

SILENCING THE CHAOS:

A New Approach to Alarm Configuration in Intensive Care through Interface Design



Master Thesis
Ileen Boelhouwer



UMC Utrecht
Wilhelmina Kinderziekenhuis



Colophon



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TU Delft supervision by

dr. Elif Özcan Vieira
dr.ir. Lyè Goto

UMC Utrecht supervision by

dr. Erik Koomen
dr. Teus Kappen
Ruben Zoodsma

A design project by

Ileen Boelhhouwer





Preface

People who know me well will know that I have not always been enthusiastic about this master's degree, or design in general. I was especially reluctant to undertake the graduation project: working all alone and making complex design decisions did not appeal to me. However, this project turned out to be one of the most enjoyable and interesting projects of the entire master's programme. I discovered that designing for healthcare, especially digital design, is something that energises me.

In particular, I would like to thank **Erik**, my supervisor at the Wilhelmina Kinderziekenhuis. Thank you for being 24/7 (literally) available for feedback, discussion or jokes. Whenever I needed anything, it was immediately arranged. From easy access to all ICU departments and meetings with external companies to arranging available nurses to test with. Furthermore, I would like to thank **Teus, Lex**, Ruben and Marijn for their feedback and for sharing their valuable knowledge about the project. **Marijn**, thank you for providing the foundation I could build on. SetWise would not have been possible without your initial prototypes. Another special thanks to **Ruben**, for patiently answering the same questions over and over again... ;).

Of course, my supervisors from TU Delft cannot be forgotten; **Elif & Lyè**, thank you for all the fun and useful meetings. I was always busy taking notes to capture as much of your valuable feedback and advice as possible. Also, I would like to thank **Sijmen** for all the conversations (and nice lunches) we had during the entire master's program; Dfl would not have been fun without you. Last but not least, a big thank you to my **friends, family** and **roommates** who had to listen to all my stories about the project time and again.

Have fun reading, I know most of you won't ;), but just scroll through the images and you'll get some understanding of my project!

Ileen

Executive Summary

This master's thesis explores how **Interface Design** can support a new approach to **alarm configuration** in the Intensive Care Unit (ICU), with the ultimate aim of reducing alarm overload. The ICU is a high-intensity environment that is frequently overwhelmed by noise. Most of these sounds originate from monitoring devices that track a patient's vital signs. This excessive alarm load contributes to **Alarm Fatigue**, a phenomenon in which frequent false, non-actionable alarms lead to inadequate responses, impacting patient safety. This thesis forms part of the Smart and Silent Intensive Care Unit (SASICU) project, a European initiative aimed at addressing Alarm Fatigue. Furthermore, the thesis was conducted in partnership between **Wilhelmina Kinderziekenhuis** and the **Critical Alarms Lab** of TU Delft.

The high number of alarms has several causes. Monitoring devices from different manufacturers are unable to communicate with each other, which can lead to multiple, redundant alarms for the same clinical event. In addition, current alarm systems rely on absolute thresholds, which means that even small, harmless fluctuations in vital signs can trigger an alarm. Finally, the configuration of alarms must be performed directly on the monitoring devices, which is a time-consuming process. As a result, alarm settings are often not tailored to individual patients, even though patient-specific configurations can help to reduce the number of alarms.

This highlights the importance of a new approach to alarm configuration. UMC Utrecht envisions a future alarm system in which all monitoring devices are connected and communicate via a central Smart Alarm Manager. This Smart Alarm Manager uses contextual information about the patient to determine whether an alarm is necessary and sends it to the appropriate healthcare professional. To make this future system functional, nurses must provide the Smart Alarm Manager with relevant contextual information through a dedicated User Interface (UI). In response to this need, **SetWise** was developed through iterative prototyping and user testing. SetWise is a configuration UI that enables nurses to **personalise alarm settings** in just two primary steps. The UI presents real-time adjustments, provides shortcuts for entering contextual patient information and allows for manual fine-tuning: the nurse stays in control.

