setup, measurement procedures, and data can be found in Appendix F.

Objective

The primary objective of this evaluation study was to determine the most reliable and safe configuration for the syringe dropping mechanism. Specifically, the study aimed to:

- Determine whether syringes should be dropped from a single fixed position or from multiple dropping positions;
- Explore whether adaptive adjustment based on landing position (e.g., camera-based feedback) may be required;
- Determine the dropping height at which syringes can reliably land inside the tray without compromising safety;
- Determine the minimum required wall height of the drawers, balancing safety margins and spatial efficiency;
- Measure the time required to fill one tray with twelve syringes.

Research questions

1. Can syringes be reliably dropped from a single fixed release position, or is it more effective to use multiple release positions? Additionally, is adaptive correction based on landing position (camera-based feedback) required to ensure accurate placement?

2. What is the maximum dropping height at which syringes can safely and consistently land within the tray?

3. What is the minimum required wall height of the drawers to ensure safe containment of the syringes, while maintaining spatial efficiency within the cooled module?

4. What is the time required to fill one tray with twelve syringes under controlled test conditions?

Method

To simulate realistic conditions, syringes were filled with water to match the weight and length of syringes used in clinical practice. This ensured that both 20 mL and 60 mL syringes behaved comparably to real feeding situations in terms of mass and balance.

All tests were conducted sequentially: first with 20 mL syringes and subsequently with 60 mL syringes. Each configuration was repeated five times to assess consistency and reliability.

The heights were measured from the top surface of the drawer on which the tray was positioned. During testing, observations were made regarding landing accuracy, interaction between syringes, and potential protrusion above the tray walls. A “reliable landing” was defined as a syringe coming to rest fully within the designated tray compartment without bouncing out.

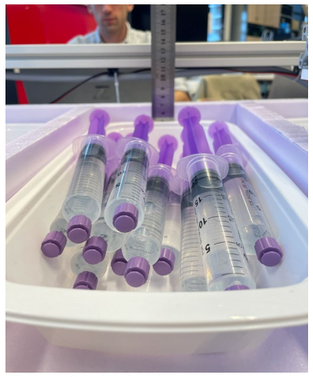


Figure 36: Height measurement

Figure 37: Syringe slightly over drawer edge

Results, conclusion and discussion

Table 4 presents the key findings and the corresponding answers to the research questions.

Table 4: Key findings and answers test B

Research topic	Finding	Comments/Discussion
Fixed or multiple release positions	Releasing syringes sequentially from three different positions (left, center, and right within the tray) resulted in sufficiently reliable placement.	The syringes positively displaced each other upon landing. The 20 mL syringes consistently landed correctly. The 60 mL syringes occasionally did not settle optimally and, from approximately the sixth syringe onward, could protrude above the tray edge. However, nurses indicated that a maximum of six 60 mL syringes are required per tray in practice, rather than eight as previously specified by Neollie. Therefore, the three-position release strategy is considered adequate for both syringe sizes.
Camera-based feedback	A simulated camera feedback approach was tested by manually observing the landing position and adjusting the drop location accordingly. This did not significantly improve the results compared to the fixed three-position release strategy.	Given the high cost and technical complexity of integrating a camera system, and considering that three fixed release positions provided reliable results, camera feedback will not be included in the design. This decision was made in consultation with G. Hak following evaluation of the test results.
Wall height of drawers	For 20 mL syringes, a wall height of 120 mm is sufficient. For 60 mL syringes, a minimum wall height of 140 mm is required.	During testing, syringes did not bounce out of the trays. However, parts of the 60 mL syringes occasionally extended above the tray edge. The drawer walls were initially designed only slightly higher than the trays to maximize spatial efficiency. Based on the test results, an increase in wall height is recommended. Although no further testing was conducted with higher walls, there is sufficient confidence that syringes will remain contained. It should be noted that increased wall height may influence the dropping behaviour of 60 mL syringes.
Dropping height	A dropping height of 107 mm above the drawer surface was sufficient for safe and consistent placement.	A pilot test was conducted to estimate the stacking height of syringes within the tray. The dropping height was then set slightly above this level. No further experimentation was conducted to determine a maximum dropping height, as the identified height represented the minimum safe operational height.
Process time	The time required to fill one tray with twelve syringes (worst-case travel distance scenario) was approximately 95 seconds.	The motion sequence can be further optimized, as the current setup includes pauses between movements. The test was conducted with four trays instead of five, providing an indicative estimate rather than an exact value. The timing assumes that syringes are immediately available and that no waiting time occurs due to the weighing subsystem. Process speed may be increased through further optimization of movement parameters.

7.4 Prototype C & Display test

Protoype C

Prototype C focused on the development and evaluation of the user interface (UI) of the DualDrop output module. While Prototype A evaluated physical workflow alignment and Prototype B assessed the technical feasibility of the dropping mechanism, Prototype C addressed the digital interaction layer of the system.

The interface prototype was developed in Figma. The screens were designed using simple buttons, including a home button and a back button to support intuitive navigation. The home menu consisted of four main sections: Load breast milk, Load trays, Refill stock, and System information. By linking the screens within Figma, participants could navigate through the interface by clicking buttons, which directed them to the corresponding screens. This allowed the simulation of realistic user interaction.

In addition to the interactive Figma prototype, a video of the Neo machine was shown. The display was presented on an iPad to simulate interaction with the machine screen. This setup enabled users to move through realistic operational scenarios. The prototype simulated the operational flow of the machine, including routine production tasks, cleaning procedures, maintenance notifications, and information retrieval functions. The design deliberately focused on clarity of information rather than visual refinement. Limited attention was given to layout styling and graphical detailing, as the primary aim of this evaluation was to determine whether the information was understandable and whether any crucial information was missing.

Figure A shows the badge scanning screen.
Figure B presents the home screen.
Figure C shows an example of an error message.
Figure D displays the in-process status screen.
Figure E provides an additional example of an error notification.
Figure F illustrates an example of an information overview screen.
All additional interface screens are included in Appendix F.

Figure 38A: Badge scanning screen

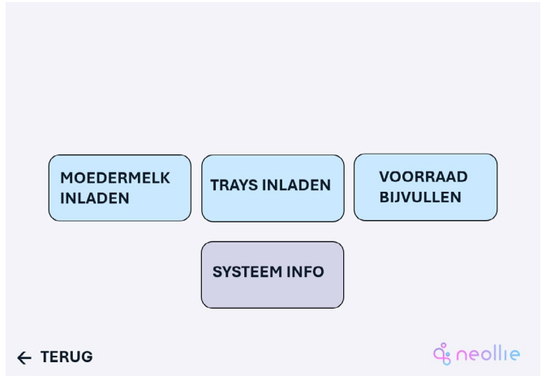


Figure 38B: Home screen

Figure 38C: Error message tray placement

Figure 38D: Process status

Figure 38E: Error notification machine problem

Figure 38F: Information overview

Display test

This section presents the evaluation of the user interface (UI) of the DualDrop output module using Prototype C. While Prototype A focused on workflow alignment and Prototype B on the technical feasibility of the dropping mechanism, this study addressed the digital interaction layer of the system.

The evaluation was conducted at the NICU department of Erasmus MC with six NICU nurses, who are the primary users of the system. The study aimed to assess how users interpret and interact with the interface in a realistic clinical context.

Objective

The primary objective of this evaluation study was to determine which information must be visible on the display to ensure that the system is intuitive, safe, and aligned with daily nursing workflow.
Specifically, the study aimed to assess:

- Clarity of step-by-step guidance during routine production runs;
- User understanding of cleaning and maintenance notifications;
- Perceived safety and risk of errors;
- Accessibility of operational information (e.g., temperature, progress, missing milk);
- Distinction between issues that can be resolved by nurses and those requiring technical intervention.

This directly contributed to answering the sub-research question 3:
How can the output stage be aligned with the daily nursing workflow in the NICU, ensuring that trays fit existing storage solutions and enable a safe and user-friendly handover to nurses?

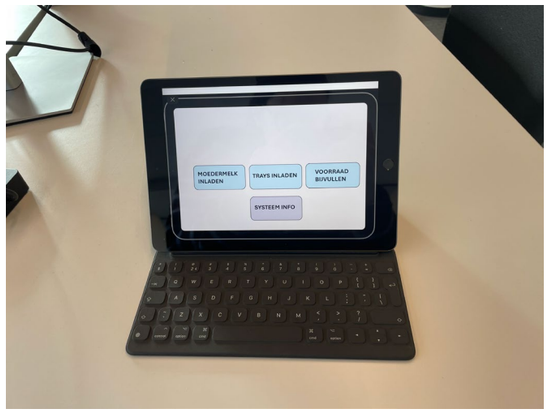


Figure 39: iPad Home Screen

Research questions

Which information must be displayed on the interface to ensure intuitive, safe, and workflow-aligned operation of the DualDrop output subsystem?

Method

A qualitative evaluation study was conducted using an interactive Figma prototype displayed on an iPad, supported by a video of the Neo system to provide contextual understanding.

Participants were asked to perform structured task scenarios divided into three categories:

1. Routine operation
2. Cleaning and maintenance
3. Information retrieval

During the tasks, participants were asked to think aloud. Observations were made regarding behaviour, hesitation, and task completion. Each task was followed by Likert-scale ratings (1–5) and a short discussion to capture qualitative insights.

A detailed description of the method, tasks, and full results is provided in Appendix F.

Results, conclusion and discussion

Table 5 presents the key findings and the design implications.

Limitations

The evaluation involved six participants, working in pairs due to practical constraints during testing. While this setup reflects aspects of the real working environment, where tasks are often performed collaboratively, it differs from individual interaction with the system. The paired setup may have influenced responses, as participants could support or influence each other's decisions and feedback. At the same time, it enabled richer discussions and allowed participants to build on each other's insights. In addition, the interface was tested using a Figma prototype rather than a fully functional system, meaning that interaction dynamics and system feedback were simulated rather than real-time. As a result, the findings should be interpreted as exploratory, providing indicative insights rather than definitive conclusions about real-world system performance.

Figure 40: Test set-up at NICU ward 2

Table 5: Key findings and answers test C

Topic	Finding	Design Implication
Errors	Error messages indicated that something was wrong, but did not always clearly explain what the specific issue was or how it should be resolved. For example, users were uncertain whether trays needed to be removed and reinserted.	Error notifications must explicitly state the problem, provide step-by-step resolution guidance, and give confirmation once the issue has been successfully resolved.
Cleaning	Cleaning procedures were not always clearly defined. Daily cleaning of the refrigerator is mandatory, but workload may prevent immediate compliance. Users requested limited postponement of cleaning notifications and confirmation after cleaning is completed.	The interface will specify what must be cleaned, allow confirmation after cleaning, permit limited postponement, and block operation after repeated dismissal.
HiX integration	Feeding prescriptions are managed in HiX by physicians, but adjustments are sometimes communicated verbally. Users expressed the need for local adjustments within the system to avoid workflow disruption.	If integrated with HiX, the interface should allow controlled modification of prescriptions. An on-screen keyboard may be required for secure data entry.
Maintenance	Users require concrete information when malfunctions occur and need clarity on whether they can resolve the issue themselves. In urgent cases, direct communication with either Neollie support or the hospital's technical maintenance staff must be possible.	Maintenance messages must specify the type of malfunction, indicate whether user intervention is allowed, and provide direct reporting options with confirmation and estimated resolution time. The system must clearly indicate whether the issue is routed to Neollie support or to the hospital's technical maintenance staff.
Information and Safety	Temperature display alone was insufficient; users must know whether it falls within a safe range. Barcode or unique patient identification was requested to prevent mix-ups. Users also require process status visibility on the home screen and a clear overview of milk availability per infant.	The interface will include color-coded temperature indicators (green/orange/red), audible alarms for critical deviations, display both patient name and unique identifier, show real-time process status with estimated completion time, and provide a bed-based dashboard overview with visual status indicators.
Display Operation	The interface must be operable while wearing medical gloves.	A glove-compatible touchscreen will be implemented. An on-screen keyboard will be provided when text input is required.
Dubbel check	Although the machine is expected to be reliable, users suggested that workflow could support informal verification by dividing loading and unloading tasks between two nurses.	The system layout may support optional role separation for verification, without making double-checking mandatory.
Alarm	Audible alarms are currently used in clinical practice for critical deviations and are considered useful for alerting nearby staff.	The system will primarily use visual feedback but activate audible alarms during safety-critical situations.
Exceptional scenarios	In emergency situations, the syringes are prepared manually.	Emergency workflows will remain manual to ensure rapid response and continuity of care.

7.5 Conclusion

The three prototypes, A, B, and C, each addressed a different but interconnected aspect of the DualDrop output module. Prototype A focused on physical workflow integration and spatial organization, validating how trays, drawers, and user interaction fit within existing NICU routines. Prototype B evaluated the technical feasibility and reliability of the syringe dropping mechanism, providing insight into optimal release positions, wall heights, and mechanical constraints. Prototype C examined the digital interaction layer, assessing how the interface supports clarity, safety, accountability, and alignment with clinical practice.

Together, these prototypes provided complementary insights. User testing revealed that consistency, predictability, and clear feedback are essential for building trust in the system. Technical testing clarified the mechanical boundaries within which safe operation can be guaranteed. Interface testing demonstrated that information must not only be available, but also contextualized and actionable.

Rather than functioning as isolated tests, the findings from Prototypes A, B, and C collectively informed the refinement of the DualDrop concept.

These findings form the foundation for Chapter 8, Embodiment Design, in which the validated principles are translated into a coherent and technically feasible final design proposal.

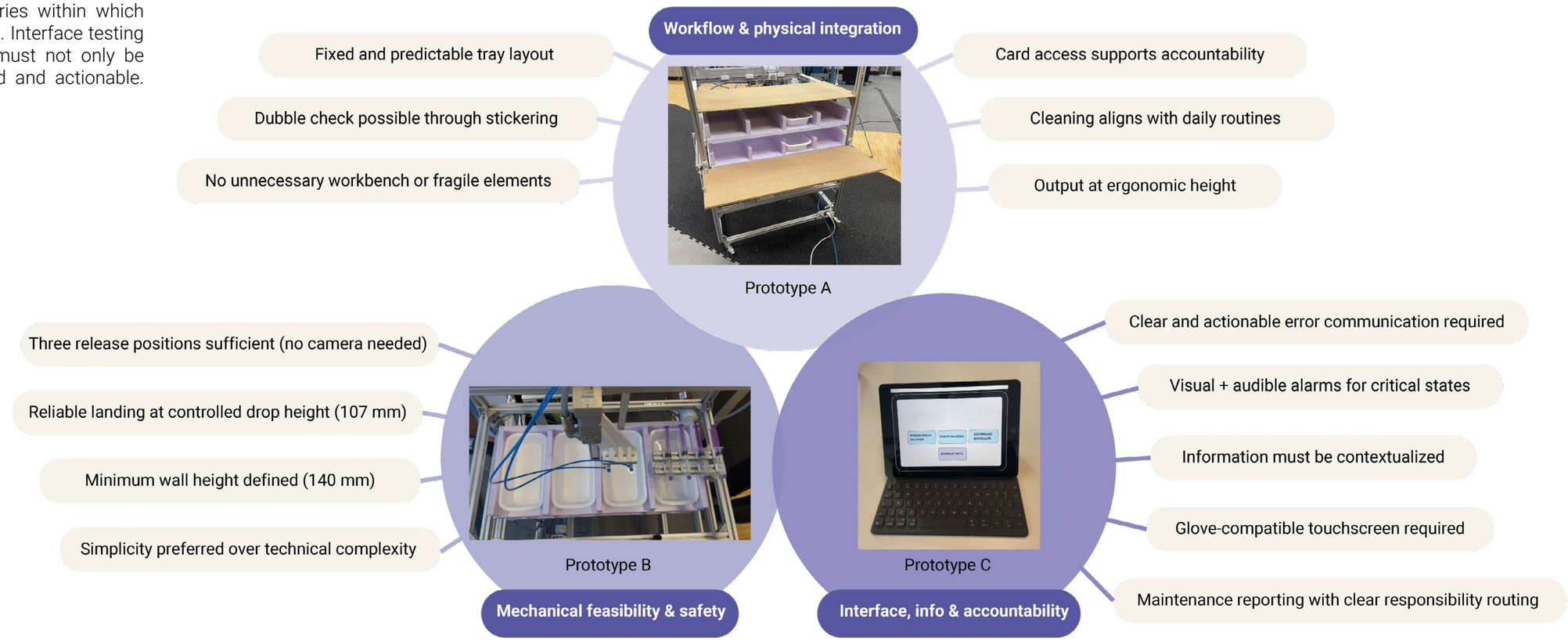


Figure 41: Validated insights for Embidiment Design

8 Embodiment Design

This chapter presents the embodiment and system integration of the DualDrop concept. It translates the validated working principle into a physically integrated and manufacturable subsystem, addressing mechanical design, cooling enclosure, sensor integration, and ergonomic positioning. In addition, material selection, production considerations, and maintenance strategies are discussed to ensure reliability, hygiene, and long-term feasibility.

8.1 Design of the final DualDrop system

After the technical feasibility of the DualDrop mechanism had been demonstrated in earlier iterations, the next step was to integrate this mechanism into a coherent product prototype. This phase marks the transition to the third diamond of the Triple Diamond methodology, the Embodiment phase, in which the focus shifts from isolated functionality toward full system integration.

The objective of this phase was to further develop the previously validated mechanism into a user-friendly and manufacturable subsystem of the Neo machine, aligned with both Neollie's design language and its existing backend hardware architecture. In addition to mechanical performance, particular attention was given to physical integration, user interaction, and the relationship between the DualDrop system and surrounding subsystems.

The DualDrop mechanism is capable of both horizontal and vertical movement, enabling it to reach multiple positions and to perform a controlled drop operation from an appropriate height. In this chapter, the DualDrop concept is elaborated in detail, with emphasis on its physical embodiment, integration within the Neo machine, and the implications for usability and workflow integration.

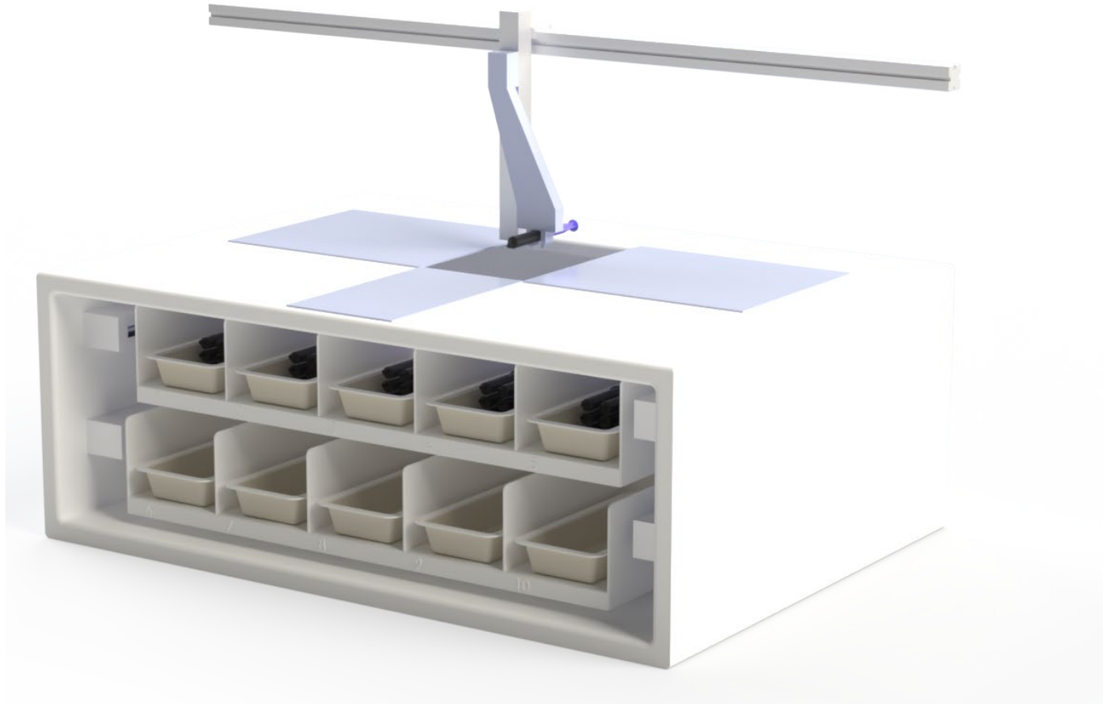


Figure 42: DualDrop mechanism and Cooled Output Module

Drawers and Dropping mechanism

Within the DualDrop concept, the drawers and the dropping mechanism together form a single, integrated subsystem. The drawers act as the receiving and organizing elements for the filled syringes, while the dropping mechanism is responsible for accurately positioning and releasing the syringes into the correct trays. Proper alignment between these two components is essential to ensure mechanical reliability, safe handling, and a clear, understandable output for nursing staff.

Drawers with linear actuator

Filled syringes are transferred directly from the dropping mechanism into the trays in the drawers. To enable this process, the drawers must be able to move in a controlled and repeatable linear motion, allowing them to position themselves precisely beneath the active drop point. Several technical solutions could be considered for this type of movement, including gear systems, belt systems, and spindle-driven mechanisms. Linear actuators with a spindle are widely used in industrial applications such as 3D printers, where they are valued for their precision, reliability, and compact integration.

Gear- and belt systems introduce multiple moving parts and are more difficult to fully shield within a closed cooling compartment. This makes cleaning and keeping it clean difficult.

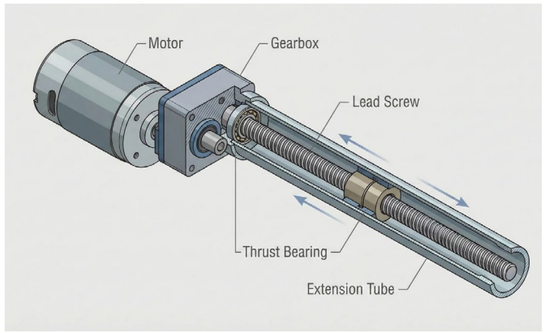


Figure 43: Linear actuator (Dickson & Automations, 2026)

Linear actuators provide controlled and repeatable motion within optionally a sealed housing, supporting hygienic design requirements. Furthermore, linear actuators enable a modular drawer configuration: each drawer can be mounted as an independent unit driven by its own actuator. This modular setup allows drawers to be easily attached and detached from the cooled output module, facilitating quick installation, removal, and cleaning. This modularity allows the system to be scaled in the future by adding additional drawers without major modifications to the underlying mechanical architecture. As such, the use of linear actuators contributes to both the scalability and maintainability of the DualDrop system. For these reasons, linear actuators were selected as the preferred solution.

Dropping Mechanism

The dropping mechanism is designed as an arm-based structure capable of both horizontal and vertical movement. This enables the syringe to be positioned above the correct drawer and tray and to be released from a controlled height. The prototype mechanism is constructed using components and design principles already applied by Neollie in other subsystems, supporting technical consistency and facilitating integration within the Neo machine. Figure 44 illustrates the X–Y arm of the dropping mechanism.

An additional element within the dropping mechanism is the syringe orientation transition. Syringes exit the filling process in a vertical orientation but must be placed horizontally within the trays. Rather than relying on a complex multi-axis robot arm, this transition is achieved through a dedicated tilting mechanism integrated near the end effector. This approach allows controlled reorientation of the syringe while maintaining mechanical simplicity.

The X-Y arm together with the tilting mechanism constitutes the proposed concept. Following discussion with G. Hak, the tilting mechanism is excluded from the current prototype and therefore remains outside the scope of this project, as sufficient confidence in its functionality exists and due to the time constraints of this project.

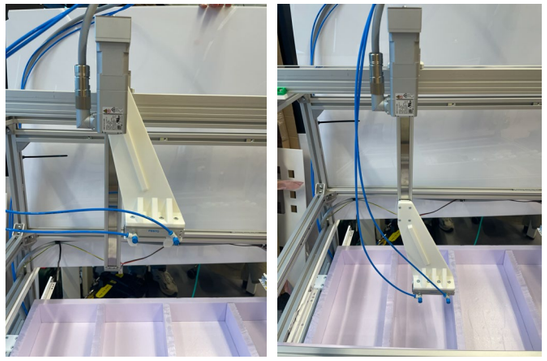


Figure 44: Dropping mechanism up and down

This concept works and could be used as mechanism in the final design, but *if* Neollie wants to scale up to more drawers, more vertical space is needed. Because the mechanism must be capable of extending further downward, it will consequently protrude more at the upper side when positioned in its zero configuration. In that case, a principle inspired by a delta robot could be considered.

A delta robot is a type of parallel robot in which multiple arms are connected via joints to maintain the orientation of the end effector. In this case, a simplified configuration with two arms instead of three was selected (Illustrated in Figure 45). This configuration better matches the spatial constraints of the system and significantly reduces the required vertical clearance when upscaling. Unlike conventional serial robot arms, which require additional space both above and below their neutral position, this parallel arrangement allows for more efficient use of the available height. As a result, the area above the mechanism can remain available for other subsystems, increasing the overall flexibility of the Neo architecture.

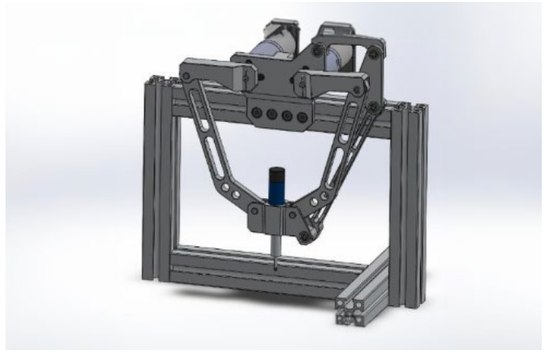


Figure 45: 2D Delta robot Structural Design (Yang et al., 2017)

The use of a six-degrees-of-freedom (6-DOF) robotic arm was currently excluded from the design. Such systems are significantly more expensive, require substantial spatial clearance, and introduce unnecessary complexity for the limited range of motions required in this application. Neollie has deliberately chosen to avoid 6-DOF arms within the Neo machine in favour of more constrained, task-specific mechanisms that are easier to control, validate, and maintain.