SetWise was evaluated by eight nurses from both the Paediatric and adult ICUs. All participants successfully configured a patient's alarm settings based on a given clinical scenario, suggesting that the UI is intuitive and demonstrates potential for future alarm systems. However, the findings showed considerable variation in perceptions of the new configuration method, indicating individual differences in work styles and preferences. Further UI improvements should incorporate flexibility to accommodate different Nurse Profiles. Some nurses are so accustomed to the current system that transitioning to an unfamiliar method may feel unsafe. Therefore, comprehensive training in the new configuration approach, along with a gradual implementation, is essential for the successful adoption of the system.

SetWise represents a tangible step towards a **quieter** and **smarter ICU**, encouraging a potential paradigm shift in alarm configuration: moving from micromanagement to patient-specific situational awareness.

Abbreviations

ICU = Intensive Care Unit

NICU = Neonatal Intensive Care Unit

PA = Physician Assistant

PICU = Paediatric Intensive Care Unit

SASICU project = Smart and Silent Intensive Care Unit project

UMCU = University Medical Centre Utrecht, the academic hospital.

UX/UI Design = User Experience and User Interface Design

WKZ = Wilhelmina Kinderziekenhuis, the child department of UMCU.

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01

Introduction

This chapter introduces the importance of reducing alarms in the ICU, to cope with the phenomena Alarm Fatigue, which is the driving factor behind this project. It outlines the assignment and design approach to develop a user-centred solution that contributes to more intelligent and effective alarm management.

1.1 Assignment
1.2 Design method



1.1 Assignment

This master thesis describes a design project done in collaboration with the Paediatric Intensive Care Unit (PICU), the ‘Wilhelmina Kinder Ziekenhuis’ (WKZ), at University Medical Centre Utrecht (UMCU). Design can contribute to making patients’ stays more comfortable, helping parents or family deal with their loved one’s hospital stay, or improving the working conditions of medical staff. This project will contribute to workflow optimisation of healthcare professionals in the Intensive Care Unit (ICU) and will indirectly improve the stay of patients and their relatives.

An ICU is a department with a high sound level, primarily due to the constant sound of alarms. These sounds not only affect the rest of the patients, but also disrupt the workflow of nurses. However, the alarms are necessary to keep the patient safe; they indicate when a clinical intervention is required. But the current alarm system generates too many alarms, meaning that approximately **90%** are **non-actionable alarms**: there is no clinical action needed (Cvach, 2012; Lawless, 1994). Additionally, alarms are intended for nurses but currently sound at the patient’s bedside, which is not beneficial to the patient, even if the alarm is essential. The alarm burden leads to so-called ‘alarm fatigue’ among nurses, which means that they no longer notice all alarms, potentially resulting in the overlooking of alarms with clinical relevance (Lewandowska et al., 2020). Failure to respond to critical alarms can have severe consequences for the patient.

SASICU

To address this problem, the project ‘Smart and Silent Intensive Care Unit’ (SASICU) was initiated, a collaboration between different hospitals, universities, research organisations and companies. The project consists of four separate studies and is funded by the European Innovative Health Initiative (IHI). “The aim of SASICU is to use smart technologies to both reduce the frequency of alarms in the ICU and make it easier for staff to identify patients at risk of deteriorating or developing post-intensive care syndrome (PICS).” (SASICU | IHI Innovative Health Initiative, 2023). UMC Utrecht collaborates with Ascom within this initiative, a supplier of healthcare devices and software. Their study assesses how algorithms can reduce non-actionable alarms without compromising patient safety.

The algorithm has already been developed by the SASICU team of UMC Utrecht. However, to make this algorithm function in practice, nurses should provide input about the patient’s clinical profile and risk level. Currently, when a patient is admitted to the ICU, the nurses manually set the alarm thresholds for each individual vital parameter, such as heart rate. With the new algorithm, setting up a new patient is reduced to two steps: selecting the clinical profile and choosing a monitoring level. There is no graphical user interface developed yet to set up the

new alarm system. However, a low-fidelity prototype of the interface was previously designed by Marijn Soeteman, a doctor in training for Paediatric Intensivist. Her design serves as the **starting point** for this project.