To ensure reliable operation of the combined drawer and dropping mechanism, accurate positioning remains critical. Even minor misalignments can result in incorrect placement of a syringe within a tray. The role of sensors and feedback mechanisms in monitoring position, presence, and system state within the output concept is therefore addressed in the following section.

Fridge: Enclosure and Boundary of the Cooled Outpud Module

Within the DualDrop concept, the output module is fully integrated into a cooled environment, ensuring that filled syringes remain under controlled conditions until they are collected by nursing staff.

For this graduation project, the design scope is deliberately limited to this cooled output module. Other parts of the Neo machine, including the complete cooling infrastructure and the upstream subsystems, are considered out of scope. As such, the cooling compartment functions not only as a functional requirement, but also as a physical and conceptual boundary for the design intervention.

The cooled module includes two functional access points. The first is located at the top side of the compartment and serves as the internal access point for the dropping mechanism, through which filled syringes are delivered into the drawers. The second access point is positioned at the front of the system and is dedicated to nurse interaction. Through this opening, empty trays are inserted into the drawers and trays containing filled syringes are retrieved.

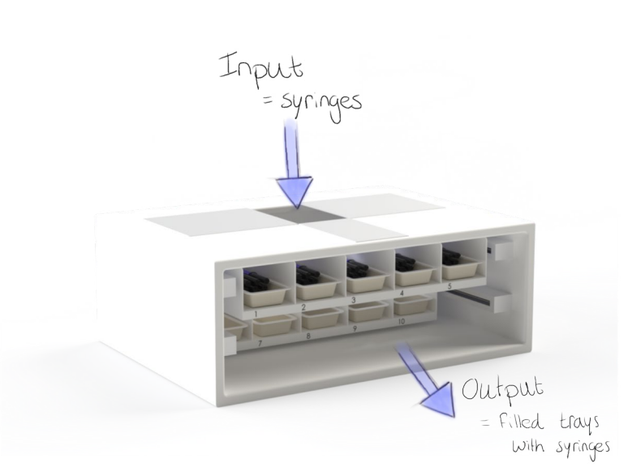


Figure 46: Front & top opening of the Output Module

Closure at the top of the Output Module

The enclosure at the top of the cooled module must closely accommodate the motion of the dropping mechanism. Sufficient clearance is required to allow vertical movement and controlled placement of syringes at a limited drop height. At the same time, heat ingress and loss of cooled air must be minimised, as syringes need to remain within defined temperature limits to ensure safe storage.

Several closure directions were explored (See morphological chart, paragrapg 6.3) for this opening, including a rubber flap with a slit, upward-opening flaps, downward-opening flaps, and sliding elements. A rubber flap with a slit was rejected because any contact with a syringe would require cleaning, which is undesirable. A downward-opening flap is also unsuitable, as the available space is limited and such a flap could obstruct access to the upper drawer. Moreover, large hinged elements increase the risk of collisions with drawers or trays, negatively affecting system reliability.

An upward-opening flap or a sliding closure moving parallel to the roof of the cooling compartment is more compatible with the spatial constraints. Both options allow temporary access for the dropping mechanism while keeping the exposed opening area relatively small. Although an upward-opening flap is more suitable than a downward-opening one, it still introduces a hinged element whose motion can interfere with the dropping mechanism, increasing the risk of collisions and reducing system reliability. Between these two, a sliding closure offers practical advantages. A hinged flap requires swing space and introduces a moving obstruction near the robot arm's operational envelope, which can restrict low and controlled dropping. A sliding panel can be retracted away from the arm path without requiring additional vertical clearance.

In addition, a sliding solution offers greater design flexibility. Instead of one flap per tray, the system could use either individual sliders per tray or a larger continuous slider that serves multiple trays. This is particularly relevant if the system is later adapted to a delta robot configuration, which occupies increasing horizontal space as more drawers are added below. A sliding closure can be dimensioned and positioned to accommodate such changes while still limiting leaking of cold air through a controlled opening size. For these reasons, a sliding closure is proposed as the preferred solution for the top access of the cooled output module (Figure 46).

Closure at the Front of the Output Module

At the front of the cooled output module, direct interaction with the nurse takes place. In Prototype A, this side was designed as a hinged flap (see Figure 32 D), with the intended advantage that the opened flap could function as a temporary work surface. However, results from the user test showed that this work surface was considered unnecessary. Moreover, this solution introduces limitations when scaling the system to multiple drawers. A hinged flap requires additional clearance space and increases in size as the front surface grows, which makes it less suitable for future expansion.

An alternative often considered is a roller shutter. A roller shutter is not a flat panel with ribs, but a flexible screen composed of many narrow horizontal slats that roll up into a housing. From a hygienic perspective, this solution has disadvantages: dirt can easily accumulate between the slats, making thorough cleaning difficult. In addition, internal space must be reserved inside the machine to store the rolled-up shutter, which reduces the available volume for functional subsystems.

These drawbacks are avoided when the opening is designed as a vertically moving door. A relevant reference is the front door mechanism used in Rapidshape 3D printers. In this system, the door first moves slightly forward and then slides vertically upward. When closing, it moves vertically downward and then shifts back into its original position, creating a well-sealed enclosure. This mechanism ensures precise alignment and effective sealing (Rapidshape, 2023), this solution also has a clean, modern, and clinical appearance, which fits well within a hospital environment. In addition, the door surface is flat and continuous, making it easy to clean.

User testing further revealed mixed preferences regarding visibility. Some nurses appreciated being able to see the process, while others explicitly stated that the system should not resemble a washing machine where one constantly watches through a window. To balance these perspectives, a semi-transparent, darkened window, similar to the Rapidshape printer, is proposed. This allows close-range inspection when needed, while preventing the process from being visually dominant in everyday use. In addition, it is essential that the door seals tightly to prevent cold air from escaping and to maintain stable storage conditions.

Finally, smooth and controlled motion of the door is critical. The door should not be freely openable during operation; instead, it must be interlocked with the system state. Similar to the 3D printer example, safety mechanisms should prevent opening while the machine is active. This not only protects the user from moving parts but also ensures that the cooling conditions and process reliability are not compromised. However, if circumstances require that the door must be able to be opened during the process, this is possible, but only in a safe manner, once the process has been stopped. Further details are provided in the Sensors and Fault Detection section and the Interface Design section.

In this design, the door opens upward. If this later conflicts with, for example, the machine's input module, a downward-opening configuration may be considered.

Figure 47: Front of the machine (door open and closed)

Internal and External Components of the Cooled Output Module

For a properly functioning cooled output module, a clear separation between internal and external components is essential. Components that generate heat or require regular maintenance, such as motors, drives, and control electronics, should be positioned outside the cooled compartment. This prevents unnecessary heat input into the cooled space and simplifies maintenance

Chapter 6 discussed the general principles of a refrigeration system and the components involved. Although the cooling infrastructure itself is outside the scope of this project, it is important to account for key elements such as the compressor and the heat exchangers (evaporator and condenser) in the overall spatial layout of the Neo system.

In a conventional household refrigerator, the compressor is located outside the cooled interior and requires a dedicated volume within the overall product (see Figure 48). Similarly, within the Neo system, space must be reserved for the compressor outside the cooled DualDrop output module. The evaporator, which absorbs heat from the interior, is typically integrated into the inner walls of a refrigerator. In the DualDrop output module, this principle is followed by embedding the evaporator in the surrounding walls rather than in the drawers themselves, as direct integration in moving components would be impractical.

The condenser releases the extracted heat to the environment through condenser coils. To prevent heat accumulation inside the Neo machine, these coils should be positioned at the rear of the cooled DualDrop output module, outside the cooled volume, similar to a conventional household refrigerator (see Figure 49). As a result, the maximum depth of the machine is largely determined by the depth of the cooled DualDrop output module, allowing the condenser to be placed directly behind it rather than within the central machine housing. Alternatively, the condenser coils could be located at the back of the machine and connected to the output module via tubing, thereby avoiding this dimensional constraint as a limiting factor in the overall machine design.

Figure 48: Dedicated volume for the compressor

Figure 49: Condensor Coils and compressor

Because the cooled module is frequently opened at both the top (for the dropping mechanism) and the front (for user interaction), some loss of cold air is inevitable. In addition, the surrounding machine contains moving mechanical components that generate heat. For this reason, controlled air circulation within the machine housing is recommended. A fan can be used to manage internal airflow and prevent local heat build-up around the cooled module.

Within the cooled compartment itself, airflow must be carefully controlled. Air circulation should be sufficient to maintain a stable temperature, but not directed straight onto the syringes, as this could increase the risk of condensation or local drying effects. The placement of ventilation elements therefore needs to be aligned with the geometry of the drawers and trays. Since condensation can never be completely eliminated, even in conventional refrigerators, it is important to account for controlled moisture management. The design should therefore include a drainage point and a collection reservoir in which condensed moisture can be gathered and periodically emptied. This prevents water accumulation inside the cooled module and supports hygienic operation.

Inside the cooled output module, only components that are functionally required in the cold environment are placed. These include the drawers with their linear actuators, the trays, the syringes, and supporting elements such as sensors.

Sensors and Fault Detection

To ensure the reliability and safety of the Neo machine, multiple control and feedback loops are required within the output concept. Although the system is designed with the ambition of operating as a so-called zero-error robot, it is essential from a design perspective to critically reflect on this assumption. In practice, machines are often designed as if they operate without error, while absolute fault-free operation is not achievable. Zero error should therefore be understood as a design objective rather than a factual state, approached through detection, verification, and fault-tolerant design strategies.

This design view is supported by recent reliability research. Rather than assuming fault-free operation, modern reliability engineering focuses on detecting and managing faults during operation. Zeng (2025) argues that failures should not only be predicted through static design models, but "by continuously monitoring the specific, evolving health of each system," reflecting a shift toward real-time observation over static reliability assumptions. This means that reliability is no longer treated as something that is fully determined during the design phase, but as something that must be actively maintained during operation.
In line with this, TU Delft research identifies "smart sensoring and big data analysis" and condition-based monitoring as key directions for future reliable system design (van Driel et al., 2024). This shows that reliability is increasingly achieved by combining fault-tolerant design with real-time sensor feedback, supporting the idea that zero error is a design goal approached through monitoring and response, not an assumed system state.

Within the DualDrop output concept, sensors play a central role in both process monitoring and fault prevention. Appendix G presents the system boundary of this process, with the start point defined as the moment a syringe passes the weight-check subsystem and enters the output module, and the end point defined as the moment the nurse removes one or more filled trays from the cooled output module and closes the system. For each step in this process, it has been determined which conditions must be verified, which sensors are required, and how the system should respond if deviations occur.

Sensor functions within the output module include:
- Detection of syringe presence in the gripper and in individual tray slots,
- Verification of drawer and tray positioning,
- Monitoring of temperature within the cooled compartment,
- Confirmation that access doors are closed during operation,
- Validation that a complete set of syringes per infant is present,
- Detection of faults such as jams, misalignment, or unexpected resistance.

When a deviation or fault is detected, the system must be capable of responding in a proportional and transparent manner. Possible responses include:
- Displaying a warning through the user interface,
- Temporarily blocking the output process,
- Marking a tray as incomplete or invalid on the user interface.

This layered response strategy prevents incorrect or incomplete feeds from entering the clinical workflow unnoticed, while still allowing controlled recovery where possible.
The effectiveness of these control mechanisms depends not only on the type of sensors used, but also on their physical placement within the system. Sensors must be integrated at functional contact points, such as along drawer rails, within the frame or walls of the cooling compartment, at door interfaces, and near the pickup zone where nurses retrieve trays. By positioning sensors at these critical interaction points, system reliability can be significantly increased without introducing unnecessary mechanical or computational complexity. Tabel 6 shows the sensors and their placement. The choice of the sensor is consistently based on what performs best in terms of precision, robustness, and minimizing the number of moving parts.

Table 6: Sensor and placement

Sensor nr.	Function	Sensor Type	Location	Action in case of error
S1	Door open/ closed/ locked	Reed switch	Door frame + lock	Block process, notification
S2	Tray present & correctly positioned	Optical reflective sensor	Each tray position	Do not start, UI notification
S3	Position drawer A	Reed switch	Linear actuator A	Stop, reposition
S4	Syringe in gripper / released	Through beam sensor	Gripper	Stop, error message
S4	Syringe correctly placed in tray	Through beam sensor S4	Gripper	Mark tray, stop, error message
S5	Temperature	Temp sensor	Cooling compartment	Break, notification
S6	Position drawer B	Reed switch	Linear actuator B	Stop, reposition
S7	Arm position	Encoder	DualDrop arm	Recalibration
S8	Syringe rotation position (vertical to horizontal)	Encoder	Tilting mechanism	Stop, error message
S9	Slide top opening status	Reed switch	Top opening	Do not drop
S10	Jam detection	Current/Encoder	Motor/Linear actuator	Safe stop + notification

8.2 System Integration within Neo

System-Level Positioning and Subsystem Dependencies

The positioning of the DualDrop concept within the Neo machine is determined by a combination of spatial, technical, and user-related factors. A primary consideration is its relationship with the other subsystems of Neo. From Neollie's perspective, the output system is regarded as a critical component of the machine. Other subsystems may therefore be repositioned if necessary to guarantee sufficient space, accessibility, and reliability of the output. The final configuration of the remaining subsystems has not yet been fixed.

However, the subsystems that precede the output phase are functionally connected and must be positioned in close proximity to each other. The output represents the final step in a sequence of dependent processes, which requires a logical and efficient internal routing of components. Although the internal layout of Neo is still open, functional coherence between subsystems forms an essential boundary condition for the placement of the DualDrop concept.

Ergonomic Height determination of the Output Module

In addition to technical integration, usability is a key factor in determining the position of the output system. The height and location directly affect ergonomic interaction with nurses. A design balance is required between what is mechanically optimal for internal placement and what is practical and comfortable for placing and removing trays. The output module should be positioned at a height that is easily reachable and visually clear, without causing awkward postures or unnecessary movements for the user.

The vertical positioning of the output module has been informed by established ergonomic guidelines for work surfaces. In contemporary kitchen design, standard countertop heights typically range between 920 and 950 mm, as defined in the Dutch standard NEN-EN 1116:2018, which specifies functional and dimensional requirements for kitchen furniture (NEN, 2018). These standards are widely applied to ensure safe and comfortable working postures during repetitive tasks.

From an ergonomic perspective, the optimal working height is not fixed but depends on the user's body dimensions. A commonly accepted ergonomic guideline, often referred to as the 15 cm rule, states that an ideal work surface is positioned approximately 10–15 cm below elbow height. This rule is internationally recognized within ergonomics literature as a means to minimize physical strain by allowing the shoulders to remain relaxed and the spine upright during manual tasks.

Anthropometric data from the TU Delft DINED database indicate that for Dutch adults aged 20–60 years, the average body height is approximately 1743 mm, with an average elbow height of 1084 mm measured from the floor (DINED, n.d.). Applying the 15 cm rule to this elbow height results in a recommended working height of approximately 930 mm. This value closely aligns with standard kitchen worktop heights and therefore provides a validated ergonomic reference for the design of the output module.

In the context of the DualDrop system, which contains two vertically stacked drawers, it is recommended that the vertical center of the output module be positioned around 930 mm from the floor. This configuration ensures that both the upper and lower drawers remain within an ergonomically acceptable reach zone for the majority of users, while maintaining consistency with established kitchen ergonomics. Further information are documented in Appendix H.

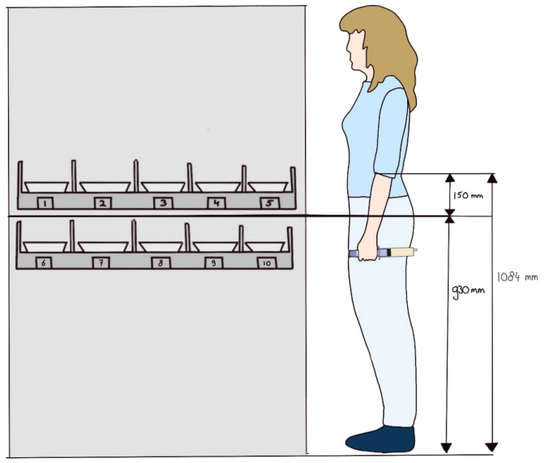


Figure 50: Elbow height relative to the output module

Relationship between Input and Output

The relationship between input and output systems has also been considered. Although the input system has not yet been designed, it is often assumed that both input and output are located at the front of the machine. However, it is not recommended to place the milk-bottle input directly above the output system. Doing so would require a significantly longer robotic arm and would no longer be compatible with the current X–Y-based arm configuration. In that case, a different robotic principle, such as a delta robot, would become necessary. For this reason, it is recommended that the primary input of milk bottles and stock be positioned on one of the side faces of the machine rather than above the DualDrop module. Although this lies largely outside the scope of this project, it has been considered to avoid design conflicts at system level.

Fixed constraints and Vertical layering

One element that is considered fixed is the position of the electronic components. The control electronics of the Neo machine are located in the lower section of the system. This area is not available for other subsystems and therefore forms a hard spatial constraint. In this same lower region, space can also be reserved for components such as the compressor and the condensate reservoir of the cooling system. This results in a vertical layering of the machine: electronics at the bottom, functional subsystems above, and sufficient free space at the top for the vertical movement of the DualDrop dropping mechanism.

The dropping mechanism requires vertical clearance above the cooled output module and must also align with the front of the machine so that filled trays can be removed there. In addition, the condenser coils are intended to be placed at the rear of the machine.

These spatial requirements confirm the importance of a compact and well-coordinated configuration of the output system. Figure 51 presents a schematic overview of the intended positioning of the DualDrop concept within the Neo machine.

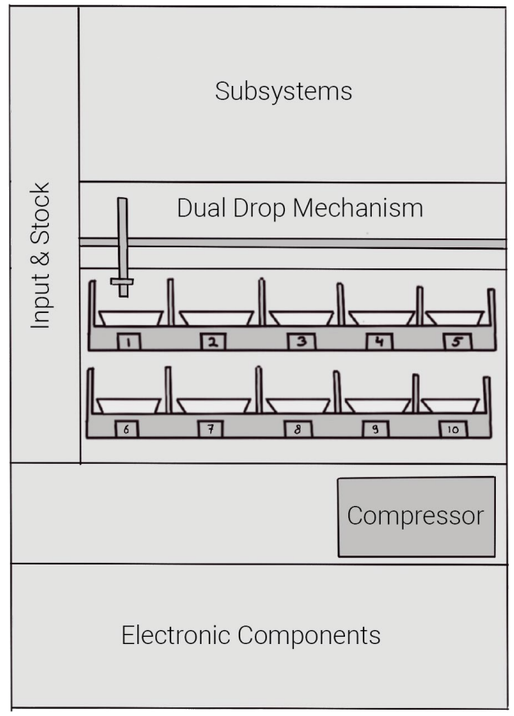


Figure 51: Schematic Overview (front view)

8.3 Materials & Production

To inform the selection of suitable materials and production techniques, an expert consultation was conducted with a technical specialist from the Protyping en Model Bouw werkplaats (PMB) of the Faculty of Industrial Design Engineering.

Material selection

The material selection for the DualDrop concept is largely determined by the context in which the system operates: a cooled environment, where hygiene, reliability, and durability are critical. The output module operates within a temperature range of 3–5 °C, in line with storage conditions for breast milk. According to Neollie's current vision, the machine may be switched off or set to a lower operating mode after completion of a production cycle. This implies that temperature fluctuations within the cooled compartment are unavoidable. Both the design and the selected materials must therefore be able to withstand repeated thermal changes.

A direct consequence of such temperature fluctuations is condensation on the inner surfaces of the cooling module. The applied materials must be resistant to moisture and should not degrade, corrode, or lose functionality under prolonged exposure to condensation. In addition to moisture resistance, corrosion resistance is a crucial requirement. Materials must not oxidize, as this would negatively affect both hygiene and the service life of the system.

Furthermore, all surfaces must be easy to clean thoroughly, in line with the hygienic requirements defined through the MoSCoW method. Smooth, non-porous materials with minimal seams, gaps, or crevices are therefore preferred.

The visual properties of materials also play a role. Light-coloured, preferably white surfaces improve visual inspectability: spills or residues are immediately visible, which supports safe and hygienic working practices.

Finally, the system must be robust and resistant to intensive daily use. Nurses should be able to operate the system quickly and confidently, without having to handle components cautiously due to perceived fragility.

Based on these boundary conditions, the following material choices are considered appropriate for the main components:

Internal cooling surfaces and drawers

Domestic and professional refrigerators commonly use polystyrene (PS) or similar thermoplastics for inner walls and drawers. These materials are lightweight, easy to clean, and suitable for insulated environments. Therefore, the internal walls of the cooled output module and the drawers that hold the trays are proposed to be manufactured from polystyrene. The evaporator coils are integrated within the walls, following standard refrigerator construction principles.

External housing of the cooling module

The external structure of the cooling module should be made from powder-coated steel or aluminium. These materials provide sufficient structural strength and offer a durable, wear-resistant finish. Powder coating also improves corrosion resistance and cleanability. The condenser coils are positioned at the rear of this housing.

Front panels and doors

For the front panel, the opening door, thermoplastic panels such as ABS/PC blends or polycarbonate are suitable. Polycarbonate is widely used in machine enclosures because it is lightweight, impact-resistant, and tolerant to temperature variations. For the viewing window, either acrylic (PMMA) or polycarbonate can be used. Acrylic is cheaper and highly transparent, while polycarbonate is stronger and more resistant to impact and scratching.

Sliding elements at the top opening

The sliding elements that close the opening of the droppings mechanism are best manufactured from aluminium. Aluminium provides stiffness, low weight, and good machinability, which simplifies integration with linear actuators. At the interface where the slider closes against the rear wall of the cooling module, a rubber or silicone sealing profile should be applied to prevent cold air leakage. The sliders are designed with interlocking grooves that guide their movement and form a rail-like system for mutual alignment.

Linear actuators

The linear actuators should be industrial-standard units with an anodized aluminium housing and sealed internal components, making them suitable for use near cooled or humid environments. Such actuators are commonly applied in food-processing equipment, medical devices, and laboratory automation systems, where cleanliness, reliability, and resistance to moisture are essential.

Prodcution

The production of the DualDrop system is approached through a combination of industrially proven manufacturing techniques and modular construction principles.

The drawers that hold the trays are designed to be manufactured from thermoplastic materials using thermoforming or injection molding. These techniques are widely used for producing hygienic components with smooth, non-porous surfaces and consistent wall thicknesses. Thermoforming is particularly suitable for relatively large, shallow components such as drawers, while injection molding can be used for smaller precision parts.

The front door and sliding closure elements are designed as separate subassemblies. Transparent or semi-transparent panels can be produced from polycarbonate or PMMA through sheet forming or CNC machining for prototyping, and injection molding or thermoforming for series production. The supporting frames and rails for these elements are produced from aluminium or coated steel profiles using standard sheet-metal bending, laser cutting, and CNC machining techniques.

The cooled output module itself requires custom manufacturing because of its specific dimensions and integration with the Neo system. While the cooling principle is based on conventional refrigerator technology, the layout of components such as the compressor, evaporator, and condenser must be adapted to fit the spatial constraints of the Neo machine. This means that the housing is produced as a dedicated enclosure, using sheet-metal fabrication and powder coating for durability and cleanability. The internal cooling elements are integrated into the walls, following established refrigerator construction principles.

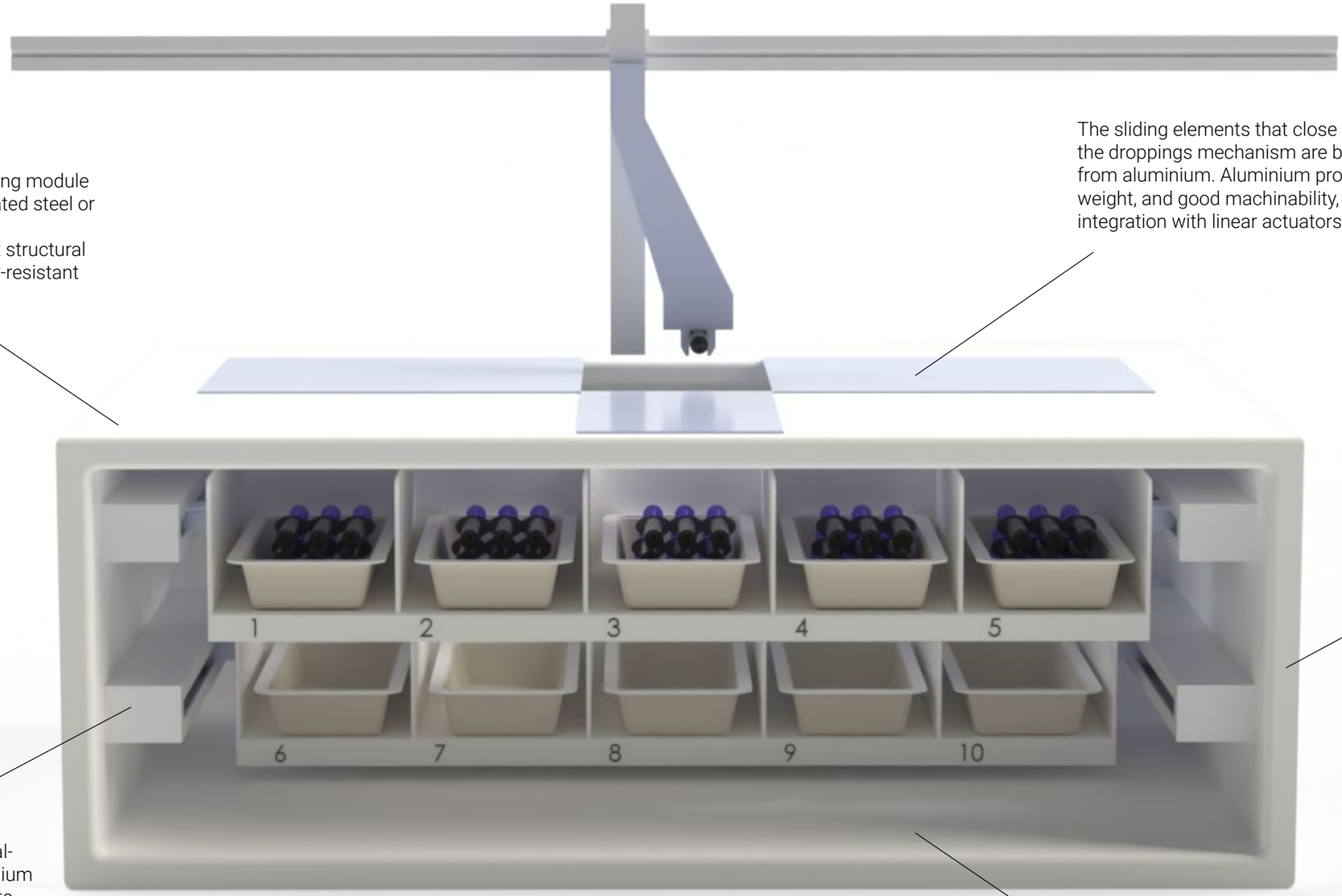
An overview of the dimensions of the DualDrop system is provided in Appendix I.