Given all this information about the project, some research questions were raised, among which the main research question:

“How to design a graphical user interface for ICU nurses to correctly set up a new central alarm system which reduces the alarm load at the ICU?”

The main question leads to different sub-questions which will be addressed through literature and field research:

- Sub-question 1:** How does the current alarm system at UMC Utrecht work?
- Sub-question 2:** How do nurses currently approach the set-up of patient alarms?
- Sub-question 3:** What does the new combined alarm system consist of and how does it work?
- Sub-question 4:** What is smart alarming?
- Sub-question 5:** What are the latest developments towards a smart and silent ICU around the world?

These research questions will guide the development of a user-centred interface to improve the alarm management in the ICU. The full assignment of this project can be found in appendix A.

1.2 Design Method

It is important to involve users continuously in the design process. The aim is to design with the user, not only for the user, which introduces so-called participatory design (Muller & Kuhn, 1993). As the new alarm system is novel, healthcare professionals may struggle to understand exactly what they are signing up for. In other words, they need to understand what the new combined alarm system entails before they can identify their future needs. They might not even know what their needs will be.

To address this issue, an **iterative design method** fits best. Already in 1998, Patel & Kushniruk argued that it is important to start early with prototyping and usability testing in an iterative manner (Patel & Kushniruk, 1998). In this way, the prototypes will be introduced to nurses early on, allowing them to start thinking about this new approach of setting alarms. Each design cycle, they will be involved in interviews and evaluation tests. Hopefully, they will adapt to the new system, each cycle a bit more.

Figure 1.1 shows an overview of the global design process of this graduation project. Before initiating the iterative process, a research and analysis phase

will be conducted to understand the context in which the design is being developed and to formulate a design direction. This phase will include field research; observations and interviews at the ICU, and a small literature review. The research will be guided by the sub-research questions proposed in section 1.1. Additionally, journey mapping will be used as a sub-method to gain insights into nurses’ workflow. Furthermore, an evaluation of the first prototype, developed by a doctor in training, will be conducted to gather design insights for the iterative process.

Each design iteration will consist of three phases: ideation, (low fidelity) prototyping and testing. The aim is to complete three iterative cycles within the twenty-week time limit for this project. The sub-methods used in each cycle may differ slightly. For example, in the second iteration, a collaborative UI design workshop with Ascom (a partner in the SASICU project) will form the base of the ideation in this cycle. Each cycle will introduce an additional design focus, based on the design goal formulated in Chapter 5. As the outcome of the iterative process, a final high-fidelity prototype in Figma will be delivered. Figma is a powerful design and prototyping tool for UI and UX (User Experience) design.