Maintenance, Replaceability and Sustainability

Maintenance and replaceability are essential design principles, given the continuous use of the system in the NICU environment. Components that are subject to wear, such as the drawers and actuators, are designed as modular units that can be replaced individually without dismantling the entire system. This increases repairability and reduces downtime.

Sustainability is addressed through both material choice and system architecture. Durable, high-quality materials are selected to ensure a long operational lifespan. In addition, the modular design strategy supports sustainability by enabling repair rather than replacement of the full system. Extending product lifespan through maintenance and component replacement reduces material waste and environmental impact.

DualDrop Mechanism with the Cooled Output Module



The external structure of the cooling module should be made from powder-coated steel or aluminium.
These materials provide sufficient structural strength and offer a durable, wear-resistant finish.

The sliding elements that close the opening of the droppings mechanism are best manufactured from aluminium. Aluminium provides stiffness, low weight, and good machinability, which simplifies integration with linear actuators.

The evaporator coils are integrated within the walls

The linear actuators should be industrial-standard units with an anodized aluminium housing and sealed internal components, making them suitable for use near cooled or humid environments.

Internal walls of the cooled output module and the drawers that hold the trays are proposed to be manufactured from polystyrene.
These materials are lightweight, easy to clean, and suitable for insulated environments.

9 Operational Design & System Integrity

This chapter describes how the DualDrop concept is operationally integrated into the clinical environment of the NICU. It discusses user interaction, interface design, workflow alignment, and data traceability, with the aim of ensuring that the system functions not only from a mechanical perspective but also in support of patient safety and daily nursing practice. By aligning physical design decisions with digital control and accountability structures, this chapter outlines how system integrity is safeguarded during everyday use.

9.1 User Interaction and Interface Design

The interaction between nurses and the Neo machine forms a critical link in the success of the DualDrop concept. Although the system is highly automated, the nurse remains ultimately responsible for retrieving and administering the feeds. The output phase must therefore not only function correctly from a technical perspective, but also be intuitive, safe, and well aligned with daily practice in the NICU. This section describes how user interaction and interface design have been incorporated into the embodiment of the DualDrop system.

Nurse Centered Design

The primary user of the output module is the NICU kitchen nurse who is currently responsible for preparing feeds. The system is designed so that the user is not required to perform complex tasks. Core actions are limited to placing empty trays, collect filled trays, and responding to system messages. The design aims to minimise cognitive load by reducing the number of steps and clearly indicating what action is required at any given moment. The guiding principle is that the user should never have to wonder: “What should I do now?”

Workflow integration

In the current workflow, mother’s milk is collected from the NICU ward and brought to the NICU kitchen, where it is stored in a refrigerator. At preparation time, two nurses typically work together for approximately two hours per day to prepare feeds, continuously double-checking for which infant each syringe is intended. Once a tray is prepared, it is placed in the NICU kitchen fridge. When all the feeding is prepared it is transported to the fridge at the NICU ward in a cooled trolley.

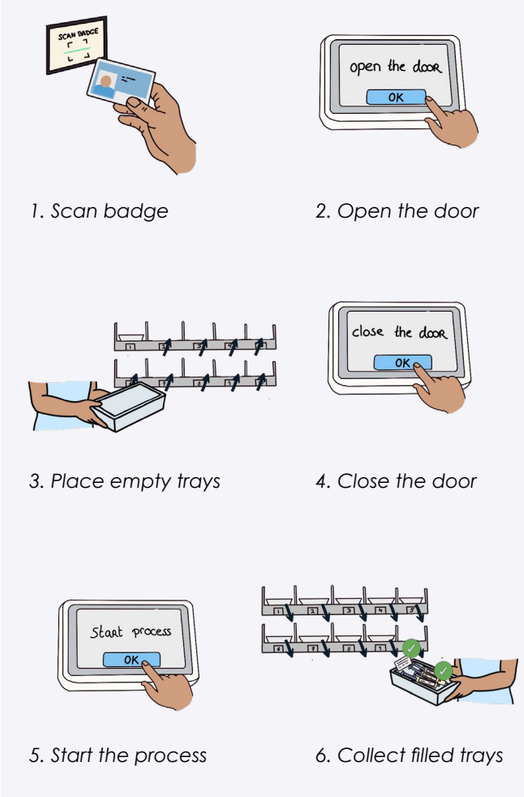
With Neo, the workflow changes significantly. Nurses place the milk bottles in the input module and insert empty trays into the output module. The machine prepares the feeds, after which the nurse only needs to collect the filled trays and transport them to the ward. This reduces repetitive manual work and increases the time available for direct patient care.

Interaction with the Output Module

The primary interaction takes place at the front of the cooled output module. Here, nurses insert empty trays into the drawers and collect filled trays. The design ensures that these actions are simple, clearly visible, and require no fine motor skills or force. Trays are organised per infant, reducing the risk of mix-ups and aligning with existing NICU routines.

User test 1 showed that nurses prefer access to be linked to personal identification, via scanning a staff badge. This allows traceability in case of errors and ensures that only trained staff can operate the machine. Although this introduces one extra step, it significantly increases safety and accountability.

The sequence of actions for the nurse is:



1. Scan badge *2. Open the door*

3. Place empty trays *4. Close the door*

5. Start the process *6. Collect filled trays*

Figure 52: The sequence of actions for the nurse

An important aspect to consider is the set of steps that take place after the use of the output module. During the test, nurses indicated that they consistently place labels on the trays. A visual aid will be implemented to support this, by numbering the drawer compartments according to patient beds. This numbering will be integrated into the overall step-by-step process.

Subsequently, a designated staff member is responsible for collecting the trays with syringes using the trolley. At this stage, a double-check is performed to verify that all trays have been correctly collected and placed in the trolley. As previously discussed, these actions should be accommodated within the existing workflow rather than eliminated. By numbering the drawer compartments, a sense of reliability and trust is expected to develop, which may allow the necessity of the double-check to be reconsidered or potentially eliminated in the future.

Pickup Moments

During User Test A, the frequency of the feeding preparation process was discussed. Currently, feedings are prepared once daily for the subsequent 24 hours. This approach ensures that there is only one moment per day during which nurses need to work together to carry out this time-intensive task. With the introduction of Neollie, it may be considered to prepare feedings for the upcoming 12 hours instead. This would allow potential adjustments to the feeding regimen to be implemented at an earlier stage. Preparing feedings more frequently than every 12 hours is not desirable, as it would require nurses to repeatedly walk back and forth to the machine, resulting in excessive time spent operating the system.

Cleaning

From User Test A, it became clear that trays are currently cleaned once per day using water and cleaning cloths, while the transport trolley is centrally cleaned in the hospital once per day. Nurses indicated that cleaing the machine should continue to be cleaned on a daily basis.

User Test C further indicated that the nurses reported cleaning the equipment on a daily basis. They stated that the Unit for Infection Prevention (UNIP) provides institutional guidelines aimed at preventing infections (Erasmus MC, n.d.-f). Consequently, Neo would need to be reviewed by UNIP, after which specific cleaning guidelines would be established. It is highly likely that these guidelines would align with the current cleaning procedures, implying that the device would need to be cleaned on a daily basis.

Interface Design

The system includes both a machine interface and a separate display interface. As previously indicated, the drawers will be provided with clear and recognizable numbering to ensure easy identification. In addition to physical interaction, digital feedback plays an important role. To determine which information should be displayed, a display user test was conducted (Section 7.4). This test focused on the content of the information rather than on visual design or form.

The interface is designed to support, not dominate, the work process. It provides clear status information such as:

- "Ready to load,"
- "Processing,"
- "Ready for pickup."

Warnings and errors are communicated clearly and unambiguously, for example:

- Tray missing,
- Drawer incorrectly positioned,
- Process paused,
- Blockage,

User testing demonstrated that providing sufficient and meaningful information within the interface is essential. Displaying the temperature alone is not adequate; users must also be able to determine whether the temperature falls within a predefined safe range. Without this contextual information, the data lacks practical value.

In addition, error communication must be clear, specific, and actionable. When a malfunction occurs, the interface should explicitly state the nature of the problem, outline how it can be resolved, and indicate who is responsible for resolving it. Users emphasized the importance of being able to report technical issues directly through the system and receiving confirmation that the report has been successfully submitted. Furthermore, they require transparency regarding the specific issue and an estimated timeframe for resolution. The system must also account for operational continuity. Since nutritional preparation takes place on a daily basis, including weekends, a clear and accessible weekend protocol is required to ensure consistent and safe use outside regular working hours.

Importantly, not all errors should be handled in the same manner. Minor issues, such as a missing tray or an open door, can be resolved directly by the nurse. In contrast, more complex faults, such as mechanical blockages, require intervention by trained technical staff or Neollie support. The interface should therefore clearly distinguish between user-resolvable issues and those requiring technical assistance.

With regard to feedback, visual feedback should be leading during normal use. However, in critical situations, such as when the temperature falls outside the safe range, an audible alarm must be triggered. Nurses explained that the current refrigerator is equipped with a XiltriX device that emits a sound and sends a notification to their phone when the temperature is incorrect. To ensure that the workflow remains consistent and familiar, Neo should provide the same type of feedback: both an audible alarm and a phone notification when critical deviations occur.

The system is operated via a resistive touchscreen. In clinical environments, where nurses frequently wear non-conductive medical gloves and hygiene is critical, resistive touchscreens are particularly suitable because they respond to pressure rather than electrical conductivity. This allows reliable operation while wearing standard medical gloves. In addition, resistive screens are generally durable and can be cleaned easily, making them appropriate for hygiene-sensitive healthcare settings (Beamers & Touchscreens, n.d.).

Look and Feel

The look and feel of the output module contribute directly to user trust. A calm, medical appearance with light colours supports visual inspection and fits within hospital aesthetics. Materials and finishes are chosen to appear clean, robust, and hygienic (see Section 8.3), without creating an overly industrial impression.

Tactile feedback is also important. Doors and drawers must move smoothly and predictably, without jerky motion or unexpected resistance. This contributes to a sense of control and reliability.

The system should feel more like a "refrigerator" than a "machine." This is achieved by limiting visible metal parts, avoiding sharp edges, hiding wiring, and using smooth plastic surfaces. Rounded corners prevent injury and support safe daily use.

Look & Feel

A typical razor integrates electronics within a well-sealed housing, demonstrating how internal complexity can be safely enclosed.

A refrigerator interior illustrates rounded edges and the absence of sharp features, supporting safe and intuitive daily use.

The fan system shows how functional components can be covered by smooth, shiny surfaces, creating a clean and hygienic appearance.

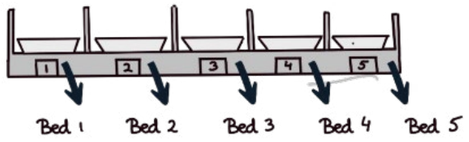
9.2 Data, Traceability and Patient Safety

Within the Neo system, data is not only a technical layer but is actively supported through physical and interaction design choices. The design of the DualDrop output module directly contributes to traceability and patient safety by making key safety principles visible, tangible, and easy to use for nurses.

User Identification and Accountability

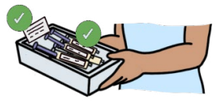
A first design element is user identification through badge access. Before a nurse can interact with the output module, they must authenticate using a personal badge. This ensures that every critical action, such as opening the output door, loading trays, or retrieving filled trays, is linked to a specific user. In case of deviations or errors, it is therefore always possible to trace who performed which action and at what time. This is not intended as a control mechanism, but as a way to support learning, accountability, and quality improvement. In this way, only trained nurses are authorized to operate and manage the device.

Spatial Organisation as Safety Mechanism



Secondly, the physical organisation of the drawers and trays supports patient traceability. Each drawer contains numbered tray positions, corresponding to fixed bed numbers. Over time, this creates a stable mental model for nurses: tray position 1 always belongs to bed 1, tray position 2 to bed 2, and so on. This spatial coding reduces cognitive load and minimizes the risk of mix-ups.

Double-Check Through Existing Clinical Practice



In addition to this spatial logic, the current clinical practice of using stickers is deliberately maintained. Nurses continue to place patient stickers on the trays after removal from the machine. This creates a double-check system: digital tracking within the machine is combined with visual identification with a sticker. Syringes already receive individual labels earlier in the process, meaning that both the syringe and the tray can always be cross-checked. By keeping this familiar routine, the design supports safety without forcing nurses to abandon trusted habits.

Controlled Physical Access

The location of the machine further supports patient safety. Because the Neo system is placed in the NICU kitchen, access is naturally limited to trained staff. Parents and other visitors cannot reach the machine. This reduces the risk of misuse or accidental interference. Access is further restricted through the badge system and an electronically locked door. The output door cannot be opened freely: it is controlled by an electromagnetic lock and only releases when the system indicates, via the display, that it is safe to do so. This prevents users from opening the system during active processes or in unsafe states. Both now and in the future, badge-based access will be implemented to ensure secure and controlled use of the device.

Integration With Medical Data Systems

With regard to digital patient data, the system is intended to align with existing hospital structures. Feeding prescriptions are currently managed in the HiX system, where physicians determine the required volumes of breast milk, fortifier, and other nutritional supplements. However, nurses indicated that adjustments to the prescribed amount of powdered fortifier are frequent in daily practice. At present, such changes are typically communicated by telephone and then manually implemented.

Although enabling local adjustments at the device level would require additional certification and regulatory compliance, potentially increasing complexity for Neollie, the user feedback clearly demonstrated that the ability to modify quantities directly at the machine is highly desirable. Integrating this process into the interface would prevent workflow disruptions and reduce the time and effort required when last-minute changes occur.

To ensure that the Neo system remains both valuable and usable in practice, it should therefore allow authorized users to adjust prescribed quantities through a controlled and traceable interface function. This would maintain clinical flexibility while supporting efficiency and preserving the system's overall desirability.

Exceptional Scenarios

The system must be able to deal with irregular situations:

- If a bed is temporarily empty, the system should give a warning but still allow the process to start after confirmation.
- If a new infant arrives unexpectedly, formula will, both in the current situation and in the near future, be prepared manually. This ensures that care can continue without delay.

In the future, the system will include an additional feature allowing milk for the newly admitted infant to be added during an ongoing preparation process. This functionality would increase flexibility while maintaining continuity of care.

10

Strategy & Implementation

This chapter explores how the DualDrop concept can be implemented in practice and further developed over time. It addresses scalability, hospital integration, and the broader conditions required for adoption.

10.1 Scalability & Future Development

Scaling up

A central design strategy throughout this project has been to not only address current requirements, but also to anticipate future growth. At the start of the project, Neo was intended to serve ten patients simultaneously. During the course of the project, Neollie indicated an ambition to scale this to twenty patients. For this reason, the DualDrop system was designed around ten trays, while structurally allowing for expansion.

Scalability is primarily achieved through the modularity of the drawer system and the vertical flexibility of the dropping mechanism. Additional drawers can be added beneath the existing ones without fundamental changes to the movement logic of the arm. However, this does require a larger cooled volume, which implies either increasing the total height of the machine or redistributing space in the lower section, where electronics and cooling components are located.

For higher capacities, two strategies are recommended: either running the system in two production shifts per day (for example every 12 hours), or deploying multiple machines in parallel. Both options reduce the need to keep a single large cooling space open for extended durations.

Frequent production cycles introduce additional complexity, particularly in the presence of emergency cases or last-minute changes. This reinforces the importance of clear procedures for exceptions, as well as robust planning of when and how often the system is operated.

Transition, trust and safety culture

Introducing automation into a highly sensitive clinical workflow is not only a technical challenge, but also a cultural and emotional one. During user tests, especially among more experienced staff, automation was sometimes perceived as exciting, yet also unsettling. Many daily actions in clinical nutrition delivery are deeply embedded in routine, including mutual double-checking practices between colleagues.
For this reason, the current design intentionally preserves familiar safety steps, such as dubbel checks, even if the system could technically automate them. This plays an important transitional role: they allow users to gradually build trust in the technology while maintaining established safety routines. Over time, as confidence grows and reliability is consistently demonstrated, certain double-check steps may be reduced, but only after careful evaluation and clinical validation.

Trust is as important as technical accuracy. Even a system that functions flawlessly will not be adopted if nurses do not feel safe relying on it. The design therefore leaves room for human control, interpretation, and intervention. The robot is intended to support healthcare professionals, not replace their judgment, so that staff feel included and supported rather than excluded from the process.
Human involvement remains essential in monitoring, decision-making, and responding to exceptions. This shared responsibility strengthens a safety culture in which technology and healthcare professionals work together rather than competing for control.

Key conditions for successful implementation include:

- Transparency: users must understand what the system is doing and why.
- Clear feedback and error detection.
- The ability to intervene when needed.
- Confidence that the right nutrition reaches the right patient at the right time.

In this way, the design supports not only technical performance, but also a gradual and safe transition toward automation within clinical practice.

Placement of Neo

At present, the Neo machine is envisioned to be placed in the NICU kitchen, which is physically separated from the NICU ward. Trays are transported using trolleys, following existing logistics. In the future Erasmus MC building (planned around 2032), the NICU kitchen is expected to be located closer to the ward.

In later phases, the system could potentially be placed even closer to, or directly on, the NICU ward. This would only be feasible if the machine operates quietly, safely, and without disrupting the clinical environment. Such placement could reduce transport steps but would require careful consideration of space, noise, hygiene, and access control.

Figure 53: Neo in the NICU kitchen

Figure 54: Neo in the NICU ward

Stakeholder and Implementation Context

Although the system is currently designed mainly for NICU kitchen nurses, successful implementation requires that a broader group of stakeholders understands how it works. This includes ward nurses, physicians, technical staff, and hospital management. Clear training, practical documentation, and a gradual introduction are therefore essential.

For wider adoption, beyond Erasmus MC, Neollie would need to provide clear implementation guidelines, including installation procedures, workflow support, and defined responsibilities for maintenance and quality control. Close collaboration with clinical staff at each hospital will be important to ensure that the system supports existing routines rather than disrupts them.

In this way, implementation depends not only on technical performance, but also on how well the system fits within daily hospital practice.

Ethical Responsibility and accountability

When implementing automation technologies in neonatal care, ethical questions arise regarding responsibility and accountability in case of errors or system failures. If an incident occurs, such as incorrect filling or the loss of breast milk, it must be clear whether responsibility lies with the machine, the operator, the designer, or the healthcare organisation. In practice, accountability is distributed across multiple stakeholders involved in the development, deployment, and use of the system.

Medical device developers and manufacturers carry an ethical obligation to prioritise patient safety throughout the design process. Because clinical technologies can cause harm in cases of malfunction or misuse, systems must be designed with predictable failure behaviour, robust monitoring, and appropriate safeguards (Citron, 2012).
Within the DualDrop output concept, this is reflected in the integration of sensor-based control loops for error detection, verification of correct tray placement, and monitoring of safe operating conditions before output is released.

Hospitals and clinical staff also play a critical role in ensuring safe operation. The introduction of robotic systems requires that users maintain a minimum level of competence and understanding. Training, clear procedures, and controlled access are therefore essential (Citron, 2012).

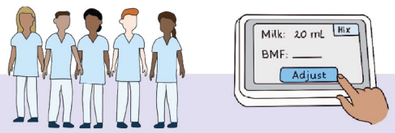
In this design, badge-based access was considered as a mechanism to ensure that only authorised and trained nursing staff can operate the system, supporting both safety and traceability.
Importantly, breast milk carries not only medical value but also significant emotional meaning for parents. Loss of milk due to technical failure is therefore not merely a logistical issue, but a sensitive ethical concern.
The DualDrop design aims to minimise such risks through controlled access, traceability, early error detection, and the possibility of human verification before feeds enter the clinical workflow.

Overall, responsibility should therefore not lie solely with the technology or with the user, but be shared between both. By combining technical safeguards with human oversight, risks can be reduced and trust in the system can gradually develop in neonatal care practice.

10.2 Strategic Roadmap

Figure 55 presents a strategic roadmap outlining the implementation and further development of the DualDrop system within the Neo machine. The roadmap distinguishes between short-, medium-, and long-term perspectives. It illustrates how the system can evolve from an initial implementation in the NICU kitchen towards broader integration within hospital infrastructure.

In the short term, the focus lies on:
- Reliable operation for up to ten patients,
- Integration into the NICU kitchen,
- Integration into workflow,
- Preserving existing safety routines.



In the medium term, the focus lies on:
- Scaling to more drawers or multiple machines, or more process cycles,
- Refining interaction and reducing redundant checks where appropriate,
- Broader training of NICU staff.
- Integration with hospital information systems (HiX)

In the long term, the focus lies on:
- Flexible placement closer to the NICU ward,
- Integration in other hospitals.

Figure 55: Strategic Roadmap

11

Evaluation and Discussion

This chapter reflects on the outcomes of the design process and assesses the developed DualDrop concept in relation to the project objectives. First, the main research question and its sub-questions are revisited and answered based on the design results. Subsequently, the design is evaluated against the established MoSCoW criteria to determine to what extent the requirements have been fulfilled. Finally, a discussion is presented in which the limitations of the study are addressed and directions for future development are identified.

11.1 Answers to Research Questions

In this section, the sub-research questions defined at the start of this project are revisited and answered based on the insights gained throughout the design process. These answers are grounded in a combination of literature, user research, technical analysis, and iterative prototyping.

At the same time, it is important to approach these findings with a critical design perspective. The proposed solutions are not presented as definitive or universally applicable outcomes, but rather as context-specific design directions shaped by the constraints, assumptions, and scope of this graduation project. Therefore, each answer is accompanied by a reflection on its limitations, the degree of validation achieved, and the extent to which the findings can be generalized beyond the specific NICU context of Erasmus MC.

Research Question

How can the output stage of the Neo system be designed to deliver cooled and well-organized syringes to nurses in a way that is safe, efficient, and seamlessly integrated into the workflow of the NICU environment?

Research Sub-Question

Cooling	Organization	User interaction	Constraints
Which existing cooling principle is most suitable to keep syringes at a stable temperature during the waiting period, and how should these principles be considered in the design?	How can syringes be grouped and presented so that each infant's feedings are clearly separated and mix-ups are prevented?	How can the output stage be aligned with the daily nursing workflow in the NICU, ensuring that trays fit existing storage solutions and enable a safe and user-friendly hand-over to nurses?	What spatial, hygienic, and regulatory requirements must the output design meet in order to be implemented in the NICU of Erasmus MC?

Cooling

Which existing cooling principle is most suitable to keep syringes at a stable temperature during the waiting period, and how should these principles be considered in the design?

The most suitable cooling principle for the Neo output module is a vapor-compression refrigeration system, comparable to conventional refrigeration. This principle was selected based on its proven reliability, scalability, and ability to maintain stable temperatures within the required range of 3–5 °C, as defined by NICU storage requirements.

Compared to alternative solutions such as Peltier elements, refrigeration systems offer significantly higher cooling capacity and energy efficiency, particularly when handling large volumes of syringes simultaneously. Within the Neo system, this principle is translated into a distributed cooling architecture, in which refrigerant tubing is integrated into the walls of the output compartment. This enables indirect cooling of syringes without direct contact, thereby supporting hygienic requirements.

From a design perspective, cooling is not treated as an isolated technical subsystem but as an integrated spatial constraint that directly influences layout, storage density, and user interaction. The positioning of tubing, airflow, and insulation defines both the geometry of the output module and the accessibility of trays.

Discussion & Limitations

While the refrigeration principle is theoretically well-founded, an important limitation of this work is that the cooling system was not physically prototyped or experimentally validated. The design therefore assumes that temperature stability can be maintained under real operational conditions, including frequent door openings and varying load sizes.

In addition, the choice for a refrigeration-based system was partly predetermined in consultation with Neollie, which limits the exploration of alternative cooling concepts. As a result, the findings are context-specific rather than broadly comparative, and may not fully represent the optimal solution space.

Organization

How can syringes be grouped and presented so that each infant's feedings are clearly separated and mix-ups are prevented?

Syringe organization within the Neo output module is structured around patient-specific physical separation combined with visual and spatial hierarchy. Each patient is allocated a dedicated compartment within a drawer, ensuring that syringes remain grouped throughout the entire output process.

This approach builds directly on existing NICU practices, where nurses already organize syringes per patient to prevent errors . By translating this logic into the design, the system maintains continuity with current workflows while reducing cognitive load.

The final DualDrop concept supports this by automatically placing syringes into predefined compartments, eliminating the need for manual sorting. In addition, clear visual indicators (e.g., labeling positions) reinforce identification and reduce the risk of mix-ups.
Importantly, organization is not only a spatial problem but also a safety mechanism, ensuring traceability and supporting double-checking practices that are critical in neonatal care.

Discussion & Limitations

Although the organizational strategy aligns well with observed workflows, it is primarily based on qualitative insights from a limited number of observations and user tests. The extent to which these findings are representative of broader NICU practices remains uncertain.

Moreover, the design assumes that physical separation alone is sufficient to prevent errors, while in practice, nurses rely on multiple redundant checks (labels, digital systems, verbal confirmation). The interaction between the Neo system and these existing safety layers has not been fully validated.