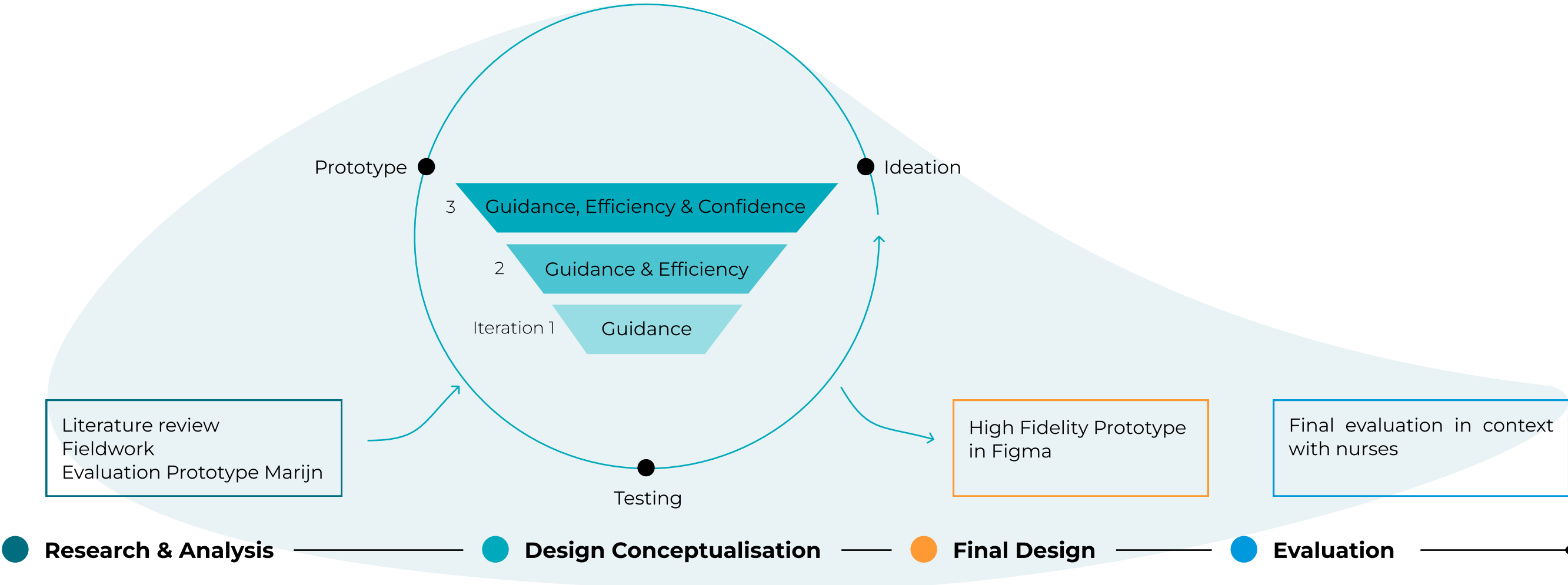


Figure 1.1: The global design process of this graduation project.

The project will conclude with usability expert interviews and a structured final evaluation of the prototype in a simulated context. The SASICU project team is developing a physiological simulation of vital parameter data of patients, combined with a simulation of alarms triggered by the conditions of the digital patient. This is a so-called digital patient twin, shown in Figure 1.2. Hopefully, it will be possible to connect the final interface prototype with these simulations to test the new way of setting alarms as completely as possible. So, nurses will be able to set the digital patient's alarms, observe the alarms generated by the simulation, and **assess the impact of their settings**.

SASICU Team

The SASICU Team brings together paediatric intensivists, anaesthesiologists, clinical technologists, researchers and a PhD candidate. Throughout this graduation project, weekly UI meetings will be held to discuss functionalities and gather feedback. The team serves not only as the client of this project, but the medical doctors are also end users.

Key members for this graduation project include:

Erik Koomen - Paediatric Intensivist, anaesthesiologist, and primary supervisor of this master's thesis.

Ruben Zoodsma - Physician and PhD candidate, developing the digital patient twin and alarm simulation.

Teus Kappen - Anaesthesiologist and Associate Professor.

Lex van Loon - Clinical Technologist, Assistant Professor and expert in Medical Digital Twins and physiological simulation.

Former team member:

Marijn Soeteman - Paediatrician in Training, who designed the initial UI prototype.

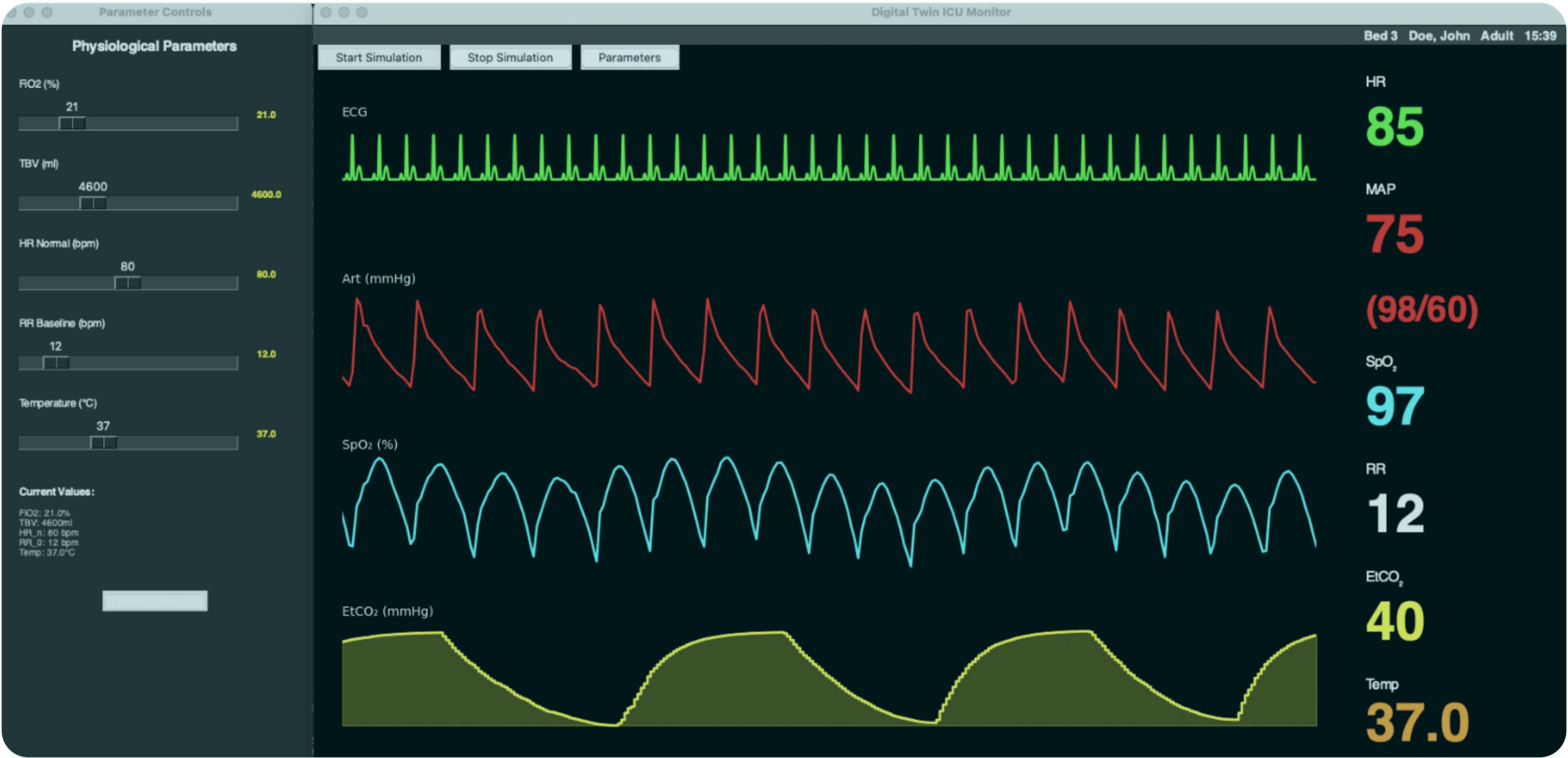


Figure 1.2: A static image of the simulated monitor of the digital patient twin. It is possible to tweak the vital parameters of the monitor with the left panel, and the simulation can also generate visual alarms (not shown in the figure). In the desired situation, the alarm configuration of this digital patient can be done with the interface designed in this project.

02

Context: The ICU

This chapter provides insight into the design context: The Intensive Care Unit. It describes the physical layout and workflow at the ICU departments of UMC Utrecht and their stakeholders. Understanding this context is crucial for designing a user interface that aligns with the complex needs of ICU stakeholders and supports a safer, quieter care environment.

2.1 The ICU at UMC Utrecht
2.2 Stakeholders of the ICU



2.1 The ICU at UMC Utrecht

The Intensive Care Unit provides care for critically ill patients who require continuous monitoring and life support. In 2023, in the Netherlands alone, 69,042 patients were admitted to all adult ICUs. Approximately 30% of these cases involved admission after planned surgery (Stichting NICE, 2023). The other cases are acute admissions of people in life-threatening situations due to different causes.