Another limitation is that the system was tested using prototypes that simulate organization but do not fully replicate real-world complexity, such as time pressure, interruptions, or high patient variability. As a result, the effectiveness of the organizational strategy in reducing errors cannot yet be quantified.

User interaction

How can the output stage be aligned with the daily nursing workflow in the NICU, ensuring that trays fit existing storage solutions and enable a safe and user-friendly hand-over to nurses?

The output stage is aligned with the NICU workflow by embedding the system within existing routines rather than introducing new ones. The design supports a workflow in which nurses collect trays, verify contents, and transport them to ward refrigerators, mirroring current practices.

Key interaction principles include:
- Direct tray-based interaction, compatible with existing trolleys and refrigerators.
- Minimal additional steps, reducing disruption to established routines.
- Ergonomic positioning, allowing safe and efficient handling.
- Clear system feedback, supporting trust and transparency.

The DualDrop mechanism contributes to this alignment by ensuring that syringes are already organized upon output, allowing nurses to transition seamlessly from collection to distribution.

Discussion & Limitations

A key limitation is that user validation was based on prototype testing in controlled or semi-controlled environments, rather than in a fully operational NICU setting. This means that factors such as time pressure, multitasking, and interruptions were only partially represented.

Additionally, the number of participating nurses was limited, which restricts the representativeness of the findings. Differences in experience levels, personal preferences, and institutional practices may influence how the system is perceived and used.

The design also assumes that integration into the workflow will lead to acceptance. However, organizational factors, such as training, hospital policies, and resistance to change, were not deeply explored. As a result, successful integration cannot be guaranteed based on design alone.

Constraints

What spatial, hygienic, and regulatory requirements must the output design meet in order to be implemented in the NICU of Erasmus MC?

The design of the Neo output module is governed by a set of strict spatial, hygienic, and regulatory constraints derived from hospital protocols and system requirements.

Spatially, the system must fit within predefined hospital dimensions and remain compatible with existing infrastructure. Hygienically, all materials and surfaces must withstand frequent cleaning and prevent contamination, with particular attention to minimizing contact with critical syringe areas.

From a regulatory perspective, the system must ensure:
- Controlled user access and traceability.
- Safe enclosure of mechanical components.
- Compliance with medical device hygiene standards.

These constraints strongly shape the design, limiting certain mechanical solutions while prioritizing safety, cleanability, and robustness.

Discussion & Limitations

While the constraints are clearly defined, an important limitation is that full regulatory validation (e.g. clinical certification) was beyond the scope of this project. As a result, the design should be considered a conceptual and pre-engineering solution, rather than a fully compliant medical device.

The project also focuses on a single hospital context (Erasmus MC), which means that spatial and procedural constraints may differ in other institutions. Therefore, the findings have limited generalizability and may require adaptation for broader implementation.

11.2 Design Requirements Evaluation

In this section, the final design is evaluated against the previously defined requirements. Each requirement is assessed to determine whether it has been fully fulfilled, partially fulfilled, or not fulfilled. A brief justification is provided for each evaluation, summarizing how the design addresses the requirement.

#	Requirement	Fulfilled?	How/Why
M1	Be able to handle up to 10 patients.	Yes	Two drawers are divided into five compartments each, resulting in a total of ten compartments, for 10 patients.
M2	Be able to handle 8 to 12 syringes per patient.	Yes	The mechanism can be adjusted per patient.
M3	Be able to handle 2 different syringe volumes. (20 ml and 60 ml)	Yes	The gripper of the DualDrop mechanism opens and closes horizontal, enabling it to handle syringes of different sizes.
M4	Syringes must be physically separated per patient.	Yes	The syringes are separated per patient, as each patient is assigned an individual compartment within the drawer.
M5	The output must clearly indicate for which infant each group of syringes is intended.	Yes	Each compartment in the drawer is labelled with a number that corresponds to the patient's bed number.
M6	Syringes must be stored in a cooled environment between 4–6 °C.	Partial	The principle has been conceptualized but has not yet been tested; therefore, it is currently at Technology Readiness Level 2.
M7	The system must continuously monitor and report internal temperature.	Yes	The machine contains a sensor that measures the temperature, which is displayed on the screen.
M8	The system must be compatible with the currently used white trays and trolley.	Yes	The drawers are designed around the dimensions of the white trays.
M9	Robotic movements and mechanical parts must be physically shielded during operation.	Partial	Although the mechanical components are intended to be shielded, this has not yet been realized in a physical prototype.
M10	The access door must remain locked during active operation.	Yes	The door remains closed due to an integrated sensor and can only be opened when the machine is not operating.
M11	All milk-contact-related components must be cleanable within 24 hours.	Yes	The surfaces are easy to clean due to the limited number of edges and seams.
M12	Surfaces must withstand cleaning with water and alcohol-based disinfectants.	Yes	The material is resistant to water and alcohol.
M13	The system must be operable while wearing medical gloves.	Yes	The system is robust and can be easily operated while wearing medical gloves; the touchscreen is also compatible with glove use.
M14	The system must report operational status and fault conditions clearly.	Yes	Sensor feedback immediately provides a notification containing clear information about the nature of the problem, how it can be resolved, who is authorized to resolve it, and the estimated downtime of the machine.
M15	The robotic handling system must minimise physical contact with the syringe and, if contact is required, it may only occur on predefined non-critical areas that do not come into contact with milk.	Yes	The DualDrop mechanism is designed to touch only the part of the syringe that has not come into contact with milk.
M16	Critical components must be modular and replaceable without full system disassembly.	Partial	The drawers and actuators can be easily replaced. The replaceability of the DualDrop mechanism has not been further elaborated, but it is also intended to be replaceable. Currently, all components are supplied by Festo.
M17	Materials must be moisture-resistant and corrosion-resistant.	Yes	Material selection has taken corrosion and condensation into account.
M18	The system must fit within the maximum allocated hospital dimensions (2500 × 1500 × 2000 mm for total machine).	Yes	The Output Module is part of the overall machine and remains within the specified dimensional constraints.
M19	Controlled user access must be implemented.	Yes	Access is only possible via a badge and is granted to nurses who have sufficient training to operate the machine.

11.3 Discussion

This project has resulted in a design proposal for the output module of the Neo system that is grounded in user research, system analysis, and iterative prototyping. The strength of the project lies in the combination of technical exploration and human-centered design thinking, which made it possible to address not only how the system should function, but also how it should be understood and used within the NICU context. At the same time, several limitations must be acknowledged when interpreting the results.

First, the project was conducted within a single institutional context, namely the NICU of Erasmus MC. This allowed for in-depth understanding of one specific workflow, but it also means that the findings are strongly shaped by local routines. For example, the use of white trays, the organization of the NICU kitchen, and the way responsibilities are divided between nurses may differ in other hospitals.
As a result, the final concept should be understood as a context-specific design response rather than a universally validated solution. Broader validation across multiple hospitals would be needed to assess the extent to which the proposed output strategy is transferable to other neonatal care settings.

Second, the representativeness of the participant group was limited. The user insights were derived from a relatively small number of nurses and stakeholders, which is appropriate for an exploratory design project, but does not allow claims of representativeness in a statistical sense.
In addition, the participating nurses differed noticeably in communication style, openness to innovation, and the extent to which they preferred structure or flexibility in the workflow. This resulted in feedback that was at times quite divergent.
This variation influenced the interpretation of the results. In several user tests, individual comments could not be taken as direct design instructions, because they sometimes reflected personal working preferences rather than shared requirements.

To address this, greater weight was given to patterns that recurred across participants and across methods, such as the need for patient-specific separation, clarity in output organization, and minimal disruption of existing tray-based workflows. In this sense, the design decisions were not based on isolated preferences, but on the convergence of repeated observations, interviews, and prototype evaluations. Nevertheless, the limited and varied participant sample remains a constraint, and future validation with a broader and more diverse group of nurses would strengthen the robustness of the conclusions.

Third, a discussion session with the team responsible for designing the new Erasmus MC hospital building, planned for 2032, was not possible within the timeframe of this thesis.
Early alignment with architectural and infrastructural plans could have provided valuable insights regarding spatial integration, utilities, maintenance access, and long-term positioning of the Neo system.
Such information may have informed final design refinements and improved the future-proof integration of the concept within the renewed hospital environment.

Fourth, the testing was primarily conducted using low-fidelity and subsystem-level prototypes. These prototypes were valuable for exploring workflow alignment, interaction logic, and safety perception, but they did not replicate the complete technical and environmental conditions of clinical use.
The full system has not yet been evaluated as one integrated operational unit. This means that important aspects such as timing, robustness, accumulated tolerances, real-world error scenarios, and interaction under time pressure remain insufficiently understood.
In a real NICU setting, interruptions, urgency, and environmental distractions are likely to influence both system use and error sensitivity. These factors could not yet be tested in full.

Finally, the cooling system was conceptually designed based on established refrigeration principles, but it was not physically built or experimentally validated within the scope of this project. Although the chosen principle is technically plausible and grounded in existing cooling practice, its integration into the specific geometry and interaction pattern of the Neo output module remains hypothetical.

The cooling concept should therefore be regarded as being at a low Technology Readiness Level (TRL 2), meaning that additional technical development, prototyping, and validation are required before implementation in a clinical environment can be considered.

These limitations do not undermine the project, but they do require a careful interpretation of the results. The design should be understood as a substantiated direction, not yet as a fully validated solution.

12 Conclusion

This chapter evaluates the final DualDrop output concept using three criteria for success: feasibility, desirability, and viability. Based on this evaluation, recommendations are provided for further development, followed by a reflection on my role and growth as a designer throughout the project.

12.1 Validation of DualDrop

This section evaluates the final DualDrop output concept using three criteria for success: feasibility, desirability, and viability, as described in the Delft Design Guide framework (van Boeijen, 2013). Together, these criteria provide a structured reflection on whether the proposed system can be realistically implemented in the NICU context, whether it meets user needs, and whether it can deliver value in the long term. At the same time, this evaluation is approached critically, acknowledging the current level of validation and remaining uncertainties.

Feasibility

Feasibility refers to the extent to which a design is technically and practically achievable within the constraints of the system and its environment. For DualDrop, feasibility was assessed primarily through mechanical integration, technological robustness, and compatibility with existing infrastructure.

From a hardware perspective, the concept was intentionally kept mechanically straightforward. The system relies on horizontally moving drawers combined with a vertically adjustable dropping mechanism, allowing syringes to be positioned and released in a controlled manner. This approach reduces unnecessary degrees of freedom while maintaining sufficient flexibility for accurate placement.

In addition, the DualDrop mechanism builds upon components and actuation principles already applied within Neollie's existing robotic architecture, such as standardized pneumatic and linear motion solutions. This increases technical compatibility with other subsystems and supports software feasibility, as the control logic can remain consistent with current development practices.

Sensor integration further strengthens feasibility. The system requires only relatively simple and well-established sensors for presence detection, positioning feedback, and temperature monitoring, which can be implemented without introducing excessive complexity.

Finally, the cooling strategy is based on a conventional refrigeration cycle rather than a newly developed cooling technology. By relying on an existing and proven principle, the design avoids unnecessary technical risk and reduces barriers related to certification and validation.
Overall, the DualDrop system is considered technically feasible within the current development direction of Neollie.

However, the feasibility assessment remains partly conceptual. The system has not yet been tested as a fully integrated mechanical setup, and key aspects such as timing and synchronization between subsystems have not been validated. For example, the DualDrop mechanism has not yet been physically connected to the preceding weighing subsystem, meaning that the transfer of syringes between these stages has not been tested in practice.

In addition, the cooling system, although theoretically grounded, has not been physically implemented within this project. As a result, feasibility is supported by design reasoning and subsystem insights, but not yet by full-system validation.

Overall, the DualDrop system can be considered technically plausible within the current development direction of Neollie, but further engineering and testing are required to confirm its feasibility in practice.

Desirability

Desirability concerns how well a design meets the needs, expectations, and daily practices of its intended users. In the case of DualDrop, the primary users are NICU kitchen nurses responsible for preparing and organizing infant feeds.

DualDrop was designed to integrate seamlessly into the existing workflow of the NICU feeding kitchen, requiring minimal disruption of current routines. By maintaining the use of the standardized white trays already familiar within Erasmus MC, the system supports intuitive handling and avoids the need for new logistical tools.

A key design intention was to minimize user interaction steps. Nurses are only required to insert empty trays, retrieve filled trays, and respond to clear system feedback. This reduced interaction load directly supports the broader project goal of freeing up nursing time for direct patient care.

As stated in the introduction of this report, *a successful design must also consider how people experience and interpret the product: does it truly work in practice as intended, and is it understood and used in the way the designer envisioned?* The qualitative evaluation sessions with NICU staff indicated that the DualDrop output concept aligns well with their expectations regarding clarity, safety, and usability. The system was generally perceived as understandable and supportive rather than disruptive, which is essential for future acceptance.

At the same time, the desirability assessment is based on a limited number of qualitative user interactions. The feedback showed variation between participants, reflecting differences in personal working styles and preferences. While consistent patterns were identified, such as the importance of clear organization and minimal workflow disruption, the results cannot be considered fully representative of all potential users.

Moreover, the evaluations were conducted using prototypes that simplify real-world conditions. Factors such as time pressure, interruptions, and long-term use were not fully captured. As a result, while the concept shows strong alignment with user expectations, further validation in a real clinical setting is required to confirm its desirability in daily practice.

Viability

Viability addresses the long-term sustainability of the concept, both in terms of technical maintenance and continued value within the clinical environment.

The DualDrop output module was developed with modularity and serviceability in mind. Key components such as drawers, actuators, and seals can be accessed and replaced independently, supporting repairability and reducing downtime in case of wear or malfunction.

Moreover, the concept does not require the hospital to introduce new consumables or storage formats, as it continues to use the trays already implemented in the NICU. This reduces operational costs and supports practical adoption.

The design also allows for future scalability. Additional drawers or expanded capacity can be considered within the same structural logic, enabling the system to evolve alongside changing NICU demands.

However, the viability of the concept has not been evaluated in terms of economic feasibility, maintenance logistics, or regulatory approval processes. Factors such as cost of implementation, required training, integration with hospital IT systems, and compliance with medical device regulations remain outside the scope of this project. These aspects will play a critical role in determining whether the system can be successfully implemented in practice.

In addition, long-term performance, including wear, cleaning cycles, and system reliability over time, has not yet been tested. As a result, the viability assessment remains indicative rather than conclusive.

Taken together, the DualDrop concept demonstrates promising characteristics for long-term integration, but its actual viability will depend on further technical development, validation, and alignment with clinical and organizational requirements.

12.2 Recommendations

This section provides final recommendations, concluding the delivery phase of this thesis. It builds upon the concept evaluation and identifies key starting points for further development.

Although the DualDrop output concept demonstrates strong potential in terms of feasibility, desirability, and long-term viability, several aspects require further development before clinical implementation can be realised. The following recommendations outline key next steps for Neollie and future design iterations.

Full System Integration and Validation

A first and essential step is the validation of the system as a fully integrated whole. Within this project, the DualDrop mechanism was developed and tested primarily at a subsystem level. The interaction between subsystems, particularly the transition from the weighing stage to the output module, has not yet been physically tested.

Future development should therefore focus on building a fully functional prototype in which all subsystems are connected. This would allow validation of timing, synchronization, and the reliable transfer of syringes between mechanisms. Testing the complete system will also provide insight into accumulated tolerances, potential failure points, and overall robustness under continuous operation.

Sensor integration and Fault handling

The reliability of an automated feeding system depends heavily on robust fault detection and clear system feedback. While this project outlines a basic sensor strategy, a complete and validated sensor architecture has not yet been developed.

Future work should focus on defining and testing a comprehensive sensor system that monitors syringe presence, positioning, and system status throughout the entire output process. In parallel, a structured fault-handling protocol should be developed, ensuring that errors are detected, communicated, and resolved in a safe and transparent manner. Given the clinical context, it must be assumed that a fully error-free system is not achievable, making controlled error handling essential.

Validation Through Higher-Fidelity Prototyping

The Prototypes provided valuable qualitative insights, particularly regarding workflow alignment and user expectations. However, future evaluations should include higher-fidelity prototypes capable of performing full syringe-dropping cycles under realistic conditions.

For this purpose, a fully functional cooling system would need to be built in order to test whether the selected materials are hygienic and resistant to condensation, and whether a stable and properly controlled temperature can be maintained.

Development and Validation of the Cooling System

Although the cooling concept is based on established refrigeration principles, it has not yet been physically implemented within this project. As a result, key aspects such as temperature stability, airflow behavior, and the influence of repeated user interaction remain uncertain.

A next step is to develop and test a working cooling prototype. This should include validation of temperature consistency (3–5 °C), as well as the effects of opening cycles and varying load conditions. In addition, material behavior under condensation and cleaning conditions should be evaluated to ensure compliance with hygiene requirements.

Integration Input and Output Modules

A next design project could be to integrate the input and output modules, especially researching the possibility to use the cooling mechanism as a shared part. This increases the energy efficiency but will reduce the size of the system as well.

Expanded User Validation in Realistic Contexts

The current evaluation of the design is based on qualitative feedback from a limited group of NICU nurses within Erasmus MC. While this provided valuable insights, the variation in responses between participants indicates that user preferences and working styles differ.

Future research should therefore involve a broader and more diverse group of users, ideally across multiple hospitals. In addition, testing should take place in a more realistic clinical context, where factors such as time pressure, interruptions, and multitasking can be observed. This would allow a more reliable assessment of usability, acceptance, and error sensitivity in daily practice.

Alignment with Hospital Infrastructure and Future Implementation

Due to time constraints, alignment with the architectural and infrastructural plans of the new Erasmus MC hospital (planned for 2032) was not established during this project. However, such alignment will be critical for successful implementation.

Future development should include collaboration with hospital planners and technical staff to ensure compatibility with spatial layouts, utilities, maintenance access, and workflow logistics. Early integration at this level can prevent costly redesigns and support long-term adoption of the system.

Economic and Regulatory Validation

Finally, the current project does not include a detailed assessment of economic feasibility or regulatory compliance. While the design choices aim to support feasibility and reduce complexity, aspects such as production costs, maintenance requirements, certification processes, and compliance with medical device regulations remain to be addressed.

A next step is therefore to evaluate the concept from a business and regulatory perspective. This includes cost analysis, lifecycle considerations, and preparation for certification procedures. These factors will ultimately determine whether the DualDrop system can move beyond a design proposal toward real-world implementation.

12.3 Reflection

At the beginning of this project, I was confronted with a question that honestly made me doubt myself: *"We, from Neollie, are mechanical and electrical engineers, what can you, as an industrial designer, add to this machine?"* The Neo robot already looked complex and highly technical. At first, I wondered what my role could really be.

Over time, I realised that my strength is not in competing on mechanical depth, but in connecting technology with people and context. By breaking the system down into smaller parts, I was able to identify where design could truly add value. That place turned out to be the output stage, the moment where automation meets the nurse. Designing how 120 syringes per day are safely organised, cooled, and handed over made the impact of the project tangible and meaningful.

During the project, I noticed that I naturally tend to focus on technical details. I enjoy mechanisms and engineering logic, which helped in understanding the system and developing feasible concepts. However, I had set a personal goal to strengthen my user-centred design skills, and this required conscious effort. I had to regularly step back and question whether decisions were not only technically correct, but also supportive of the nurse's workflow, safety, and trust. Learning to balance these perspectives became a key development point throughout the project..

Looking back at the original project brief, the main goal was to scale the Neollie robot while optimising usability and aligning with hospital requirements. The DualDrop output module addresses this by enabling structured, cooled, and patient-specific syringe handling at scale. Workflow integration, hygiene requirements, safety, and repairability have all been considered and embedded in the design. Through prototyping and testing with nurses, the concept was evaluated not only technically, but also from a user perspective, , but also in relation to user interaction and acceptance.

At the same time, I recognise that my process could have been stronger in how I communicated ideas. Visualisation and illustration are skills I am confident in, yet I did not consistently use them early enough in the design process. In several phases, I focused more on refining concepts internally, while stronger visual communication could have helped to test ideas earlier, align stakeholders, and make design intentions more tangible. This has shown me that clear visualisation is not only a presentation tool, but also a critical design tool for thinking, validating, and convincing others. In future projects, I aim to use visualisation more actively throughout the process to strengthen both my design decisions and my ability to communicate them.

In addition, I recognise that I can further develop my ability to communicate and defend design decisions more explicitly. While the design is well substantiated, there is still room to become more confident and structured in explaining choices, especially when working in multidisciplinary teams.

This project helped me grow as an Integrated Product Designer. I learned that my value lies in shaping how complex technology fits into real healthcare environments. What initially felt like a purely mechanical challenge became a meaningful design opportunity at the intersection of safety, workflow, and human trust.
It forms a solid foundation for my future as an Integrated Product Designer.

Non finis est, sed initium.

Valérie Klemann

References

A

Alphenaar, W. (2019). The NICU neighbourhood: Supporting parents during neonatal intensive care hospitalization through design [Master's thesis, Delft University of Technology]. TU Delft Repository. https://repository.tudelft.nl

C

Citron, P. (2012). Ethics Considerations for Medical Device R&D. Progress in Cardiovascular Diseases, 55(3), 307–315. https://doi.org/10.1016/j.pcad.2012.08.004

D

De Ruiter, A. (2025, June). Mother milk, machines, and medicine: A qualitative study on the potential use of the mother milk robot and how it reshapes the way parents experience caregiving at pediatric and neonatal intensive care units [Master's thesis, Erasmus Universiteit Rotterdam]. Erasmus School of Health Policy & Management.

Dickson, R., & Automations, F. (2026, February). What is a Linear Actuator? The Ultimate Guide to Understanding Linear Actuators. Firgelli Automations. https://www.firgelliauto.com/blogs/actuators/linear-actuators-101?srsltid=AfmBOooUNoxJenhahaJdDlgxcbxkYtKN7KJDMXB_LwvhBK3S110RrDxI

DINED (n.d.). DINED Anthropometric Database: Men/Women 20-60 years (2004). https://dined.io.tudelft.nl/en/database/tool

E

Eglash, A., Simon, L., & The Academy of Breastfeeding Medicine. (2017). ABM Clinical Protocol #8: Human milk storage information for home use for full-term infants (Revised 2017). Breastfeeding Medicine, 12(7), 390–395. https://doi.org/10.1089/bfm.2017.29047.aje

Erasmus MC. (2024). Annual report 2024: Strategy and perspective. https://jaarverslag.erasmusmc.nl/jaarverslag-2024/

Erasmus MC. (n.d.-a). Onze projecten - Erasmus MC. https://www.erasmusmc.nl/nl-nl/vastgoed/onze-projecten#eef8774e-cee9-4126-bd1c-d237d1f3a38b

Erasmus MC. (n.d.-b). Neonatologie intensive care - Kliniek - Erasmus MC Sophia. https://www.erasmusmc.nl/nl-nl/sophia/patientenzorg/klinieken/neonatologie-intensive-care

Erasmus MC. (n.d.-c). NIDCAP-programma. Sophia Kinderziekenhuis. https://www.erasmusmc.nl/nl-nl/sophia/patientenzorg/klinieken/neonatologie-intensive-care

Erasmus MC. (n.d.-d). [Voedingsbeleid intensive care neonatologie]. https://folders.erasmusmc.nl/folders/folders?action=downloadpdf&folderid=FLDR-0VF31546616915PVU8

Erasmus MC. (n.d.-e). Borstvoeding [Patient information leaflet]. https://folders.erasmusmc.nl/folders/folders?action=downloadpdf&folderid=FLDR-LAKA1575387639URZJ

Erasmus MC. (n.d.-f). Infectiepreventie - Specialisme - Erasmus MC. https://www.erasmusmc.nl/nl-nl/patientenzorg/specialismen/infectiepreventie

G

Guetbach, H. (2025). The introduction of the mother milk robot in neonatal care: Understanding nurses' and support workers perspectives [Master's thesis, Erasmus Universiteit Rotterdam]. Erasmus School of Health Policy & Management.

H

Hak, G., Huijbregts, C., Mârroufi, M., Porsul, M., Sperczyński, K., & Tertelici, G. (2024, October). Mission report [Student report, TU Delft Minor Robotics]. TU Delft.

Hak, G., Huijbregts, C., Mârroufi, M., Porsul, M., Sperczyński, K., & Tertelici, G. (2024, November). Design report [Student report, TU Delft Minor Robotics]. TU Delft.

Hak, G., Huijbregts, C., Mârroufi, M., Porsul, M., Sperczyński, K., & Tertelici, G. (2025, January). Pro & con analysis and recommendations: Prototype handover document [Student report, TU Delft Minor Robotics]. TU Delft / Erasmus MC Sophia Children's Hospital.

Heijne, K., & Van der Meer, H. (2019). Road map for creative problem solving techniques: Organizing and facilitating group sessions. Boom uitgevers

I
ICT&health. (2020, February). Innovatie in geboortezorg op afstand bij Amphia en Erasmus MC. ICT&health. https://www.icthealth.nl/nieuws/innovatie-in-geboortezorg-op-afstand-bij-amphia-en-erasmus-mc

ISO - Standards. (n.d.). ISO. https://www.iso.org/standards.html

Ito, M., Tanaka, M., Date, M., Miura, K., & Mizuno, K. (2025). Possibility of microwave thawing of human milk: Effects on milk composition and temperature distribution. Journal of Human Lactation, 41(4), 587–596. https://doi.org/10.1177/08903344251365640

M
Marin-Garcia, J. A., Garcia-Sabater, J., Garcia-Sabater, J. J., & Maheut, J. (2020). Protocol: Triple Diamond method for problem solving and design thinking. Rubric validation. WPOM-Working Papers on Operations Management, 11(2), 49–84. https://doi.org/10.4995/wpom.v11i2.14776

N
NEN. (2018). NEN-EN 1116:2018 en: Kitchen furniture - Coordinating sizes for kitchen furniture and kitchen appliances. https://www.nen.nl/nen-en-1116-2018-en-243331

Neollie. (2025, May). Robottler Neo Promo 2025 [Video]. YouTube. https://www.youtube.com/watch?v=-6CptAlNSxc

Newcandle. (2025). Welke soorten touchscreens - Dé touchscreen specialist legt uit. Beamers & Touchscreens.nl. https://www.beamers-en-touchscreens.nl/welke-soorten-touchscreens/

P
Petersohn, I., Hellinga, A. H., van Lee, L., Keukens, N., Bont, L., Hettinga, K. A., Feskens, E. J. M., & Brouwer-Brolsma, E. M. (2024). Maternal diet and human milk composition: An updated systematic review. Frontiers in Nutrition, 10. https://doi.org/10.3389/fnut.2023.1320560

R
Roozenburg, N. F. M., & Eekels, J. (2016). Productontwerpen, structuur en methoden (2e druk). Boom Uitgevers.

MichaelAlbrandt. (2026). Dental 3D Printing Solutions & More | Rapid Shape. Rapid Shape. https://rapidshape3d.com/

S
Schutter, A.-S. (2025, June). Robots: The saviours or destructors of pediatric care by nurses? [Master's thesis, Erasmus Universiteit Rotterdam]. Erasmus School of Health Policy & Management.

V
van Boeijen, A., Daalhuizen, J., van der Schoor, R., & Zijlstra, J. (2013). Delft Design Guide: Design strategies and methods. BIS Publishers.

van den Akker, H., & Mudde, R. F. (2023). Fysische transportverschijnselen: Denken in balansen.

Van Driel, W. D., Pressel, K., Soyturk, M., Knoll, H., & Hille, P. (2024). Outlook to the Future of Reliability. In Recent Advances in Microelectronics Reliability (pp. 385–399). https://doi.org/10.1007/978-3-031-59361-1_16

Van Riel, V. S. A. (2025). From manual to automated: How the introduction of a mother milk robot affects neonatal nurses' safety perceptions [Master's thesis, Erasmus Universiteit Rotterdam]. Erasmus School of Health Policy & Management.

van Veldhuizen-Staasen, G., & Kleintjes, S. (2008). Moedermelk: de volwaardige zuigelingenvoeding. KNOV. https://www.borstvoeding.com/files/TvV_Borstvoeding_volwaardig.pdf

W
World Health Organization. Global strategy for infant and young child feeding (2003).

Y
Yang, X., Wang, S., Dong, Y., & Yang, H. (2017). D2 delta robot structural design and kinematics analysis. IOP Conference Series: Materials Science and Engineering, 274(1), 012009. https://doi.org/10.1088/1757-899X/274/1/012009

Z
Zeng, Z. (2025). The evolving paradigm of reliability engineering for complex systems: A review from an uncertainty control perspective. https://www.preprints.org/manuscript/202512.2830

Declaration of Authorship

All illustrations included in this report were created by the author. All photographs were taken by the author unless otherwise indicated; where other sources are used, the appropriate source is clearly acknowledged.

The tool Grammarly (https://app.grammarly.com/) was used for spelling and grammar checking.

Appendices

Appendix A: Extended stakeholder overview

While patients and nurses are the primary stakeholders of the Neo project, several other groups also play a crucial role in shaping its design and implementation. These groups can be classified as secondary or tertiary stakeholders, depending on the degree of their involvement.

Parents of Patients
Parents represent an important secondary stakeholder group. Although they are not directly involved in operating the robot, they remain closely connected to the feeding process, often delivering breast milk to the hospital. Their interests are primarily emotional and informational: they seek reassurance that their child's feed is prepared safely and correctly, and they value transparency in the process.

Medical Staff
In addition to nurses, doctors, such as neonatologists, prescribe fortifiers and establish the feeding requirements for individual patients. While they are not expected to interact with the robot on a daily basis, the accuracy and reliability of the robot's output are directly relevant to their work. From their perspective, the main value of the system lies in reducing the risk of milk swaps and dosage errors.

IT Department
The hospital's IT department represents another secondary stakeholder. Although their contact with the robot is indirect, they are responsible for ensuring that the system integrates securely with the hospital's digital infrastructure. Their priorities include protecting patient data, guaranteeing cybersecurity, and ensuring that the robot communicates effectively with existing hospital systems.

Hospital Management
Hospital management can be considered a tertiary stakeholder group. They are not involved in daily interactions with the robot, but the outcomes of its operation influence workforce planning and resource allocation. Their interest lies in reducing nursing workload and enabling a greater focus on patient care.

Inventory and Logistics Staff
Staff responsible for inventory management ensure that medical disposables, such as syringes and containers, are available. They do not operate the robot directly, but they must ensure compatibility between the robot's requirements and the hospital's supply system. Their interest is that the robot uses standard, readily available consumables without requiring significant changes in procurement.

Financial and Legal Teams
Within the tertiary stakeholder group, both the financial and legal departments play a decisive role. The financial department defines the budgetary limits within which the robot must be developed, ensuring that it remains affordable and can eventually be implemented on a larger scale. The legal department, in contrast, is responsible for safeguarding compliance with hospital safety protocols and broader medical regulations. Although neither department is directly involved in the daily use of the robot, the conditions they set strongly influence its overall feasibility and the likelihood of its long-term integration within the hospital.

Appendix B: Subsystems

To identify design gaps, an assessment of Neo's subsystems was conducted using documentation provided by Neollie B.V. Each subsystem has been evaluated according to its current state, using the framework of Technology Readiness Levels (TRLs). In addition, the degree of complexity of the problem, the relevance of the subsystem from both a technical and design perspective, and the suitability of the topic as a graduation project have been considered.

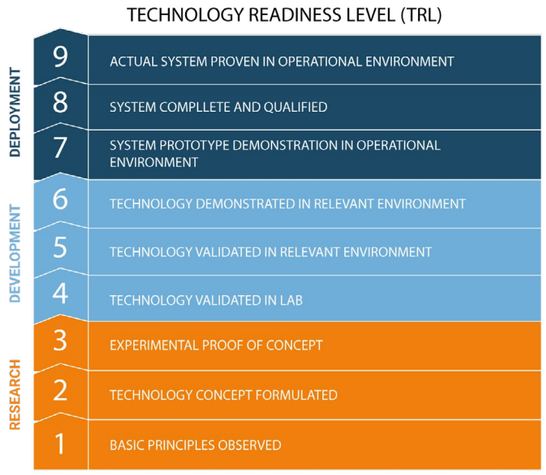


Figure B: Technology Readiness Level

Input subsystem
The input subsystem represents one of the most critical components of Neo, since a wide variety of materials must be introduced into the machine before any processing can take place. These materials include BMF powder, LCT powder, formula powder, stickers, containers of breast milk with caps, empty containers with caps, syringes of both 60 ml and 20 ml, syringe caps, water, and electricity.

The nature of these inputs allows the subsystem to be understood as consisting of two categories. The first category relates to daily production, in which breast milk containers are placed into the system on a case-by-case basis. The second category concerns stock, consisting of powders, stickers, syringes, caps, and water, all of which require regular replenishment but are not tied to a single feeding cycle.

While the stock inputs can still be regarded as TRL 1, the daily production input has already been tested at a basic level. In the first prototype, it was possible to manually place a single breast milk container into the storage matrix. However, this process has not yet been scaled up, nor has the interaction between the nurse and the system been properly developed. For this reason, the subsystem remains in an early stage overall, but its partial validation highlights both the technical feasibility and the need for significant design improvements. These gaps of both categories create interesting opportunities for further research, particularly with respect to usability and workflow integration.

Identification subsystem
Following the introduction of inputs, the identification subsystem plays a crucial role in ensuring that the machine correctly recognizes each breast milk container. The underlying principle of the system is that every container carries a unique code, which must be read and registered before further processing can occur.

Several approaches have been proposed to achieve this identification. One method would be to rotate the container until the scanner can detect the code. Another possibility would be to position multiple scanners around a stationary container, so that the code can be detected regardless of orientation. A third option would involve a scanner that moves entirely around the container until it locates the code.

A preliminary list of potential scanning devices has already been compiled, based on the types of codes currently used in hospital settings. The input to this subsystem is therefore a breast milk container with an unrecognized code, while the output is a container that has been successfully identified.

Although conceptually sound, the system has not yet been tested in practice, which places it at TRL 3. Since scanning technologies are widely available and well-established, the integration challenge is relatively modest. For this reason, the subsystem does not present an exciting opportunity for graduation-level design research.

Cooled container storage subsystem
Once containers have been identified, they must be stored under cooled conditions until they are needed by the next subsystem. Several cooling strategies have been considered for this purpose. In the first Neo prototype, the use of Peltier cooling was successfully demonstrated, allowing containers to be preserved in a cooled matrix configuration.

This subsystem is currently at TRL 4. It is of particular interest from a design perspective because it requires immediate cooling upon intake, thereby linking it closely to the input subsystem. In addition, a comparable cooling process is also necessary at the syringe stage, which raises the possibility of integrating both cooling functions into a single subsystem. Determining whether such an integration is feasible or whether distinct solutions are preferable remains an open question for further design exploration.

Dosing feed and bottle cap opening subsystem
In order to add the prescribed powders into the breast milk, the system first requires a reliable mechanism that can remove the cap from the container. Once the cap has been unscrewed, the correct combination of BMF powder, LCT powder, or formula powder is introduced. The dosage is entirely dependent on the infant's medical prescription, which means that the system must be capable of handling multiple scenarios: in some cases, only BMF powder is required, in others, both BMF and LCT, and in situations where there is insufficient breast milk from the mother, formula powder must also be dispensed. Formula powder requires the addition of water to ensure the correct nutritional composition, making this subsystem more complex than simple powder dosing alone.

The principle of this subsystem has already been validated by means of a prototype, and the technology can therefore be assessed at TRL 5. Because of its relatively advanced development and because Neollie B.V. is actively working on it, the subsystem appears less suitable as a focus for graduation-level design research. Nevertheless, its integration with surrounding processes still leaves open interesting challenges for future refinement.

Tap water dispensing subsystem
The tap water dispensing subsystem is essential whenever formula milk must be produced. Formula powder requires the addition of water in precise proportions, making the controlled dispensing of water a critical step. In the current system design, the water dispensing function is expected to be integrated directly with the dosing and cap opening subsystem.

Although technically straightforward, the subsystem must still meet strict requirements for hygiene and water quality. Furthermore, the temperature of the dispensed water may also need to be controlled to ensure optimal dissolution of the formula powder. These factors introduce additional complexity compared to a simple domestic tap, even if the core functionality remains relatively simple.

Despite these considerations, the subsystem is still not complex enough to serve as an independent graduation project. Its value lies primarily in how it integrates with the dosing and mixing subsystems to create a coherent and reliable chain of operations.

Mixing subsystem
After powders and, if required, water have been added to the breast milk container, the contents must be thoroughly mixed to ensure a homogeneous solution. In the first Neo prototype, this was achieved by shaking the container in a motion that closely resembles the manual technique used by nurses. This approach proved effective and was validated as part of the prototype testing, placing the subsystem at TRL 6.

Although the principle has been proven, several areas for refinement remain. For instance, rotational mixing could be explored as an alternative or complement to shaking, potentially reducing mixing time or energy consumption. The subsystem is already relatively mature and does not present the kind of open design space that would justify it as a primary focus for a graduation project.

Syringe orientation tip subsystem
Before syringes can be filled, it is crucial that their orientation is correctly aligned. Because the syringe tip is slightly offset, misalignment could prevent accurate filling or sealing. The orientation subsystem addresses this by pressing the syringe tip against a mechanical stop until it cannot rotate further, thereby establishing a consistent orientation.

This subsystem is still in its early stages, with a TRL of 2. While the concept is functionally clear, it leaves several open questions. For example, alternative approaches to orientation and error detection and recovery are also important.

Although the subsystem still involves unresolved technical questions, Neollie B.V. is already actively investigating this area, and the scope of the design challenge is relatively narrow. It can therefore be concluded that this subsystem is not a suitable candidate for graduation-level research.

Syringe cleaning subsystem
In order to progress from the input stage, where milk is still contained within a breast milk container, to the output stage, where the milk is stored in syringes, the system requires a reliable method for filling syringes. During this process, the syringe is immersed in the breast milk, after which the prescribed quantity is drawn inside. However, this step creates the risk that milk residue remains on the outside surface of the syringe. According to ISO standards, cross-contamination between samples must be strictly prevented (ISO Standards, n.d.), which means that each syringe must be cleaned before proceeding to the next subsystem.

A number of potential cleaning methods have already been proposed, but none have yet been implemented or validated. For this reason, the subsystem is still at TRL 2. Its early stage of development makes it an interesting candidate for further design research, since there is significant room for innovation in determining how the cleaning can be carried out efficiently, reliably, and in a way that fits the workflow of the machine. Possible approaches could include mechanical wiping, liquid rinsing, or the use of disposable protective films.

The hygienic challenges and regulatory requirements make it a technically demanding area that could benefit from further exploration. At the same time, the subsystem may have limited interaction with nursing staff, as the process is expected to occur largely within the machine itself. This makes it slightly less attractive from the perspective of user-centered design.

Syringe capping subsystem
Once syringes have been filled and cleaned, they must be sealed to prevent leakage. This requires two distinct but interdependent processes. The first process involves orienting the caps so that they are ready for placement, while the second process involves physically attaching the cap to the syringe.

The orientation of caps poses a significant challenge because current industrial solutions are designed for large-scale production lines. For Neo, such mechanisms would need to be drastically miniaturized in order to fit within the compact design of the machine. This subsystem is currently estimated at TRL 3. While technically feasible, the degree of miniaturization required makes it an engineering rather than a design challenge, and it is therefore less suitable as the primary focus of a graduation project.

The placement of caps onto syringes has already been validated in an earlier prototype, reaching TRL 5. Although minor optimizations could still be made to improve reliability or reduce error rates, the fundamental process is already established. For this reason, the capping subsystem as a whole is not considered sufficiently complex or open-ended to form the basis of a graduation project.

Syringe stickering subsystem
Once syringes have been filled and sealed, it is essential that they are clearly identified. This ensures that syringes are not mixed up and allows any errors in the machine to be traced back to a specific container of breast milk. The most straightforward method for achieving this is through the application of stickers, which is also the current practice in hospitals. The stickers must display information such as the infant's name and feeding details in a way that is durable and legible.

Commercial stickering machines are already widely available, but most existing systems are designed for industrial-scale applications. Neo requires a miniaturized solution that can operate reliably on a smaller scale. Because the technical challenge lies primarily in scaling down an existing technology rather than inventing a new principle, this subsystem is not regarded as a strong candidate for further design development.

Weight Check subsystem
To ensure that syringes are filled with the correct volume of milk, the system incorporates a weight check subsystem. This process verifies that the amount of milk drawn into each syringe matches the prescribed volume.

The concept of weight verification was already validated in the first Neo prototype, and the subsystem is currently assessed at TRL 5. Although this verification step is crucial for guaranteeing dosage accuracy, the technical challenges have already been largely resolved. As such, the subsystem does not present a high enough level of difficulty or openness to serve as the basis for a graduation project.

Cooled syringe storage subsystem
After the syringes have been filled, sealed, and labelled, they must be stored under cooled conditions until they are collected by nursing staff. Since the machine prepares all syringes in a batch, they may remain inside for a considerable period before being used. A cooling system is therefore required to maintain the syringes at the appropriate temperature throughout this period.

Several possible solutions have been considered, ranging from the use of cooling elements to systems that cool the entire storage space in a manner similar to a refrigerator. However, none of these ideas has been developed into a prototype, which places the subsystem at TRL 1. Its early stage of development makes it particularly interesting for further design research, since it presents both technical and user-related challenges.

The design of this subsystem is complex because it involves both input and output: syringes are placed into the cooling environment, stored for a variable amount of time, and then retrieved. This requires reliable temperature control in combination with a smooth logistical flow. Furthermore, the subsystem might be integrated with the cooling required for breast milk containers, either by using a single system for both stages or by adopting distinct solutions. From a user perspective, nurses could interact directly with this subsystem when collecting syringes, which makes usability and ergonomics especially relevant considerations.

Output
Finally, the outputs of the machine consist of empty containers and ten trays, each containing twelve syringes filled with the prepared milk. The syringes vary in volume, either 20 mL or 60 mL, depending on the medical requirements of each infant.

At present, the output subsystem has not been studied in detail and remains at TRL 1. For this reason, it offers considerable potential for further exploration. In particular, the way in which the filled trays are organized and presented to nursing staff could significantly influence usability, efficiency, and safety. Since this stage involves direct interaction between nurses and the robot, the design of the output subsystem is highly relevant for user-centered design and represents a promising area for graduate-level research.

General layout of subsystems
During the assessment of Neo's subsystems, the question was raised whether the overall subsystem layout should also be included within the scope of this project. The original project brief may suggest an intention to redesign the entire robot, including the organization of all subsystems. However, the focus lies on input and output processes, as these already connect multiple subsystems and involve substantial complexity.

The subsystems are currently being developed and tested independently rather than as an integrated whole. Because of this, considering the overall layout at this stage would be premature. Key aspects such as hygiene, maintenance, and nurse interaction remain central considerations, but these are already embedded in the challenges of the input, output, and cooling subsystems.

For these reasons, the subsystem layout as a complete entity does not fall within the current scope. Therefore, the project concentrates on subsystems that directly shape usability and workflow, particularly those involving interaction with nurses and offering open opportunities for design development.

Appendix C: Co-creation Session

Method

A structured session plan was developed by the designer in advance to guide the co-creation workshop (see Table C).
To enable active participation in the session, facilitation was assigned to a fellow student who also had completed the Creative Facilitation course at TU Delft. This facilitator executed and guided the session based on the plan designed by the researcher. This approach ensured that the session followed a well-defined structure, while allowing the designer to actively contribute to the ideation process rather than managing the session itself.

The session took place at the Living Lab of Erasmus MC and lasted approximately two hours. Three participants were involved, all Master's students from the Integrated Product Design programme. These participants had prior experience working on projects within Erasmus MC and were therefore familiar with the hospital environment and general context of the project.

Before the session, all participants signed a consent form. During the workshop, participants were encouraged to think freely and collaboratively, with a focus on user interaction, workflow integration, and practical usability.

The session consisted of a series of creative exercises designed to stimulate idea generation across three successive "waves" (Figure C1). The first wave focused on generating common and expected ideas, allowing participants to explore familiar solutions. The second wave encouraged unusual and "silly" ideas, promoting divergent thinking and breaking conventional patterns. The third wave aimed at generating ideas that combine novelty with practical usefulness.

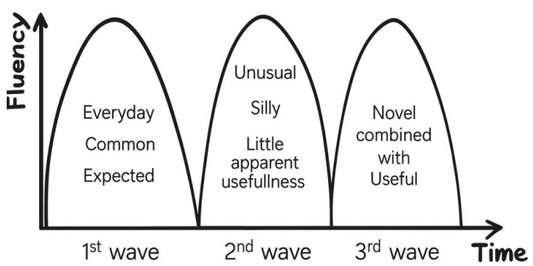


Figure C1: Heijne, K., & Van der Meer, H. (2019)

The exercises were specifically selected to guide participants as efficiently as possible towards this third wave, as ideas within this phase are considered most valuable for design development. This structured progression supports a transition from conventional thinking towards more innovative yet feasible solutions.

Results

The outcomes of the individual exercises are presented in Figures C2 to C6. All generated ideas were discussed and subsequently clustered during the co-creation session into eleven distinct groups, illustrated iin Figure C7.

These clusters were created collaboratively by the research group through discussion and comparison of the ideas, identifying similarities in functionality, application, and underlying principles. Several ideas shared common characteristics and were therefore grouped together, while others represented more unique directions and formed separate clusters.

The clustering process provided an overview of the design space and revealed recurring themes, as well as areas with potential for further exploration. In addition, it helped to structure the large number of generated ideas into more manageable categories for further analysis and development.

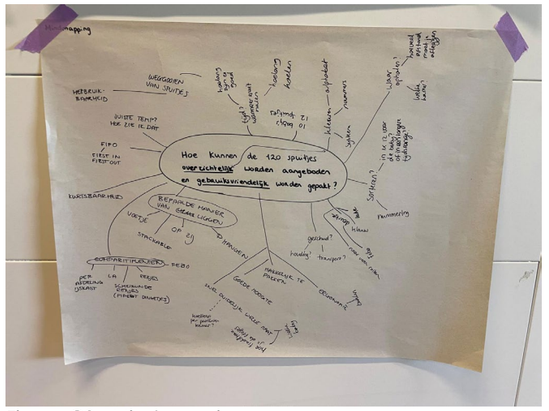


Figure C2 : Mindmapping

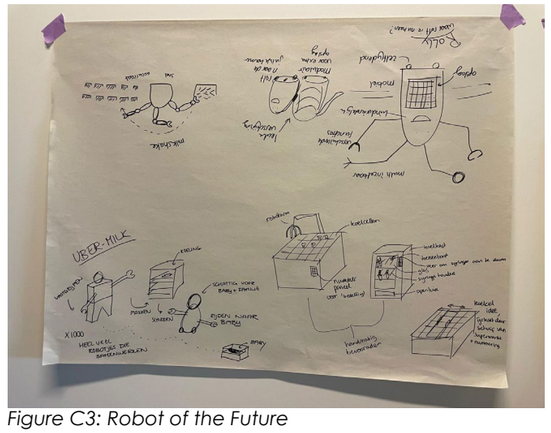


Figure C3: Robot of the Future

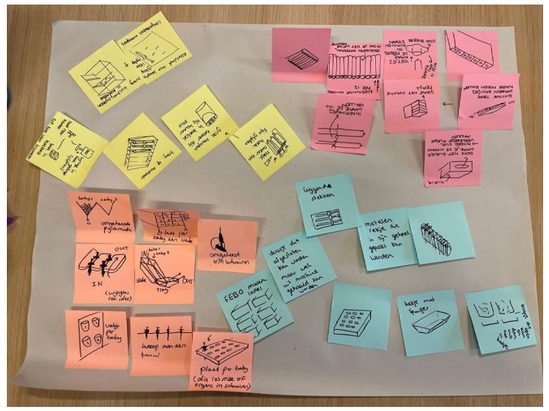


Figure C4: Brainwriting with post-its

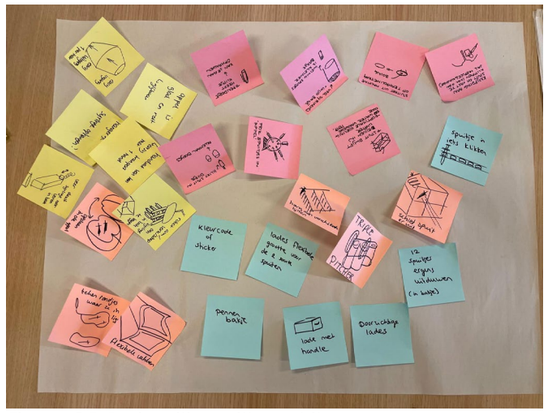


Figure C5: Brainwriting with post-its

Figure C6: Clustering post-its

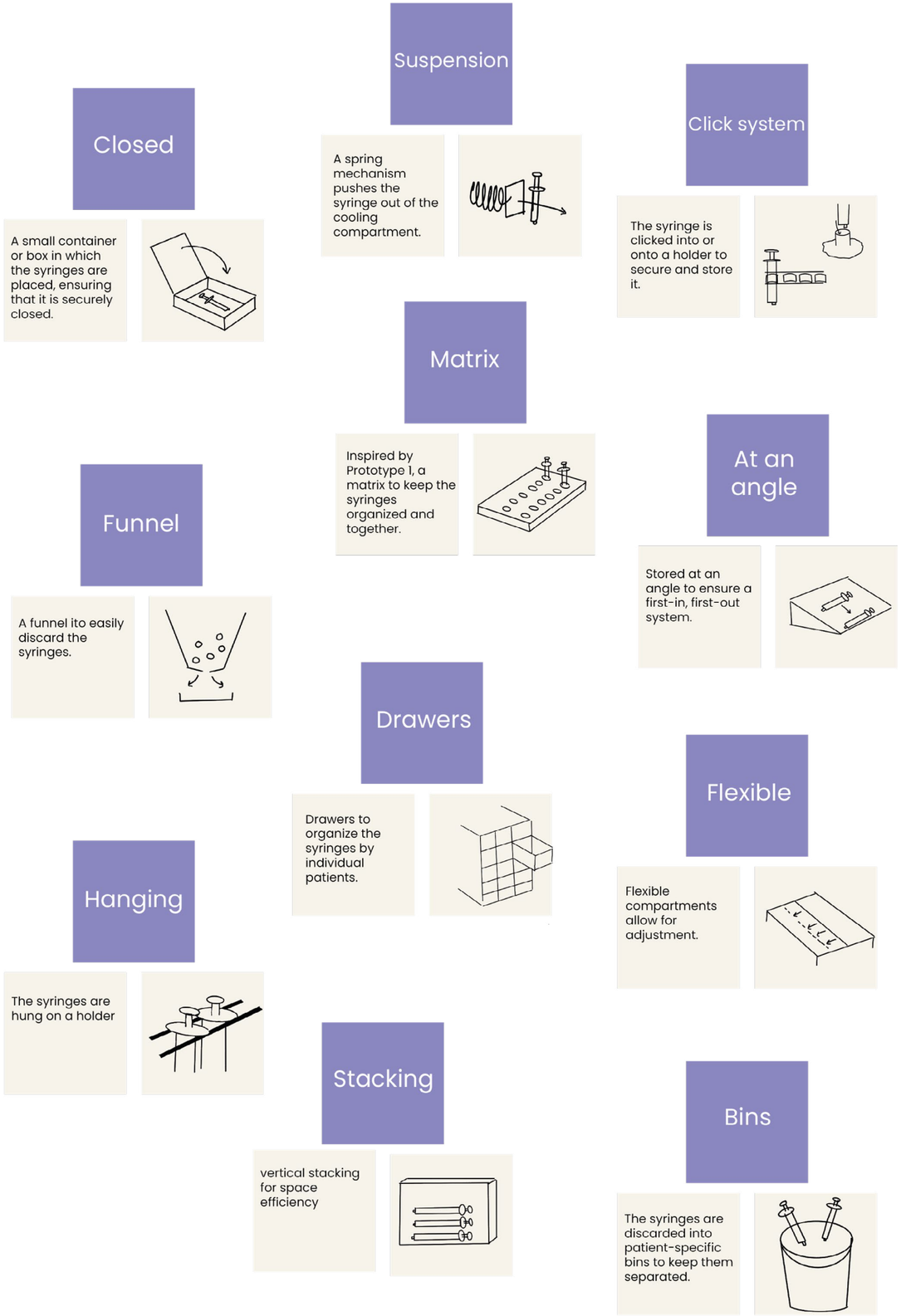


Figure C7: Cluster overview with explanation

Discussion

A limitation of this co-creation session is related to the composition of the participant group. All participants were fellow students with a design background, and no healthcare professionals, such as nurses, were involved. As a result, the session primarily reflected a design-oriented perspective, potentially lacking practical insights from daily clinical practice. Including healthcare professionals could have contributed additional context-specific knowledge and may have led to different or more applicable solutions.