The urgency of Intensive Care cases creates a high-pressure and rapidly changing work environment for healthcare professionals. In the ideal situation, one nurse has responsibility for one patient during a day shift. Unfortunately, this is not always possible due to a structural nurse shortage in the Netherlands (Capaciteitsorgaan, 2023). This results in nurses being responsible for two or even three patients during a

shift. During a night shift, one nurse is typically responsible for two or more patients, as there are fewer scheduled tasks compared to the day shift. Most hospitals work with a 'buddy' system, whereby a colleague nurse is designated as secondarily responsible for a patient. This colleague takes responsibility during periods when the primary nurse is unavailable, such as during breaks.

UMC Utrecht has three different ICU's: the Paediatric Intensive Care (PICU) for children between 28 days and 18 (21 for some specific patients) years old, the Neonatal Intensive Care (NICU) for prematurely born, aterm, babies and the "normal" adult ICU for patients from 18(21) years old. The information in this section is based on observations done at those three different units at UMC Utrecht.

PICU & NICU

Currently, both the PICU and NICU consist of units where all patients stay in the same room, except for those who need to stay in isolation due to, e.g., an infection. Figure 2.1 provides a simplified overview of the current PICU's floor plan. One unit consists of eight beds and one nurse station, where nurses maintain an overview and manage their administrative tasks. Some curtains can surround the bed to provide limited privacy, offering a sense of privacy for patients and their families. The nurse station is also used as a social area, where nurses gather for coffee and conversation. See Figure 2.2 for an impression of the nurse station at the PICU. The NICU is very similar, but the nurse station does not provide monitoring and is not separated by a glass wall. Additionally, the three NICU units are more closely located to each other, which results in higher overall sound levels.