This limitation became particularly evident in later stages of the project, where it was observed that nurses frequently make use of existing tools such as standardized trays. If this information had been incorporated earlier, it might have influenced the direction and outcomes of the co-creation session.

Additionally, the researcher participated in the session rather than solely facilitating it. While this allowed for deeper engagement with the idea generation process, it also introduced the risk of unintentionally influencing other participants. This potential bias was acknowledged based on insights from the Creative Facilitation course. To mitigate this effect, the researcher consciously adopted a more passive role during the exercises, allowing other participants to share their ideas first before contributing.

The decision to participate rather than facilitate was made deliberately. Facilitation often requires focusing on process management, such as timekeeping and guiding exercises, which can limit active involvement in idea generation. By separating these roles, the session aimed to balance structure with creative contribution.

Regarding validity, the outcomes of this session should be interpreted as exploratory rather than representative of clinical practice. The findings reflect early-stage ideation within a controlled and design-oriented setting and may not fully capture the complexities of real-world healthcare environments. Therefore, the results mainly serve as a source of inspiration and direction for further development, rather than as validated solutions.

For future improvement, it is recommended to involve a more diverse group of stakeholders, including healthcare professionals such as nurses and technicians, to ensure that practical constraints and user needs are better represented. Additionally, conducting follow-up sessions that build upon existing clinical insights could help refine and validate the generated ideas. Incorporating real-world observations prior to ideation sessions may further enhance the relevance and applicability of the outcomes.

Conclusion

The co-creation session successfully explored various approaches to organizing and positioning syringes within the system. The results demonstrated that this challenge can be addressed in multiple ways, ranging from straightforward organizational solutions to more innovative concepts.

The session provided a broad set of ideas and insights, which were structured into clusters and used as a foundation for further concept development. Despite its limitations, the session contributed valuable input to the design process and highlighted the importance of integrating both creative exploration and practical context in future iterations.

Table C: Session Plan

CREATIVE FACILITATION - VALERIE KLEMANN

Overview			
Datum	20-okt-25	**Duration**	2 hours
Locatie	Erasmus MC - living lab		
Aim of today	Focus on idea finding		
PO	Valérie Klemann		
Facilitator	Klaske		
PaG	**Hoe kunnen de 120 spuitjes overzichtelijk worden aangeboden en gebruiksvriendelijk worden gepakt?**		
To do prior to the			
	PaG on flipover		
	Program of the day on flipover		
	Bring Yellow pencil case with markers		
	Make a poster prep		
	Rules diverging, reverging, converging printen		
	Collect Random objects		
	Prepare example post-its for Ladder of abstraction		
Materials	**What**		
PO	Yellow etui		
	Markers		
	Post-its		
	Flipover paper		
	A3 of A4 paper		
	Stickers Hits or Dots		
	Random Objects / Visual stimuli		
	Road map for creative problem solving book		
	2x Printed session plan		
	snackies		
	milk container + syringes		
	Laptop with powerpoint		

Sessionplan							
Stage	**Time**	**What**	**Goal/Aim**	**Phase + sessio dutie**	**Materials needed**	**Individually / in group**	**Notes / important!**
Intro							15
	15:00 (5 min)	Goal of today Explain why Klaske is the Facilitator. Explain I will join them, the Research Group. Problem owner explains the problem		Briefing by the problem owner	Powerpoint Presentation with Project, Big flipover with the Problem as Given (PaG)	Group	> Are there any questions for the PO?
	(5 min)	*Welcome & introduction of facilitator* *What is the plan for the day?* *- 2 hour session* *- Programm and excersices* *- working both individually as in a group*		Intro Welcome & Introduction	Program flipover	Group	> Is everything clear?
	(5 min)	Flower association	Free up their minds to enable generating ideas	Purge excersice	Markers, flipover	Group	*Mother Milk Preparation Machine* as starting word on flipover

Problem Finding							25
	15:15 (5 min)	Icebreaker	Create a robot of the future	Fun and start of creation/ imagination	A4 and color markers	Group	> How do you think an organizing robot/machine will look like in the future > Make a fun drawing of it > Which special feature has your robot/machine?
	(5 min)	Mindmapping			PaG in the middle of flipover & markers	Group	They are allowed to speak out loud
	(10 min)	Ladder of Abstraction	Many questions will arise that help me in the further graduation process.		Example post-its, post-its, markers	Individualy/ Group	> Explain using example post-it > Hitchhike > How else? Why else?
	(5 min)	Restating the Problem	Ensure that the problem is clear to everyone.	SPARK the PaP	SPARK on post its *Specific* *Positive* *Ambitious* *Relevant* *Keep it simple*	Group	> PaP does not have to be very different from PaG, as long as it is clear what the problem is that they need to find a solution for.
	(5 min)	Break					Snacks! 5

Idea Finding							40
Postpone judgement - Hitchhiking - Quantity breeds quality - Freewheel	**15:45** (15 min)	Brainwriting with post-its	Ideation		Post-its, markers	Individualy	When fluency is low: > Think about letter of the alphabet > having someone focus on specific post-it > absurd questioning > what would a criminal do? Etc? > SCAMPER
	(10 min)	Explaining	Starting discussion: Let them explain what they wrote down.			Group	
	(15 min)	Random objects			Random Objects	Group	Tell each other what the connection is for a very short time and then continue individually
	(5 min)	Break					Snacks! 5

Solution Finding							25
Use affirmative judgement - protect orginality - trust the hedonic response - have action in mind	**16:30** (10 min)	Spontaneous Clustering		Gallering by everybody explaining there post it's if its not clear		Group	PO might conclude a certain area is not been explored at all
	(5 min)	Dot voting		Hits or Dots	Stickers (green & blue)	Individual	
	(5 min)	Make a poster		choose best 2 or 3 options	Flipover poster fill-in	Duo's	
	(5 min)	Presenting Solutions				Duo's	
Outro							5
Reflecting	**16:55** (5 min)	Thank the RG for their effort		Wrap-up & closing			Ensure all output is being photographed, reported and stored

Random Objects	
Random Object, is designed to stimulate fluency and flexibility in idea generation. By associating everyday objects with robot research, participants are encouraged to think beyond conventional approaches. This method forces them to find unexpected connections, leading to original insights that might not emerge through traditional brainstorming. It ensures a broad range of creative solutions.	

Totale min
120
van
120

Appendix D: Interview Notes - NICU kitchen

This appendix contains notes from an exploratory interview conducted on October 29 in the NICU kitchen at Erasmus MC with two nurses responsible for preparing infant feeds.

Context and Participants
The interview was conducted in Dutch, as all participants were Dutch speakers, ensuring clarity and preventing misunderstandings. The participants were two NICU nurses who were actively preparing infant feeds at the time of the interview. This reflects the standard workflow, in which feeds are typically prepared by two nurses working together.

The interview took place during their routine activities in the NICU kitchen, allowing for direct observation of the preparation process, tools used, and interactions with the environment.

Aim of the Interview
The interview was exploratory in nature and aimed to:
- Gain insight into the current workflow of preparing infant feeds
- Understand how syringes are organized, handled, and transported
- Identify practical constraints and requirements for integration of the Neo output system
- Explore potential opportunities and concerns regarding automation

Method
A semi-structured approach was used. While several guiding questions were prepared beforehand, the conversation remained flexible, allowing the designer to respond to observations and spontaneous events during the session.

The interview was not recorded or transcribed verbatim. Instead, key responses, insights, and observations were documented and summarized.

Questions and notes
1. Syringes are currently placed in trays. Why are these trays disposable?
Previously, stainless steel trays were used, but they started to rust. Therefore, they switched to disposable plastic trays. In the future, these will likely be replaced by reusable plastic trays.

2. Could the tray be designed differently? For example, would a metal rack be an option?
The nurses are open to alternative solutions. However, the system must still fit within the refrigerators. Currently, around 8 to 9 trays fit inside one refrigerator.

3. Is it preferred to collect all syringes at once in the morning, or would it be useful to retrieve syringes per patient earlier?
It is important that syringes remain clearly separated per patient. The preference is to prepare everything at once. Similar to the current workflow, it is expected that the preparation area will be located at some distance from the NICU ward. Therefore, it is most practical to prepare everything in one go, transport it using a cooled trolley, and store it in the NICU refrigerator.

**Observation:*
During the conversation, the nurses raised a question: “Who will clean the machine, and how?” They emphasized that, after preparing syringes for one patient, the entire workspace must be cleaned. Similarly, the machine must be cleaned thoroughly to prevent cross-contamination.

4. Where are labels currently placed?
Labels are applied to each individual syringe, as well as to the tray containing the syringes.

5. What happens to milk that does not fit into the 12 syringes?
Any leftover milk must not be discarded and is therefore frozen.
Prepared syringes cannot be frozen, as the added BMF powder is only valid for 24 hours.

In some cases, there may be insufficient breast milk available. In such situations, labeled but empty syringes are placed in the tray and filled later in the day when new milk becomes available.

6. What would be the best way to notify nurses when the syringes are ready?
Since syringes are typically collected once in the morning, a fixed preparation time would be sufficient. Alternatively, the NICU ward could be notified by phone.

7. What is the most practical way to deliver the syringes?
Syringes should be delivered grouped together. Additional handling, such as transferring syringes into trays or other systems, should be minimized, as this would take too much time.

8. What would be a convenient way for multiple nurses to access the robot system?
A badge-based system would be preferred, as all nurses already use access cards.

**Observation*
A cooled trolley was used to transport filled trays to the NICU ward.

**Observation*
Nurses expressed concern that the robot might require a significant amount of their time, for example by needing constant monitoring

**Observation*
Large syringes (60 mL) are used infrequently. When needed, they are typically required in small quantities (maximum of around eight). Nurses indicated that, if necessary, they would be willing to continue preparing these manually, as this occurs only rarely.


Figure D1: White tray used in NICU kitchen


Figure D2: White tray fits perfectly in trolley

Key take-aways
- Hygiene is of utmost importance, and cross-contamination must be strictly avoided.
- The nurses are concerned about having to stand next to the machine all the time.
- A verification mechanism preferable, as nurses currently check each other’s work; a similar system should be implemented in the machine.
- Large syringes of 60 mL are prepared a maximum of eight times per day, though typically around six.

Limitations
This interview involved only two participants and represents a single moment in time within one hospital setting. No variation in experience level, shift, or role was included. Additionally, the interview was not recorded verbatim, meaning some nuances may have been lost in summarization.

Therefore, the findings should be interpreted as exploratory insights rather than comprehensive or representative conclusions.

Appendix E: Extended Ideation & Concept Development

This appendix provides additional detail on the ideation phase of the Neo output subsystem. It includes the description of the explored concept principles, the intermediate iteration variants, and the concept selection process. The main report only presents a summary of these steps.

Concept Direction 1 - TopFill

Principle Explained

The TopFill concept is based on a simple and transparent layout. Ten tray positions are arranged horizontally next to each other within a cooled environment. The trays remain permanently inside the cooling compartment, while the dropping mechanism is positioned above them. The robotic arm moves exclusively in the horizontal direction, along a single axis, and releases the filled syringes vertically into the trays from a fixed height.
Above each tray position, a dedicated opening with a closing mechanism is integrated. As a result, only a small section of the cooling compartment needs to be opened during filling, which limits heat loss. At the front of the system, a closable access opening allows nurses to remove the trays once they are fully filled.

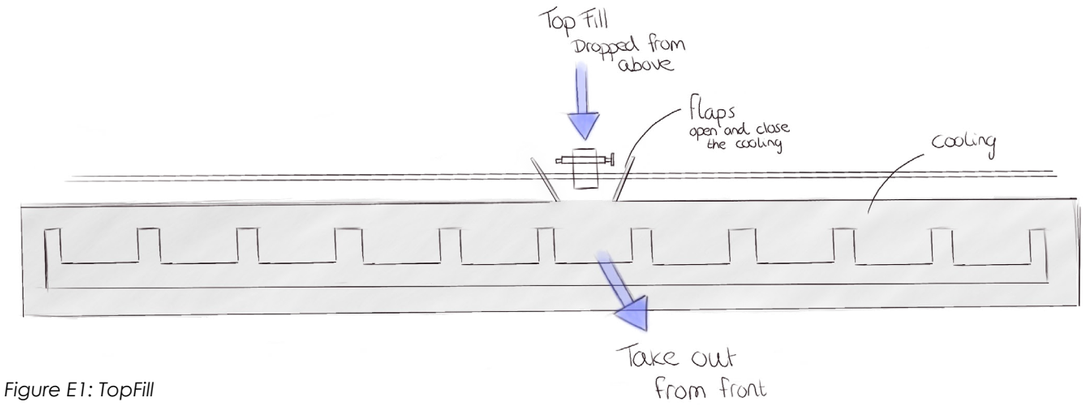


Figure E1: TopFill

Advantages

- Simple dropping mechanism with movement along a single axis.
- Relatively easy to realise from a technical perspective.
- Immediate overview of all trays positioned side by side.

Disadvantages

- Large overall width required for the system.
- Additional mechanism required to rotate the syringe from a vertical to a horizontal orientation.

The white trays have a width of approximately 18 cm. When ten trays are placed next to each other, this results in a total width of roughly two metres, including separators and structural elements. Although this dimension formally falls within the maximum size of a hospital bed, it is not ideal from a usability perspective. Continuously moving along a long row of trays may negatively affect efficiency and ergonomics.

Expand on TopFill idea: Moving drawers and X/Y dropping mechanism

The first iteration of the TopFill concept introduces moving drawers in combination with a dropping mechanism that can move both horizontally and vertically. In this configuration, ten individual drawers are divided over two levels, with five trays per level. Both the drawers and the dropping mechanism are actively moving, allowing the syringe to be positioned above each tray location.
Although this configuration reduces the required width, it introduces significant mechanical complexity. The simultaneous movement of multiple subsystems increases the risk of failures, raises control complexity, and makes synchronisation more critical. As a result, the solution becomes less robust and more difficult to maintain.

Expand on TopFill idea: Fixed drawers with clearance for arm movement

In the second iteration, the movement of the drawers is eliminated. Instead, clearance is created between the two tray levels, allowing the dropping mechanism sufficient freedom to move above all tray positions. As a result, only the dropping mechanism remains actively moving.
This approach reduces mechanical complexity compared to Iteration B, but introduces another drawback: a substantial portion of the internal volume of the cooling compartment remains unused in order to accommodate the arm movement. This leads to inefficient use of space, which is unfavourable given the constrained dimensions of the Neo machine.

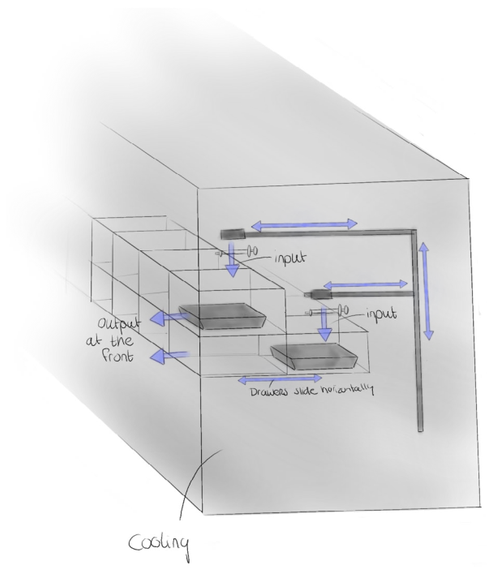


Figure E2.1: TopFil iteration I (b)

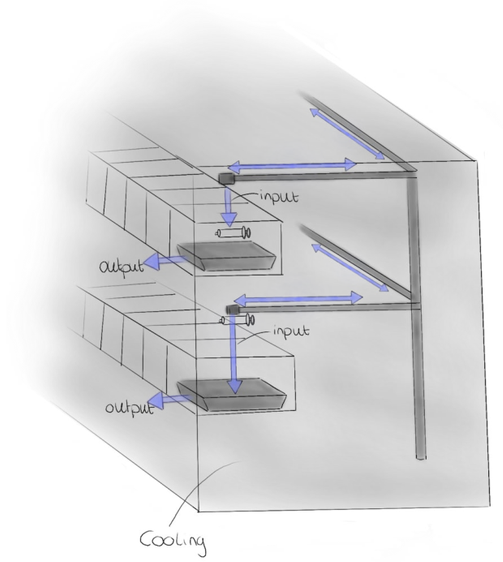


Figure E2.2: TopFil iteration II (c)

Concept Direction 2 - CircuLade

Principle Explained

The CircuLade concept is based on a rotating carousel in which multiple trays are positioned along a circular path. Through rotation, one tray at a time is brought to a fixed position. The filling of trays takes place at the top of the system, while the insertion and removal of trays by nurses occurs at the front of the machine.
The carousel is fully enclosed within a cooled environment. By means of rotation, a new tray is continuously positioned underneath the dropping mechanism, after which the filled syringe is released vertically into the tray. Once a tray has been completely filled, further rotation brings it to the output position, where it can be removed and replaced by an empty tray.

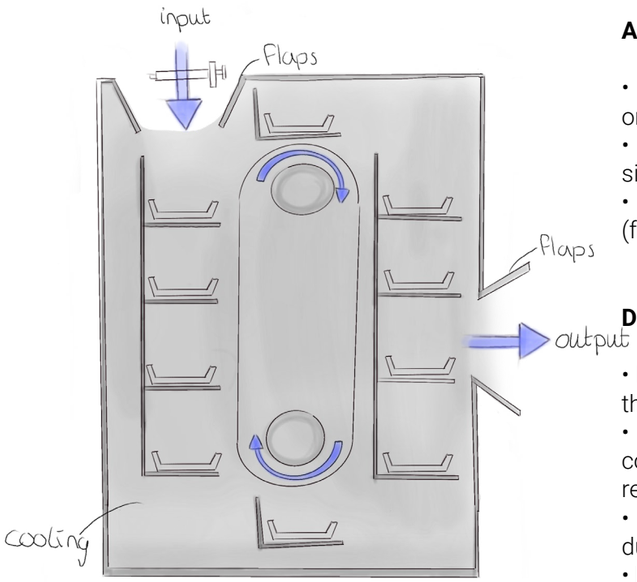


Figure E3: CircuLade

Advantages

• Compact principle in which multiple trays are organised within a single continuous system.
• Fixed positions for filling and retrieval, which simplifies the dropping mechanism.
• Clear separation between input (top) and output (front).

Disadvantages

• Requires relatively large amounts of space due to the circular configuration.
• Mechanically complex as a result of rotating components, actuation, and positioning requirements.
• Risk of trays wobbling or becoming misaligned during rotation, particularly with uneven loading.
• More difficult to clean due to shafts, bearings, and moving interfaces.
• Requires a complex click or locking mechanism to allow trays to be both secure and removable.
• Limited overview, as only one tray is visible to the user at any given time.
• Trays must be loaded and unloaded sequentially, reducing overall efficiency.

Concept Direction 3 - SlideGate

Principle Explained

The SlideGate concept is based on guiding the syringe into the tray in a controlled manner, without requiring the syringe to be actively tilted into a horizontal orientation. Instead of a vertical drop, the syringe is guided into position via a sloped guiding element. By using gravity in combination with a guiding path, the syringe is intended to slide into the tray and come to rest in the correct orientation.
The underlying aim of this concept is to simplify the dropping mechanism by avoiding rotation or tilting of the syringe. The syringe exits the filling station in a vertical orientation and is guided through the SlideGate towards the tray, where it is expected to settle horizontally.

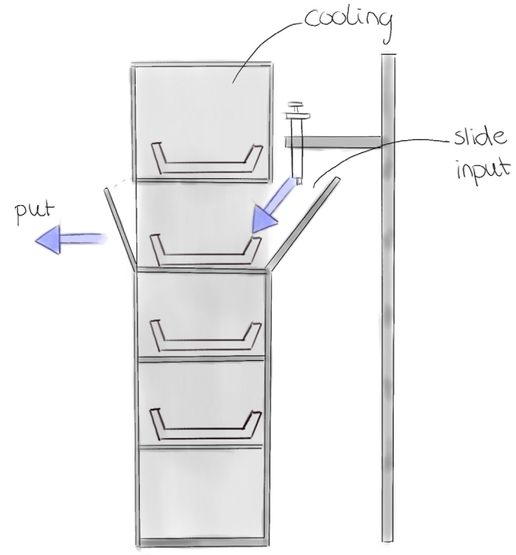


Figure E4: SlideGate

Advantages

• No active tilting of the syringe required.
• In theory, a simpler dropping mechanism.
• Compact guiding solution without a vertical drop distance.

Practical observations and limitations

Physical testing of this principle revealed that the shape and dimensions of the syringes have a significant impact on system reliability. Due to the asymmetrical geometry of the syringe, including the tip and flange, syringes frequently became stuck within the guiding path or failed to reach a consistent final position. This resulted in blockages and made the process highly error-prone.

In addition, the SlideGate principle introduces substantial hygienic concerns. The guiding surface comes into direct contact with parts of the syringe that, in an earlier subsystem, have been in contact with breast milk. From a hygiene and safety perspective, this is undesirable, as any surface that contacts the syringe may contribute to cross-contamination.

To mitigate this risk, the SlideGate would need to be thoroughly cleaned after each individual patient. This introduces additional handling steps, increases system complexity, and directly conflicts with the objective of reducing repetitive tasks for nursing staff.

Disadvantages

• Low reliability due to frequent jamming of syringes in the guiding path.
• Strong dependence on syringe geometry.
• Direct contact with milk-related parts of the syringe, introducing hygienic risks.
• Requires frequent cleaning, potentially after each patient.
• Additional maintenance and cleaning effort.
• Increased likelihood of system failures and process interruptions.

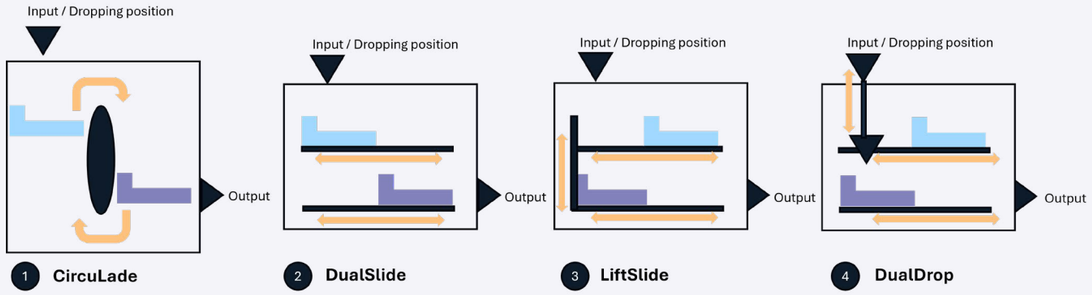
Iteration Session

Following the initial concept development of CircuLade and TopFill, an iteration session was conducted to further refine these ideas and evaluate their suitability within the defined constraints. During this phase, the focus shifted towards reducing system complexity, improving integration with the existing workflow, and increasing efficiency in both the filling and retrieval of trays.

Iteration on CircuLade

The initial CircuLade concept was based on a configuration of ten individual compartments, each accommodating a single tray. The carousel rotated continuously, with one fixed position used for dropping syringes and another fixed position for inserting and removing empty or filled trays. Although this principle was functionally feasible, it proved inefficient in practice. Trays had to be filled and removed one at a time, requiring the carousel to rotate after each individual action. This resulted in unnecessary time loss and a fragmented interaction for nurses.

As an iteration on this concept, a revised configuration was developed in which five trays were positioned next to each other and combined into a single drawer. Instead of ten separate trays, this resulted in two larger drawers that could rotate as complete units. This adjustment reduced the number of required rotations and handling steps, while also improving clarity and usability during the loading and unloading process.



Iteration on TopFill

For the TopFill concept, the iterative phase started from a configuration consisting of two drawers, each accommodating five trays arranged side by side. This setup immediately improved clarity and allowed multiple trays to be accessed simultaneously by the nurse. Based on this configuration, several variants were explored to optimally align the drawer movement with the syringe drop mechanism.

- DualSlide

In the DualSlide principle, the drawers move horizontally while the dropping point remains fixed. The correct drawer is positioned underneath this fixed drop location. From a mechanical perspective, this solution is relatively straightforward, as it limits movement to a single axis for the drawers. However, because the syringe is released from a constant height, this approach can result in relatively large drop distances, reducing control over the final placement of the syringe and potentially affecting reliability.

- LiftSlide

To reduce the drop height, the LiftSlide principle was explored. In this configuration, the drawers move horizontally and the lower drawer is subsequently lifted vertically towards the fixed dropping point. While this reduces the drop distance, it introduces an additional axis of movement within the drawer system itself. This significantly increases mechanical complexity and places higher demands on positioning accuracy, synchronization, and overall system reliability.

- DualDrop

The DualDrop principle combines horizontally moving drawers with a vertically movable dropping mechanism. Instead of lifting the drawer towards the dropping point, the dropping mechanism itself moves downward to the desired height above the drawer. This allows the syringe to be placed in a controlled manner with a minimal drop distance. The approach reduces the moving mass of the drawers, increases placement precision, and offers flexibility for future scalability, such as the addition of extra drawers.

Choosing a concept

As outlined earlier, it is essential that the selected technology is not only conceptually strong but also technically feasible within the constraints of the Neo machine. Technological limitations may arise when a robotic system is unable to perform certain movements, requires disproportionate amounts of space, or does not align with the modular and linear system architecture envisioned by Neollie. To mitigate these risks at an early stage, design decisions must be evaluated in close collaboration with the company's technical experts.