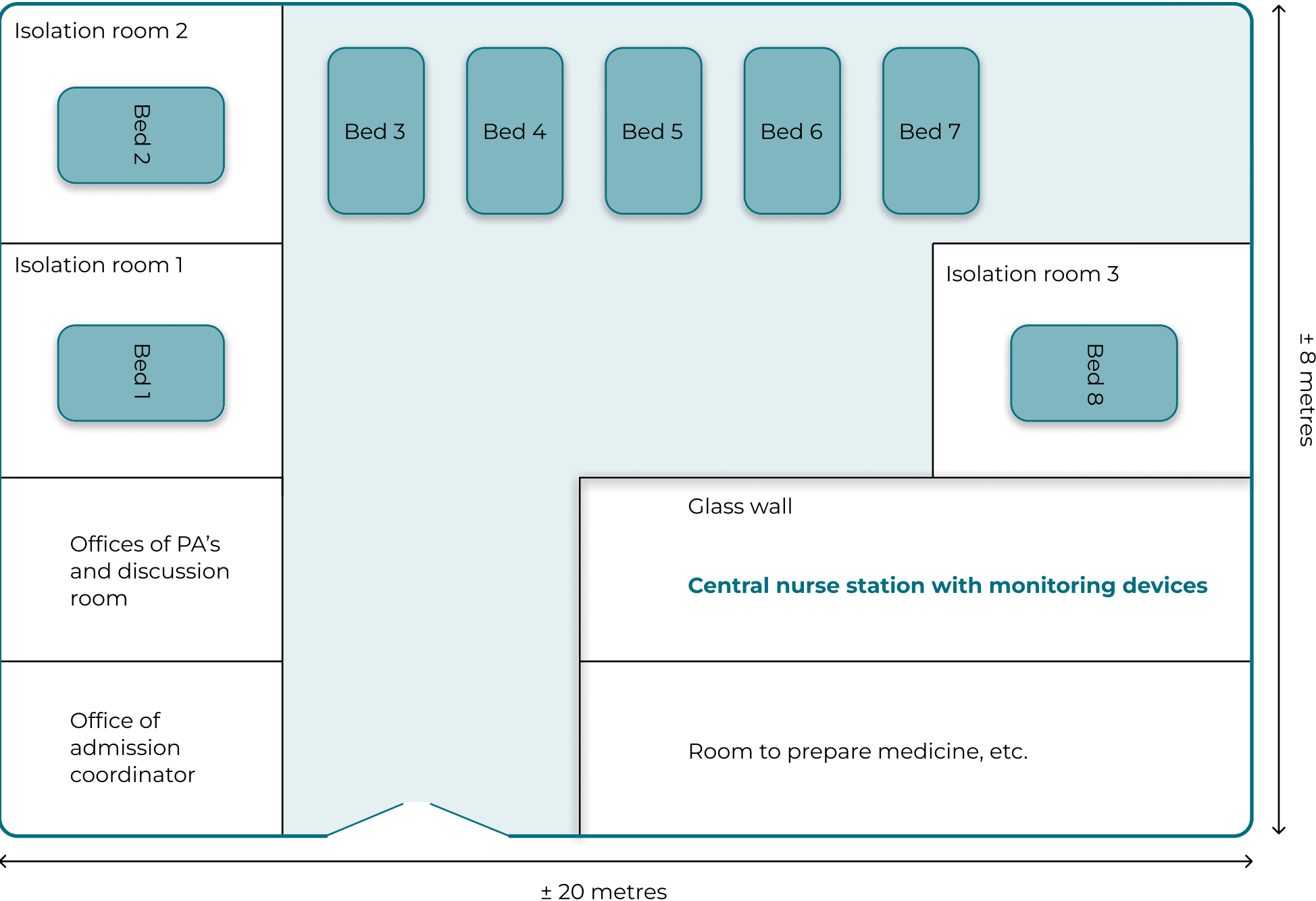


Figure 2.1: Simplified floor plan of the PICU at WKZ.



Figure 2.2: the central nurse station in the PICU of WKZ.

Currently, new PICU and NICU units with separate rooms for all patients are being constructed, with completion expected around May 2026. Figure 2.3 provides an impression of the future PICU at WKZ, which contrasts significantly with the current PICU depicted in Figure 2.2.



Figure 2.3: An artist's impression of the future PICU of WKZ, currently being built. Image by **EGM Architects**.