In this context, two discussion sessions were held with engineers from Neollie (G. Hak, K. Sperczynski, and G. Tertelici). During these sessions, the previously developed concepts were critically assessed with regard to technical feasibility, integration within the overall system, and robustness in use. In addition to these qualitative discussions, a weighted trade-off analysis was conducted to systematically compare the concepts across a set of higher-level evaluation criteria. Together, these methods provided a balanced basis for decision-making, combining expert judgement with a structured and transparent evaluation framework.

Based on these discussions and analyses, it was concluded that although the CircuLade concept initially appeared promising, further iteration on the TopFill principle ultimately led to the selection of the DualDrop concept.

Comparison of concept variants

CircuLade was initially considered a viable solution; however, closer evaluation revealed that a configuration consisting of two drawers with five trays each introduced mechanical complexity that was disproportionate to its functional benefits. In particular, the rotational movement, limited accessibility, and increased demands on cleanability reduced its suitability for this application. In contrast, a solution based on sliding drawers proved more promising, provided that the dropping mechanism could be designed in such a way that syringe placement would be reliable and reproducible.

To structure this comparison, four principles (CircuLade, DualSlide, LiftSlide, and DualDrop) were evaluated together with the engineers from Neollie. The advantages and disadvantages raised during the discussion are presented in Table E1.

Table E1: Advantages and disadvantages

	CircuLade	DualSlide	LiftSlide	DualDrop
Advantages	*No distinct advantages compared to the alternative concepts.*	Mechanically, relatively the simplest. Drawers can be easily removed for cleaning.	Syringes are dropped from a consistent height.	Syringes can be placed from a controlled and minimal height. Drawer actuation remains mechanically simple. Improved reliability and precision of the dropping process.
Disadvantages	Requires more unused space compared to other configurations. Mechanically very complex for its function. Drawers are difficult to remove for cleaning.	Syringes are always dropped from the same height; for the lower drawer this results in a large drop distance, reducing placement reliability.	Entire drawer must be lifted, causing unwanted air movement and increased risk of cold air loss within the cooled environment. Mechanically complex due to the transition from horizontal to vertical motion. More difficult to clean because of additional moving components.	The dropping mechanism itself is technically more complex.
	Although the presence of unused space remains a drawback for each concept, this was deemed acceptable in consultation with Neollie, as reliability and reproducibility are considered more critical than maximum space efficiency in this application.			

Weighted trade-off analysis

To further support a structured and transparent comparison of the subsystem options, a weighted criteria method (Roozenburg & Eekels, 2016) was conducted. This analysis was deliberately applied as a complement to the qualitative discussion sessions. While the technical discussions primarily addressed functional feasibility and performance, not all relevant design considerations were explicitly covered. In particular, aspects such as cleanability, complexity, maintainability, and adjustability are critical within a NICU context and therefore required a more systematic and explicit evaluation.

Rather than directly replicating the individual design requirements defined within the project scope, the weighted criteria method employed a set of higher-level evaluation criteria that capture overarching system qualities relevant to the design of Neo. These criteria function as evaluative dimensions that synthesise multiple detailed requirements and insights gained throughout the design process.

The selected criteria (controllability, cleanability, maintainability, adjustability, cost efficiency, power efficiency, mass weight, complexity, precision, and space efficiency) were derived from the project's design scope, system constraints, and contextual considerations of the NICU environment. Although these terms are not always explicitly stated as standalone requirements, they represent aggregated interpretations of the underlying functional, mechanical, hygienic, and operational demands identified during the project.

The weighting of the criteria reflects both the priorities expressed by stakeholders and the designer's interpretation of their relative importance within the defined project scope. As such, the weighted criteria method should not be interpreted as a fully deterministic decision-making tool, but rather as a means to translate a complex, multi-dimensional design problem into a structured, comparable, and communicable overview.

Each criterion was assigned a relative importance rank ranging from 1 to 5, with the total sum of ranks equal to 31. These ranks were subsequently normalised into weights by dividing each rank by the total sum, resulting in a combined weight of 1.00. Each design option was then scored per criterion on a scale from 1 to 3, where 1 represents poor performance, 2 neutral performance, and 3 good performance.
Weighted scores were calculated by multiplying each criterion score by its corresponding weight. The weighted scores per option were summed to obtain a total score for each concept, after which the results were normalised into final grades to facilitate comparison between the alternatives.

Table E2: Weighted Criteria Method

			Option 1		Option 2		Option 3		Option 4	
Quantitive Metric	**Rank**	**Weight**	**CircuLade**	**Weighted 1**	**DualSlide**	**Weighted 2**	**LiftSlide**	**Weighted 3**	**DualDrop**	**Weighted 4**
Controlability	2	0.06	3	0.19	1	0.06	3	0.19	3	0.19
Cleanability	5	0.16	1	0.16	3	0.48	1	0.16	3	0.48
Maintainability	3	0.10	1	0.10	3	0.29	2	0.19	3	0.29
Scalability	3	0.10	2	0.19	1	0.10	3	0.29	3	0.29
Cost efficiency	2	0.06	1	0.06	3	0.19	2	0.13	2	0.13
Power efficiency	4	0.13	1	0.13	3	0.39	2	0.26	2	0.26
Mass weight	1	0.03	1	0.03	2	0.06	2	0.06	2	0.06
Complexity	4	0.13	1	0.13	3	0.39	2	0.26	3	0.39
Precision	5	0.16	2	0.32	1	0.16	3	0.48	3	0.48
Space efficiency	2	0.06	1	0.06	2	0.13	2	0.13	2	0.13
Total	31	1		1.39		2.26		2.16		2.71
Grade				**4.62**		**7.53**		**7.20**		**9.03**

Design Decision

The results of the weighted criteria method, together with the outcomes of the discussions with the engineers of Neollie, indicate that the DualDrop concept achieves the highest overall grade across the selected evaluation criteria. Based on these outcomes, the DualDrop concept was selected for further elaboration in the Embodiment Phase.

The CircuLade concept received a substantially lower grade, primarily due to limited performance across multiple criteria, which makes it unsuitable within the constraints and requirements of the NICU context. The DualSlide and LiftSlide concepts achieved moderate overall scores; however, their increased mechanical complexity negatively impacts aspects such as maintainability, cleanability, and system robustness. As a result, these concepts were not considered suitable for further development despite their average performance in the weighted evaluation.

Appendix F: Prototypes and User tests

Prototype A

This section presents the evaluation study conducted with Prototype A of the DualDrop output module. The aim of this study was to obtain qualitative insights into user interaction, workflow alignment, and perceived safety and trust, rather than to quantitatively validate system performance. The prototype enabled nurses to physically interact with the system, allowing assumptions made during the design phase to be discussed and reflected upon in a realistic context.

Objective
The primary objective of this evaluation study was to assess how well the DualDrop output concept aligns with the daily nursing workflow in the NICU kitchen, and to what extent it supports a safe, intuitive, and trustworthy handover of prepared syringes. In particular, the study aimed to explore:

- how nurses interact with the output module in relation to existing tools such as trolleys and trays;
- how safety, control, and trust are perceived during use;
- how cleaning routines, logistics, and exceptional scenarios fit within current practices;
- whether the design choices support Research Question 3, or require refinement.

Rather than functioning as a formal usability test, this study combined guided workflow walkthroughs, observation, and semi-structured interviews, and is therefore referred to as an evaluation study.

Research question
How can the output stage be aligned with the daily nursing workflow in the NICU, ensuring that trays fit existing storage solutions and enable a safe and user-friendly handover to nurses?

Method

Participants
Two NICU kitchen nurses participated in the evaluation study. These participants were selected because they are directly responsible for preparing and handling enteral feeding and are the primary intended users of the Neo-machine. Their expertise and familiarity with existing workflows made them well-suited to evaluate the proposed output concept.

Procedure
The evaluation study consisted of four phases:

1. Introduction and context setting
   Explanation of the study purpose, scope, and what aspects of the prototype were being evaluated.
2. System explanation and demonstration
   A walkthrough of the DualDrop concept and demonstration of the prototype's intended functionality.
3. Workflow walkthrough and hands-on interaction
   Participants followed the proposed workflow using the prototype, including opening the output module, placing trays, and simulating tray removal.
4. Semi-structured interview and reflection
   Discussion of observations, perceived strengths and weaknesses, safety concerns, and suggestions for improvement.

Due to time constraints and the clinical context, phases 3 and 4 partially overlapped, with participants performing actions while simultaneously reflecting on them.

Tools
- Prototype 1 of the DualDrop output module (connected to hospital compressed air)
- Interactive interface mock-ups displayed on an iPad (Figma)
- Standard white NICU trays
- 12 × 20 mL syringes
- 12 × 60 mL syringes

Data collection
No audio or video recordings were made. Given the small population of NICU kitchen nurses and privacy considerations, only anonymized qualitative key findings were documented. The interview questions are provided in the next section.

Process Tasks
The following steps describe the intended user interaction when starting and completing a production cycle of the machine. It is assumed that the breast milk has already been loaded into the input system.

1. The nurse collects eight white trays.
2. The nurse scans their personal badge.
3. The nurse selects the option "Load trays" on the interface.
4. The cooling compartment is opened.
5. The nurse places the eight trays inside the cooling module.
6. The cooling compartment is closed.
7. The nurse verifies on the display whether the process can be started.
8. The nurse presses "Start process."
9. The machine begins operation. The display indicates the estimated time remaining until all syringes are filled.
10. Once completed, the display shows: "Process completed – syringes ready for pickup."
11. The nurse returns with the transport trolley.
12. The nurse scans their badge again.
13. The front door is opened.
14. The trays are removed and placed into the trolley.
15. The door is closed.

After completion:
16. The system displays a notification: "Cleaning required."
17. The drawers are removed.
18. The nurse cleans the drawers.
19. The drawers are placed back into the system.

Interview questions
General Feedback
- What is your overall impression of this process?
- What works well/ doesn't work well?

Cleaning
- How often is the trolley cleaned?
- Who is responsible for cleaning the trolley?
- How is the trolley cleaned, and which cleaning materials are used?
- How often do you think the drawers should be cleaned?
- How often should the cooling compartment be cleaned?

Trust
- What makes a machine trustworthy for you as a nurse?
- Would you prefer the process to be visible (for example through a transparent window)?
- Does visibility influence your level of trust?

Use of Stickers
- Why are stickers currently placed on the trays? Is this for additional safety, or mainly routine?
- Do you consider the sticker necessary, or would the labeling on the syringes be sufficient?
- If stickers are required, at which moment would it be most practical to apply them?
  Before placing the trays in the machine?
  After the trays are filled, based on the syringe labels?

Feedback from the System
- What type of feedback would you expect when placing trays in the machine?
  (For example, confirmation that all trays are inserted correctly.)
- Is screen-based feedback sufficient and clear?

Physical Interaction
- Would it be useful to manually pull the drawer slightly towards you, or should it remain fixed in the system?
- Should the door open automatically or manually?
- Is the integrated work surface useful, or does it interfere with the trolley?
  (To be observed during testing.)

Interface
- Which functions do you consider necessary on the screen?

Ergonomics
- Is the current working height comfortable?
- Would a different height be preferable?

Results

The evaluation study yielded a set of recurring qualitative insights, clustered around trust and safety, workflow integration, and cleanability.

Safety, Control, and Trust
- A fixed and predictable layout inside the machine supports learning, checking, and confidence building.
- Nurses are accustomed to using stickers on trays as a form of double-checking and visual identification; they strongly prefer to retain this practice during the transition phase.
- Trust in the robot is not immediate and must be earned through repeated correct operation.
- Consistency is critical: for example, tray slot 1 should always correspond to the same patient (e.g. bed 1).
- Double-checking by two nurses is considered essential in the current phase and should be supported rather than eliminated.

Access Control and Accountability
- Card scanning was positively received by one participant as a means of ensuring that only trained personnel operate the machine.
- Access control was associated with accountability rather than distrust:
  “If you are not trained yet, you are not allowed to work with it.”
- While the NICU kitchen itself is already a restricted space, card-based access was seen as valuable for traceability and safe use.

Workflow and Logistics
- A fold-down workbench was considered unnecessary and potentially fragile; trays are placed directly into the trolley.
- No strong preference was expressed for take-out height, as long as trays can be easily and safely removed.
- Feeding preparation typically occurs once every 24 hours. Preparation with the machine every 24 hours or every 12 hours was discussed. Both are acceptable but increasing the pickup times more frequency than every 12 hours was viewed as undesirable, as it would negate time savings.

- Opinions on a viewing window differed: one participant appreciated visibility, while another compared it to “staring into a washing machine.”

Cleaning Practices
- Trolleys are cleaned daily in a central facility in the basement of Erasmus MC.
- White trays are cleaned manually using water and a cleaning cloth. Wiping the machine with water and a cleaning cloth is considered sufficient.
- It was again indicated that the white trays are preferred, as they fit both in the transport trolley and in the refrigerator. The metal trays are no longer used, as they were found to corrode over time. Reusable ceramic trays were also discontinued because they frequently chipped or broke. The white trays are therefore reused in daily practice.
- Drawer interiors would require less frequent cleaning than trays and could be cleaned by support staff.

Additional Insights on Preparation Timing and Flexibility

Feeding plans are typically determined 24 hours in advance, similar to medication workflows. However, prescriptions may change last-minute, resulting in:
- Prepared syringes becoming obsolete (waste);
- Additional syringes needing to be prepared.

This raises strategic questions regarding:
- Whether preparation should occur 24 hours, 12 hours, or on demand;
- How frequently last-minute changes occur;
- Whether adjustments should be handled via hospital information systems (e.g. HiX) or locally at the machine.

Discussion

Differences in prior exposure to the concept influenced the nature and depth of the feedback. One nurse had previously been exposed to the system through a video demonstration, which provided her with preliminary understanding and resulted in more reflective and forward-looking feedback. The second nurse had no prior knowledge of the system and responded more spontaneously and reactively. She indicated that she had already been considering potential solutions independently and expressed appreciation for the idea that such a machine could be implemented in the future. This difference in prior knowledge was reflected in the extent to which the feedback generated new and actionable insights, with the nurse familiar with the concept providing more substantial contributions.

Due to significant time constraints and limited availability of the participants, the evaluation could not be conducted in four distinct phases as originally planned. Instead, the test was executed as a combined action-and-discussion session, in which the participants performed tasks while verbalizing their thoughts, and their interactions were observed concurrently.

To support the participants during the procedure, a display was provided that showed the workflow steps. Nevertheless, assistance was still required to verbally guide them through the individual steps.

The execution of the final workflow step involving the trays was affected by the absence of fully loaded trays. As the trays were empty rather than filled with the intended 120 syringes, the participants stacked the trays manually and simulated placing them into the trolley. Although this meant that the final step of the workflow was not fully representative of real use, both participants clearly indicated that an additional workbench was not necessary, as the trays could be placed directly into the trolley. Consequently, the findings regarding ergonomics, storage, and the need for auxiliary surfaces remain valid.

In addition, questions were raised regarding the user interface, specifically concerning which information should be displayed and who determines these interface requirements, as well as whether user authentication through badge scanning is necessary. These aspects are discussed further in User test C.

Given that the evaluation involved only two participants, the findings should be interpreted as qualitative and indicative rather than representative. The results primarily serve to provide initial insights into user interaction and system perception, rather than definitive conclusions about usability in clinical practice.

Prototype B

Objective
The primary objective of this evaluation study was to determine the most reliable and safe configuration for the syringe dropping mechanism. Specifically, the study aimed to:

- Determine whether syringes should be dropped from a single fixed position or from multiple dropping positions;
- Explore whether adaptive adjustment based on landing position (camera-based feedback) may be required;
- Determine the dropping height at which syringes can reliably land inside the tray without compromising safety;
- Determine the minimum required wall height of the drawers, balancing safety margins and spatial efficiency;
- Measure the time required to fill one tray with twelve syringes.

Research question

1. Can syringes be reliably dropped from a single fixed release position, or is it more effective to use multiple release positions? Additionally, is adaptive correction based on landing position (camera-based feedback) required to ensure accurate placement?
2. What is the maximum dropping height at which syringes can safely and consistently land within the tray?
3. What is the minimum required wall height of the drawers to ensure safe containment of the syringes, while maintaining spatial efficiency within the cooled module?
4. What is the time required to fill one tray with twelve syringes under controlled test conditions?

Method
To simulate realistic conditions, syringes were filled with water to match the weight and length of syringes used in clinical practice. This ensured that both 20 mL and 60 mL syringes behaved comparably to real feeding situations in terms of mass and balance.

All tests were conducted sequentially: first with 20 mL syringes and subsequently with 60 mL syringes. Each configuration was repeated five times to assess consistency and reliability.

The heights were measured from the top surface of the drawer on which the tray was positioned. During testing, observations were made regarding landing accuracy, interaction between syringes, and potential protrusion above the tray walls. A “reliable landing” was defined as a syringe coming to rest fully within the designated tray compartment without bouncing out.

The tests were structures in multiple series:
Test 1a: Drop in the middle (fixed position)
Test 1b: Drop from 3 different positions.
Test 1c: Drop from 5 different positions.
Test 2: Determining the height of the drop.
Test 3: Determning the wall height.
Test 4: Determining the time required to fill the outermost tray with 12 syringes

Test Results
The results of the dropping mechanism tests are summarized in Table 4 in the main report. This section provides additional context and explanation of the observed behaviour during testing.

Release positions (fixed vs multiple)
During testing, syringes were released sequentially from three different positions (left, center, and right) within the tray. This approach resulted in sufficiently reliable placement, as the syringes positively displaced each other upon landing, contributing to a more even distribution within the tray compartments.

For 20 mL syringes, consistent placement was achieved across all trials. For 60 mL syringes, occasional instability was observed from approximately the sixth syringe onwards, where syringes could protrude above the tray edge. However, in practice a maximum of six 60 mL syringes is typically used per tray. Based on these findings, the three-position release strategy was considered adequate for both syringe sizes.

Camera-based feedback
A simulated camera-based feedback approach was explored by manually observing the landing position of syringes and adjusting the drop location accordingly. This method did not result in a significant improvement in placement reliability compared to the fixed three-position release strategy.

Considering the additional cost and technical complexity associated with implementing a camera system, and the sufficient performance of the existing approach, camera-based feedback was not included in the design.

Wall height of drawers
The required wall height of the drawers was determined based on observed syringe behaviour during impact. For 20 mL syringes, a wall height of 120 mm was sufficient to ensure that syringes remained within the tray boundaries.

For 60 mL syringes, a minimum wall height of 140 mm was required, as syringes occasionally extended above the edge of the drawer at lower wall heights. The drawers were initially designed with a lower wall height to maximise spatial efficiency. However, based on the test results, an increase in wall height is recommended to ensure safe containment.

Dropping height
A dropping height of approximately 107 mm above the drawer surface was used during testing and was found to be sufficient for safe and consistent placement of syringes. This height was determined empirically by manually placing syringes into the tray and estimating the required release position of the dropping mechanism.

Throughout the tests, this dropping height did not result in any observed failures or instability, and was therefore considered adequate. However, it should be noted that this value was not systematically validated through extensive testing across multiple height variations. A more detailed investigation would be required to determine the exact optimal dropping height and its safety margins.

Process time
The time required to fill one tray with twelve syringes was measured at approximately 95 seconds under a worst-case scenario, including maximum travel distances within the system.

It should be noted that this value represents a conservative estimate. The current motion sequence includes pauses between movements, and the test setup involved four trays instead of five. Additionally, the timing assumes that syringes are immediately available in the intermediate subsystem, without waiting time.

Further optimisation of movement parameters and system sequencing is expected to reduce the total process time.

Table F.B1: Results test B

Test 1a	**Drop position in the middle (fixed position)**			
	Start conditions			
	Droppings height in python -170			
	distance from the tray to the centre of the syringe (centre of the gripper) 107 mm			
	Wall height 7 cm			

Nr.	Test 1A (20mL)	Notes	The part that extends above the drawer	**Test 3** The wall height should be
1	Good		1	8
2	Good	The syringes push each other aside (in the right place)	3	11
3	Good		3	11
4	Good	Several syringes came 4 cm above the drawer	4	**12**
5	Good		3	11

Nr.	Test 1A (60mL)	Notes	The part that extends above the drawer	**Test 3** The wall height should be
1		Didn't go entirely well	5	12
2		Things go wrong from the 7th syringe onwards	5	12
3		Fine, just a tiny bit sticking out of the drawer with the top of the syringe	5	12
4	Good		5	12
5		Syringes 6 and 7 reached a height of 14 cm (7 cm above the drawer)	7	**14**

Test 1b	**3 drop positions**			

Nr.	Test 1B (20mL)	Notes	The part that extends above the drawer	**Test 3** The wall height should be
1		The first two syringes are positioned very close to each other, with one protruding slightly, but this was again corrected by the other syringe	3	10
2		One syringe is sticking out a little further	5	**12**
3	Good		2	9
4	Good		3	10
5		It was just over 3 cm, but that was corrected again by other syringes	1	8

Nr.	Test 1B (60mL)	Notes	The part that extends above the drawer	**Test 3** The wall height should be
1		looks much tidier, less unstable, more reliable than test 1a	5	12
2	Good		5	12
3	Good		6	13
4	Good		5	12
5		The last syringe was placed in the middle, so it sticks out a lot.	7	**14**

Test 1c	**5 drop positions (-50 -30 0 30 50) whereby we determine what the new position should be (simulating the camera)**			

Nr.	Test 1B (20mL)	Notes	The part that extends above the drawer	**Test 3** The wall height should be
1	Good		2	9
2	Good		2	9
3	Good		2	9
4	Good		2	9
5	Good		1	8
		Overall: nothing out of the ordinary		

Nr.	Test 1B (60mL)	Notes	The part that extends above the drawer	**Test 3** The wall height should be
1		One syringe went over the edge of the drawer	5	12
2	Good		5	12
3	Good		5	12
4	Good		6	13
5	Good		6	13
		Overall: everything is going well up to 6 syringes.		

Discussion
The results demonstrate that reliable syringe placement can be achieved with a relatively simple system configuration. In particular, the findings support the DualDrop principle, where a vertically movable dropping mechanism enables a controlled and minimal dropping height, improving placement consistency.

The experiments further indicate that increasing system complexity does not necessarily lead to improved performance. While multiple release strategies were explored, the results show that a configuration with three predefined dropping positions provides sufficient reliability. This approach allows syringes to distribute naturally within the tray through interaction, without requiring additional system complexity.

Similarly, the potential of camera-based feedback was explored by simulating its function through manual observation and adjustment of drop positions. This did not result in a significant improvement compared to the three-position release strategy, and was therefore not included in the final design.

An important insight from the study is the role of passive safety features. The height of the drawer walls proved to be critical in preventing syringes from extending beyond the edge of the drawer. This highlights that reliable system behaviour is not solely dependent on precise control mechanisms, but also on well-designed physical constraints.

The results further illustrate that, in this context, system reliability is primarily governed by physical design choices rather than advanced control strategies.

These findings directly informed the final design decisions, particularly the implementation of a vertically movable dropping mechanism, a three-position release strategy, and increased drawer wall height within the DualDrop concept.

It should be noted that the tests were conducted under controlled conditions using water-filled syringes and a functional prototype. While this provides a realistic approximation, variations in real clinical conditions may still influence system behaviour.

Finally, the testing process revealed that each experiment led to new questions and opportunities for further refinement. Although additional iterations could have provided more detailed insights, the testing phase was concluded once sufficient evidence was obtained to support the key design decisions within the scope of this project.

Prototype C

This appendix provides a detailed overview of the user interface evaluation conducted with Prototype C of the DualDrop output module.

Objective
The study focused on assessing how nurses interpret and interact with the digital interface, with particular attention to clarity, safety, and workflow alignment.

The primary objective was to determine which information must be displayed to ensure intuitive, safe, and workflow-aligned operation of the system.

Research question
Which information must be displayed on the interface to ensure intuitive, safe, and workflow-aligned operation of the DualDrop output subsystem?

Participants
Six participants took part in the study, working in pairs. All participants were NICU staff involved in feeding preparation and therefore represent the primary user group of the system.

The paired setup reflects aspects of real-world collaboration, but may also have influenced responses, as participants could support or guide each other during tasks.

Method
The evaluation was conducted using an interactive Figma prototype displayed on an iPad, supported by a contextual video of the Neo system.
Participants completed structured task scenarios divided into three categories:

1. Routine tasks
2. Cleaning and maintenance scenarios
3. Information retrieval tasks

Participants were asked to think aloud during task execution. Observations were made regarding:
- Hesitation and confusion
- Task completion
- Interpretation of interface elements

Each task was followed by:
Likert-scale evaluation (1–5) assessing clarity, usability, safety, and independence
qualitative discussion
The evaluation was not recorded; instead, key observations and participant statements were documented and summarized.

Task Overview
Participants completed eight tasks:
- Routine workflow (Tasks 1a–1h)
Starting and completing a production cycle.
- Error and maintenance handling (Tasks 2–4)
Resolving tray errors, cleaning notifications, and maintenance messages.
- Information retrieval (Tasks 5–8)
Accessing temperature, cleaning schedules, process status, and missing milk.

Materials
The answer sheet with the Likert scale has been added (see Illustration F.C1), and all the screens that were displayed on the iPad during the test have also been included (see Illustration F.C2).

Results
The results are summarized in Table 5 in the main report. This section provides additional context and interpretation of the findings.

1. Errors and Guidance
Participants were able to recognize that an error had occurred, but often struggled to understand the exact cause and required action.
- Uncertainty existed about whether trays needed to be removed and reinserted
- Lack of confirmation feedback created doubt about whether the issue was resolved

Insight:
Error messages must clearly state:
- What is wrong
- What action is required
- When the issue is resolved

2. Cleaning
Cleaning procedures were not always clearly understood.
- Participants were unsure what exactly needed to be cleaned
- Cleaning frequency (daily vs per session) caused confusion
- Participants indicated limited time availability

Insight:
The interface must:
- Clearly specify what to clean
- Allow confirmation after cleaning
- Allow limited postponement

3. Maintenance
Participants expressed a strong need for clarity during technical malfunctions.
- Need for direct communication with technical staff
- Desire for urgency indication (e.g. “resolve within X hours”)

Insight:
The system must clearly distinguish between:
- User-resolvable issues
- Technical issues requiring external support

4. Information and Safety
Participants indicated that some critical information was missing or insufficiently visible.
- Temperature values lacked context (safe vs unsafe range)
- Need for visual indicators (green/orange/red)
- Desire for real-time process overview on the home screen
- Need for clear patient identification to avoid mix-ups

Insight:
Information must be:
- Immediately visible
- Interpretable without additional knowledge
- Safety-oriented

5. Display Interaction
- The interface must be operable while wearing medical gloves
- Minimal complexity is preferred (“not too many buttons”)

6. Workflow Integration
- Double-checking between nurses is part of current workflow
- Participants suggested optional support for this behaviour

7. Alarms and Feedback
- Visual feedback is important
- Audio feedback is useful depending on machine location

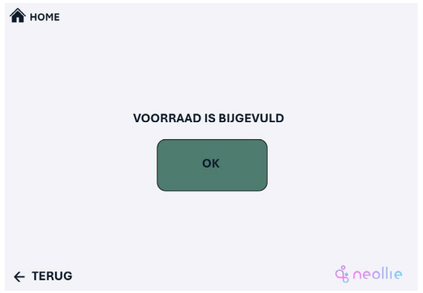
8. Information Retrieval
Participants indicated that key information should be directly visible rather than hidden in submenus.
- Process progress should be visible at a glance
- End time visible
- Missing milk should be visually linked to patient overview

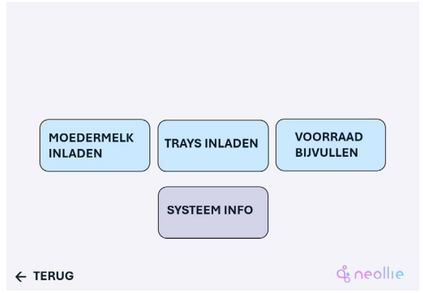
Discussion
The results demonstrate that the usability of the interface is primarily determined by clarity of information rather than interaction complexity. Participants were generally able to navigate the interface, but uncertainties arose when information was incomplete or ambiguous.
A key finding is that the interface must explicitly guide the user in decision-making, particularly in error and maintenance scenarios. Users do not only need to know that something is wrong, but also what action to take and whether they are responsible for resolving it.
In addition, the study highlights the importance of aligning the interface with existing clinical practices, such as double-checking and visual verification. Rather than replacing these practices, the system should support them.

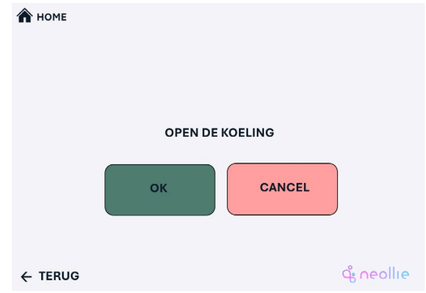
The results further show that critical information must be immediately visible on the home screen. Requiring users to navigate through multiple layers reduces usability and may introduce risks in time-sensitive situations.

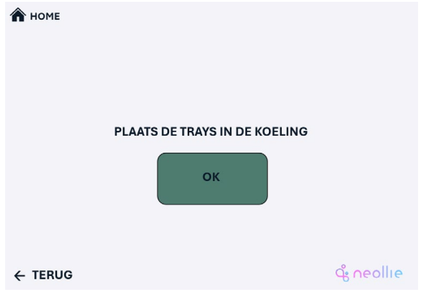
Limitations
The evaluation involved six participants working in pairs, which may have influenced individual responses due to collaboration during tasks. While this setup enabled richer discussion, it may have reduced independent decision-making behaviour.

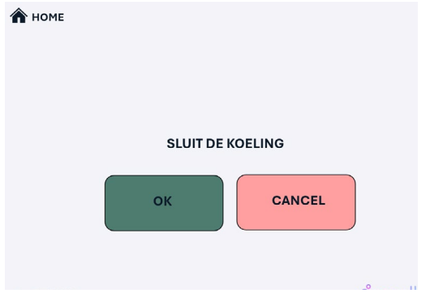
Additionally, the interface was tested using a Figma prototype rather than a fully functional system. As a result, interaction dynamics and system feedback were simulated rather than real-time.
Therefore, the findings should be interpreted as exploratory, providing indicative insights rather than definitive conclusions.

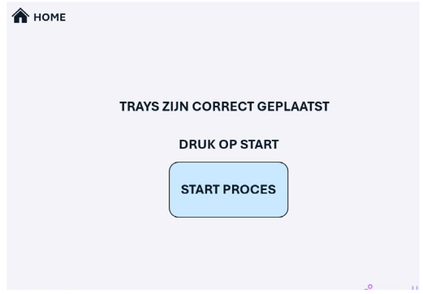


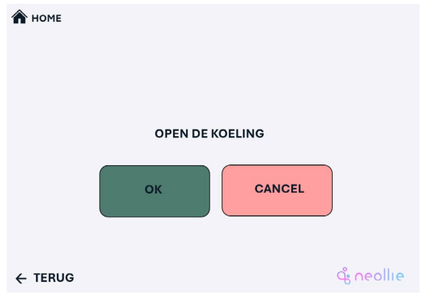


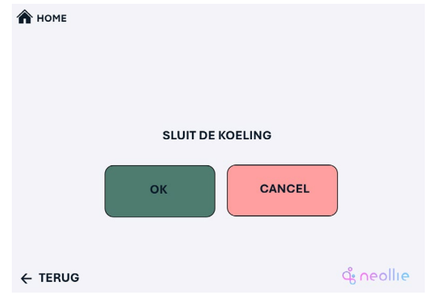


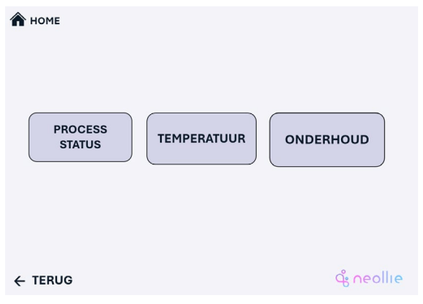












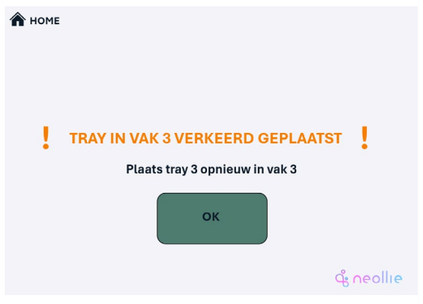


Figure F.C1: Screens

Taks 1	Oneens				Eens
	1	2	3	4	5
De stappen waren duidelijk	☐	☐	☐	☐	☐
Ik wist steeds wat ik moest doen	☐	☐	☐	☐	☐
De interface voelde logisch	☐	☐	☐	☐	☐
Ik had het gevoel dat ik deze routine foutloos kon uitvoeren, en dat dit geen risico vormt voor de patiënten	☐	☐	☐	☐	☐
Ik denk dat andere NICU verpleegkundigen dit zonder fouten kunnen doen	☐	☐	☐	☐	☐

Taks 2	Oneens				Eens
	1	2	3	4	5
Ik begreep wat het probleem was	☐	☐	☐	☐	☐
Ik begreep hoe ik het probleem kon oplossen	☐	☐	☐	☐	☐
Ik begreep dat ik zelf het probleem op kon lossen en dat er niemand extern te pas hoefde te komen	☐	☐	☐	☐	☐
De melding voelde niet stressvol of verwarrend	☐	☐	☐	☐	☐
Ik denk dat andere NICU verpleegkundigen dit zouden kunnen oplossen	☐	☐	☐	☐	☐

Taks 3	Oneens				Eens
	1	2	3	4	5
Ik begreep wat het probleem was	☐	☐	☐	☐	☐
Ik begreep hoe ik het probleem kon oplossen	☐	☐	☐	☐	☐
Ik begreep dat ik zelf het probleem op kon lossen en dat er niemand extern te pas hoefde te komen	☐	☐	☐	☐	☐
De melding voelde niet stressvol of verwarrend	☐	☐	☐	☐	☐
Ik denk dat andere NICU verpleegkundigen dit zouden kunnen oplossen	☐	☐	☐	☐	☐

Taks 4	Oneens				Eens
	1	2	3	4	5
Ik begreep wat het probleem was	☐	☐	☐	☐	☐
Ik begreep dat ik NIET zelf het probleem op kon lossen en dat er iemand extern te pas moet komen	☐	☐	☐	☐	☐
De melding voelde niet stressvol of verwarrend	☐	☐	☐	☐	☐
Ik denk dat andere NICU verpleegkundigen zouden weten wat ze in deze situatie moeten doen	☐	☐	☐	☐	☐

Taks 5	Oneens				Eens
	1	2	3	4	5
Ik kon de informatie snel vinden	☐	☐	☐	☐	☐
De informatie was duidelijk	☐	☐	☐	☐	☐
Ik moest niet zoeken of gokken	☐	☐	☐	☐	☐

Taks 6	Oneens				Eens
	1	2	3	4	5
Ik kon de informatie snel vinden	☐	☐	☐	☐	☐
De informatie was duidelijk	☐	☐	☐	☐	☐
Ik moest niet zoeken of gokken	☐	☐	☐	☐	☐

Taks 7	Oneens				Eens
	1	2	3	4	5
Ik kon de informatie snel vinden	☐	☐	☐	☐	☐
De informatie was duidelijk	☐	☐	☐	☐	☐
Ik moest niet zoeken of gokken	☐	☐	☐	☐	☐

Taks 8	Oneens				Eens
	1	2	3	4	5
Ik kon de informatie snel vinden	☐	☐	☐	☐	☐
De informatie was duidelijk	☐	☐	☐	☐	☐
Ik moest niet zoeken of gokken	☐	☐	☐	☐	☐

Figure F.C2: Likert scale answer sheet

Appendix G: Process Flow Diagram

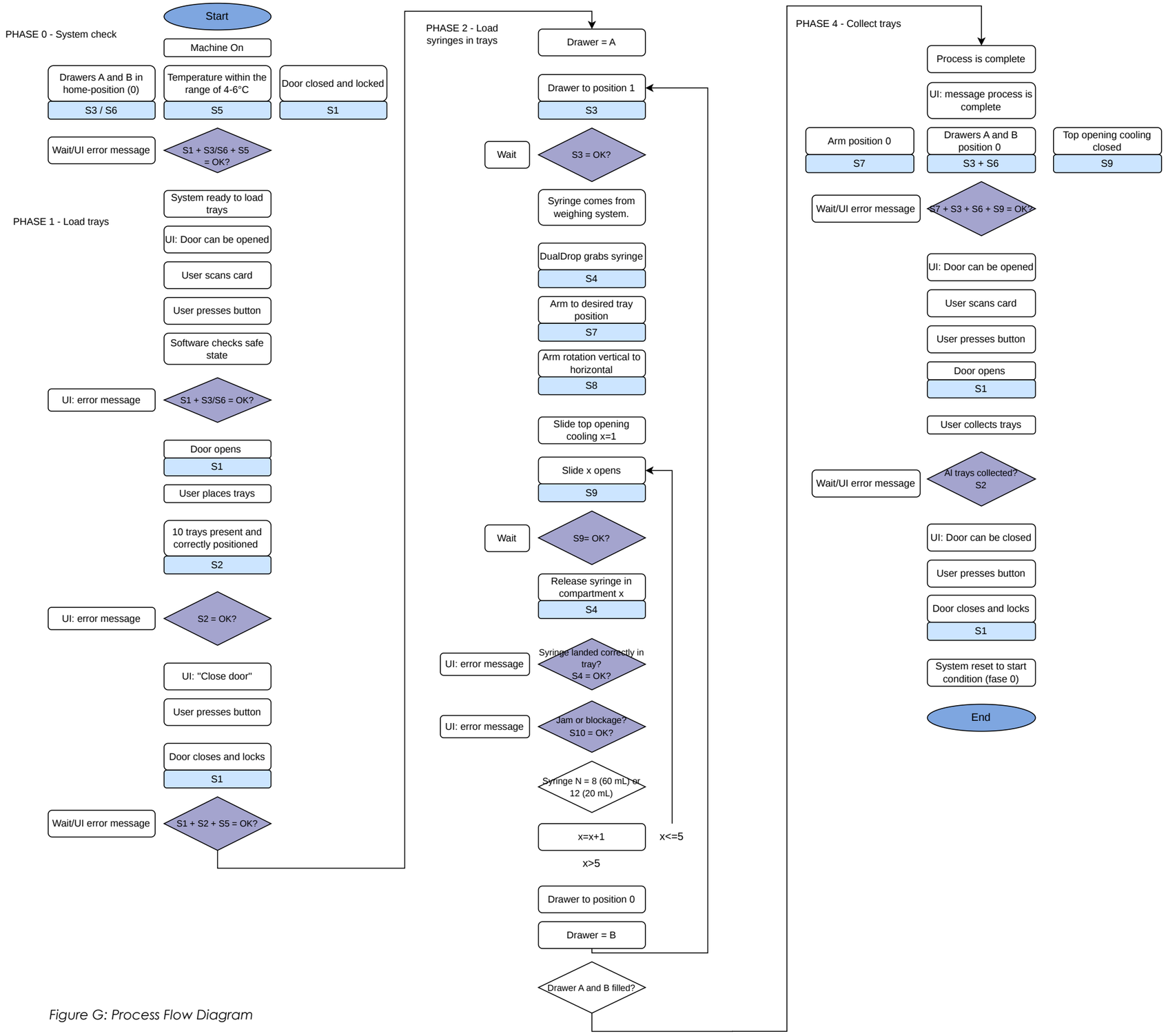


Figure G: Process Flow Diagram

Table G: Sensor and function

Sensor nr.	Function
S1	Door open/ closed/ locked
S2	Tray present & correctly positioned
S3	Position drawer A
S4	Syringe in gripper / released
S4	Syringe correctly placed in tray
S5	Temperature
S6	Position drawer B
S7	Arm position
S8	Syringe rotation position (vertical to horizontal)
S9	Slide top opening status
S10	Jam detection

To clearly identify the required sensors, a comprehensive system overview was developed covering the entire process, from the moment the syringe is weighed and transferred to the DualDrop system, to the removal of the tray containing the filled syringes. At each stage of the process, an analysis was conducted to determine which sensors are necessary to ensure its complete and reliable operation.

Appendix H: Ergonomic Dimensions

DINED is an anthropometric database containing measurement data on the variation of human body dimensions and proportions. The database is an initiative of the Technische Universiteit Delft (TU Delft) and serves as a reference source for applying anthropometric data in design and product development. By providing statistical information on human body measurements, DINED supports designers and engineers in developing products and systems that accommodate a wide range of users.

For determining the vertical positioning of the Output Module in the DualDrop system, anthropometric data from the DINED database were used. The database provides body measurements for several population groups. For this project, data for Dutch adults aged 20–60 years were considered. It should be noted that this dataset dates from 2004, which represents a limitation of the database. However, the measurements remain a commonly used reference in ergonomic design.

In this analysis, elbow height was selected as the primary reference measurement. Elbow height is widely used in the design of work surfaces such as kitchen countertops, as it provides an ergonomic reference for comfortable interaction with objects and equipment. Following established ergonomic guidelines, a working height approximately 15 cm below elbow height was applied to determine a suitable interaction height.

The relevant anthropometric measurements used for this calculation are presented in Table H. To illustrate the ergonomic context, the DINED reference illustration (Figure H1) is placed alongside the Neollie machine configuration (Figure H2). This comparison provides a visual indication of the recommended vertical position of the Output Module within the machine.

Source: https://dined.io.tudelft.nl/en

Table H: Dined measures

populations	Dutch adults 20–60, female		Dutch adults 20–60, male		Dutch adults 20–60, mixed	
measures	mean	sd	mean	sd	mean	sd
Stature (mm)	1668	67	1817	83	1743	106
Elbow height, standing (mm)	1034	51	1134	59	1084	74

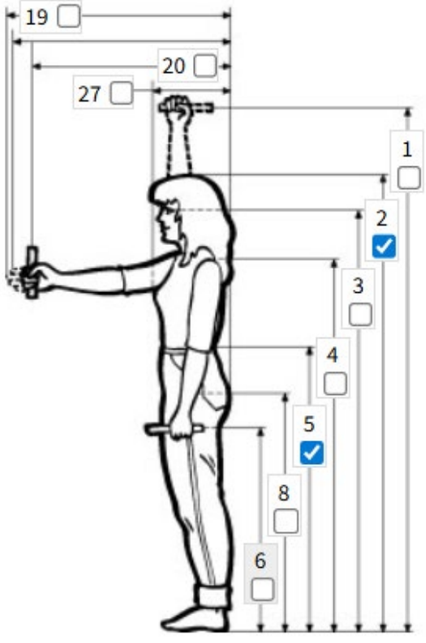


Figure H1: Dined reference illustration

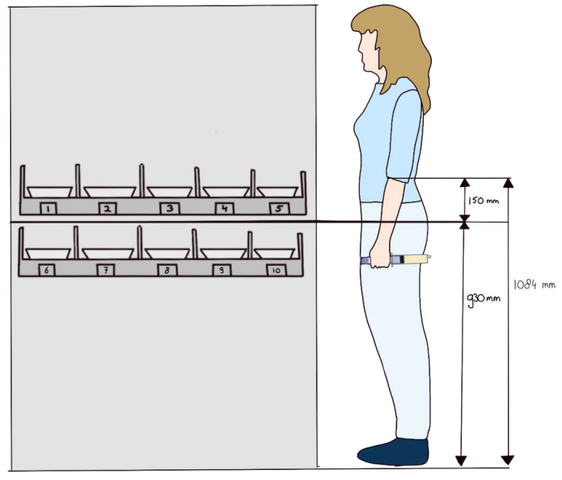


Figure H2: Dined reference illustration alongside Neo

Appendix I: Dimensions of the DualDrop

The design of the DualDrop output module is based on the dimensions of the existing white trays used in the NICU workflow. These trays measure 170 mm in width, 325 mm in length, and 50 mm in height.

To allow for sufficient clearance during insertion and removal, the internal width of each compartment within the drawer is set to 190 mm (wall-to-wall). The internal depth of the compartment is 185 mm. The required internal height of the drawer is determined through the dropping tests and is set at 140 mm, ensuring safe accommodation of stacked syringes without obstruction.

The wall thickness of the drawers is currently defined as 5 mm. This value is based on an informed estimate and should be further optimised during detailed engineering and production development.

The overall dimensions of a single drawer are 980 mm in width and 355 mm in depth. The spacing between the two drawers is minimized to 20 mm in order to maintain a compact cooled output module. Further testing is required to validate the reliability of this spacing.

The linear actuator must enable a backward travel distance of 355 mm to fully extend the drawer. The actuator sizing is based on an initial estimation, as detailed mechanical components such as fasteners and mounting structures have not yet been fully integrated.

The internal width of the output module is 1196 mm, measured from inner wall to inner wall. The wall thickness of the module is currently set at 25 mm, although this may require adjustment depending on the integration of cooling components such as evaporator coils.

The overall external dimensions of the output module are:
1266 mm (width),
470 mm (height),
and 925 mm (depth) .

In conclusion, the presented dimensions provide a well-considered approximation of the output module. However, further optimization is required during the engineering and production phases to refine these values based on detailed mechanical design and testing.

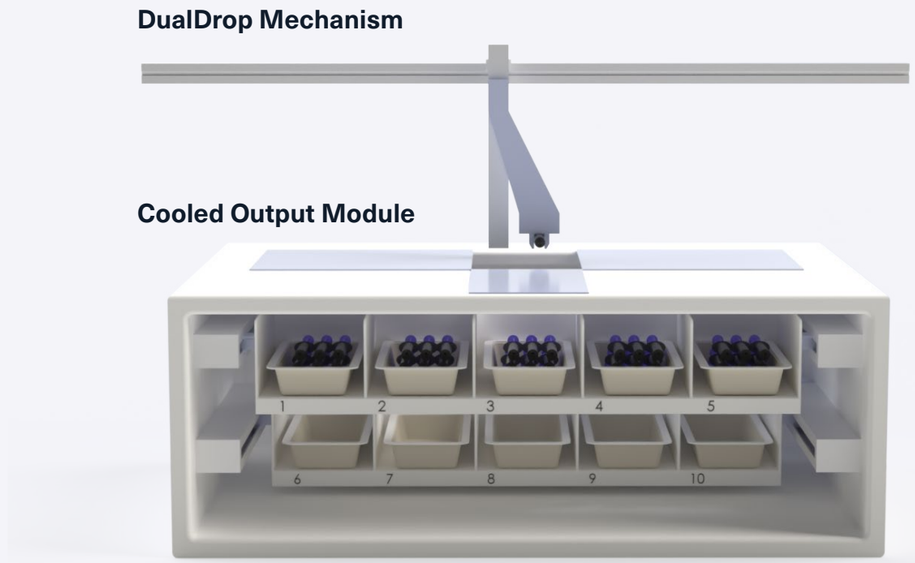


Figure I: DualDrop Mechanism with the Cooled Output Module

Appendix J: HREC Approval

Date 05-Jan-2026
Correspondence hrec@tudelft.nl

Human Research Ethics
Committee TU Delft
(http://hrec.tudelft.nl)

Visiting address
Jaffalaan 5 (building 31)
2628 BX Delft

Postal address
P.O. Box 5015 2600 GA Delft
The Netherlands

Ethics Approval Application: Mother Milk Robot
Applicant: Klemann, Valérie

Dear Valérie Klemann,

It is a pleasure to inform you that your application mentioned above has been approved.

Thanks very much for your submission to the HREC which has been approved.

In addition to any specific conditions or notes, the HREC provides the following standard advice to all applicants:
• In light of recent tax changes, we advise that you confirm any proposed remuneration of research subjects with your faculty contract manager before going ahead.
• Please make sure when you carry out your research that you confirm contemporary covid protocols with your faculty HSE advisor, and that ongoing covid risks and precautions are flagged in the informed consent - with particular attention to this where there are physically vulnerable (eg: elderly or with underlying conditions) participants involved.
• Our default advice is not to publish transcripts or transcript summaries, but to retain these privately for specific purposes/checking; and if they are to be made public then only if fully anonymised and the transcript/summary itself approved by participants for specific purpose.
• Where there are collaborating (including funding) partners, appropriate formal agreements including clarity on responsibilities, including data ownership, responsibilities and access, should be in place and that relevant aspects of such agreements (such as access to raw or other data) are clear in the Informed Consent.

Good luck with your research!

Sincerely,

Appendix K: Project Brief

DESIGN FOR our future

TU Delft

Personal Project Brief – IDE Master Graduation Project

Name student: Valérie Klemann

Student number: 4,682,459

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

Project title

Scaling the Neollie Mother Milk Robot in Erasmus MC

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

Introduction

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

The Neollie Mother Milk Robot is an innovative solution designed to support the preparation, warming, and distribution of breast milk in a hospital context. Currently, nurses spend a significant portion of their time preparing bottles of milk, adding nutritional fortifiers, and warming and administering the correct portions. This process is labor-intensive, error-prone, and contributes to a high workload, while nurses' available time is becoming increasingly scarce.

An important issue is that nurses often need to prepare multiple bottles simultaneously for different patients. The current prototypes of the Neollie robot are mainly designed for processing a single bottle at a time, and therefore do not fully reflect the daily reality of healthcare professionals. In addition, the design must not only be scalable in terms of handling multiple bottles but also safe, reliable, and user-friendly, allowing nurses to integrate the robot into their workflow without additional cognitive burden.

The main stakeholders are nurses working in neonatal and pediatric wards, hospitals seeking more efficient processes, and Neollie as a startup developing a product that meets both user and market needs. For these stakeholders, there is a clear opportunity to create a robot that reduces workload, minimizes errors, and fits more effectively into existing hospital practices.

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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 current prototype of the Neollie Mother Milk Robot primarily focuses on processing a single bottle at a time. In practice, however, nurses prepare a large number of different bottles for different babies over the course of a single day. This means the current design does not align with the real workflows in hospitals. The lack of a scalable solution increases the risk that the robot adds additional steps and waiting time rather than reducing them.
In addition, challenges exist in terms of user experience, safety, and reliability. The robot must not only support nurses but also inspire confidence through an intuitive interface, clear feedback, and minimal risk of errors such as bottle swaps. At the same time, the mechanical design must be robust enough for daily use, compatible with standard bottles and syringes, and easy to maintain. Hygiene is a non-negotiable requirement in a hospital environment, as milk preparation directly affects the health of vulnerable patients.

The core problem is therefore to develop a design that is both scalable to handle the preparation of many different bottles for different patients throughout the day and user-friendly and reliable for nurses in clinical practice. By integrating these elements the Neollie robot becomes a valuable tool in healthcare and contribute to its mission of reducing workload and improving patient safety.

Assignment

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

Design an intervention to scale up the Neollie Mother Milk Robot for handling many different bottles across the day, while optimizing the user experience of nurses through scenarios and/or (partial) prototypes, taking into account the needs of hospitals and Neollie as a startup.

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 follows the Triple Diamond design method, focusing on both user experience and technical upscaling.

In the first diamond (Discover/Define), the current workflows of nurses will be studied through literature research, observations, and interviews. Special attention will be given to the interaction points where nurses engage with the robot: loading bottles, selecting nutritional fortifiers, and retrieving bottles or syringes. At the same time, the technical limitations of the current prototype will be analyzed.
In the second diamond (Develop/Deliver), concepts will be generated that improve both interaction design and mechanical scalability. These concepts will be made tangible through scenarios, mock-ups, and partial prototypes. Nurses will test these prototypes, with efficiency, error prevention, trust, and usability as central evaluation criteria.
In the third diamond (Deploy/Implement), the outcomes of the design and testing phases will be synthesized into a set of scalable design principles and implementation guidelines. These will provide Neollie with a clear direction for further product development and future integration of the robot into hospital workflows.

VALÉRIE KLEMANN