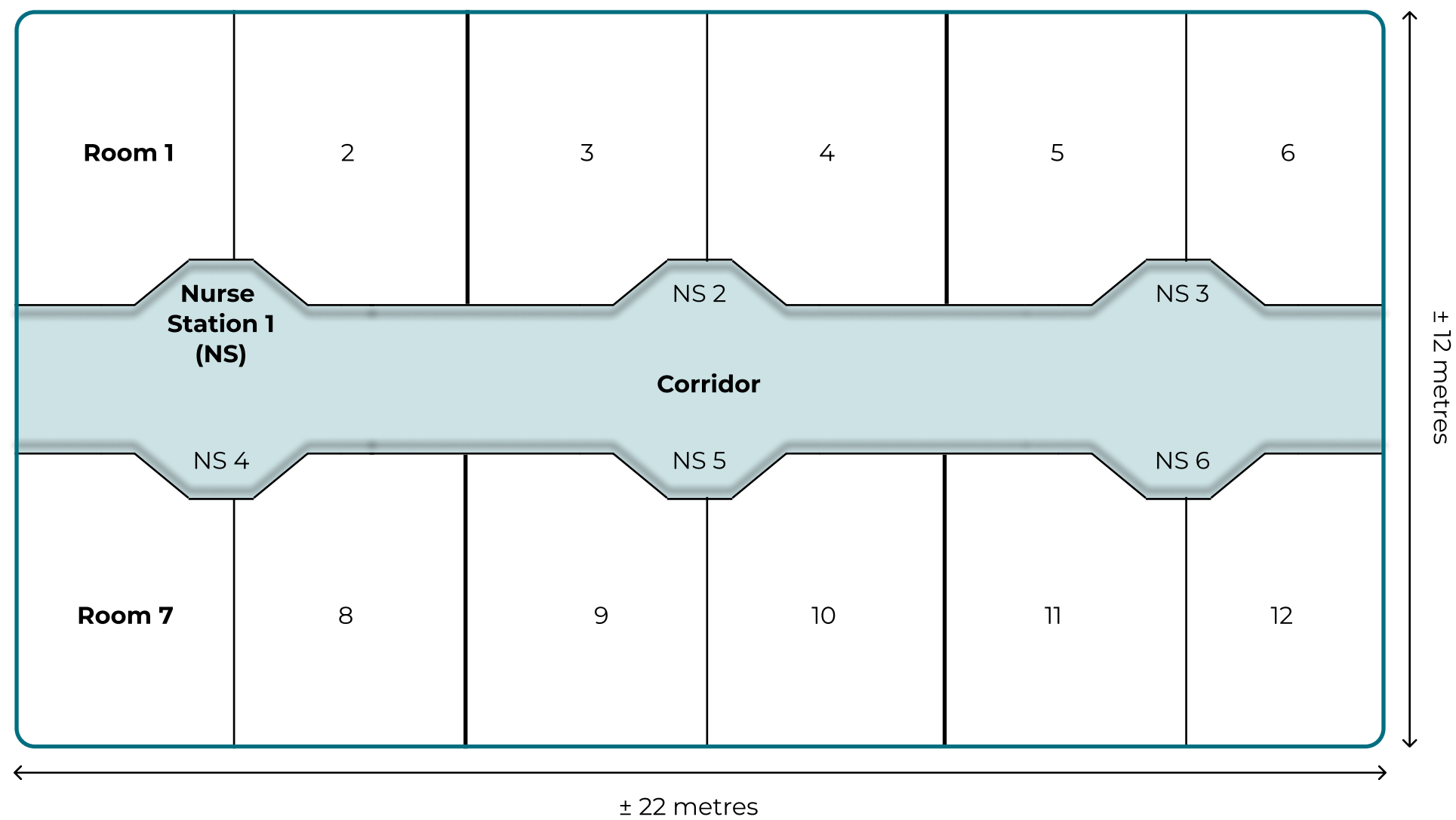


Figure 2.4: a simplified floorplan of one unit of the adult ICU at UMC Utrecht.

Adult ICU

In contrast, the adult ICU of UMC Utrecht has just been renovated and already has separate rooms for all patients; see a simplified floor plan in Figure 2.4. This improves the rest and privacy for the patient and family, because they are isolated from alarms and noises of other patients. The nursing stations are individual or dual, located next to the patient's room in the corridor. The image on the cover page of this chapter provides an impression of the corridor, while Figure 2.5 offers a view of the individual patient room.



Figure 2.5: The individual patient room of the adult ICU at UMC Utrecht.

2.1 Stakeholders of the ICU

The ICU team primarily consists of **Intensivists** (doctors specialised in Intensive Care) and **ICU nurses**. Furthermore, some nurses are specialised as **Physician Assistants (PAs)**, allowing them to take on certain responsibilities from intensivists and perform additional medical tasks, alongside the intensivists. Alongside the nurses, **care assistants** support them in their work processes, such as assisting with patient hygiene. **Other specialist doctors**, including neurologists and cardiologists, also regularly visit the ICU to check patients and give advice to other healthcare professionals on specific pathologies. Additionally, **non-medical staff** are sometimes present, such as researchers and cleaning staff.

Alongside healthcare professionals, **patients** are key stakeholders. Although they are often unconscious, the alarm soundscape can negatively affect their rest and recovery. Finally, **family members** and **other relatives** also have a significant role in the ICU environment. Previous research has shown that family members contribute to the care of their loved ones, and their presence can have a positive impact on the patient's recovery. However, nurses may need to assist and guide families in doing so (Williams, 2005). The ICU can be a stressful environment for families, as they are often anxious about their relative's condition. Additionally, the constant noise from medical equipment is overwhelming.

Figure 2.6 provides a visual overview of all stakeholders at the ICU, illustrating the relationship between the time spent at the ICU and the estimated alarm burden. The visual is based on the observations done at the three different ICUs of UMC Utrecht. The alarm burden refers to the extent to which a stakeholder is affected by alarms. This figure suggests that more time spent in the ICU results in a higher alarm burden, which is to be expected. However, while family members are not present as frequently as nurses, they still experience a high alarm burden. When an alarm goes off, they often do not know what it means for their relative, and this lack of understandable information increases their stress level (Jee et al., 2012). In many cases, it appears that the patient is fine; for example, their heart rate exceeded the threshold just a little because of the patient's movement, meaning that the stress was unnecessary.

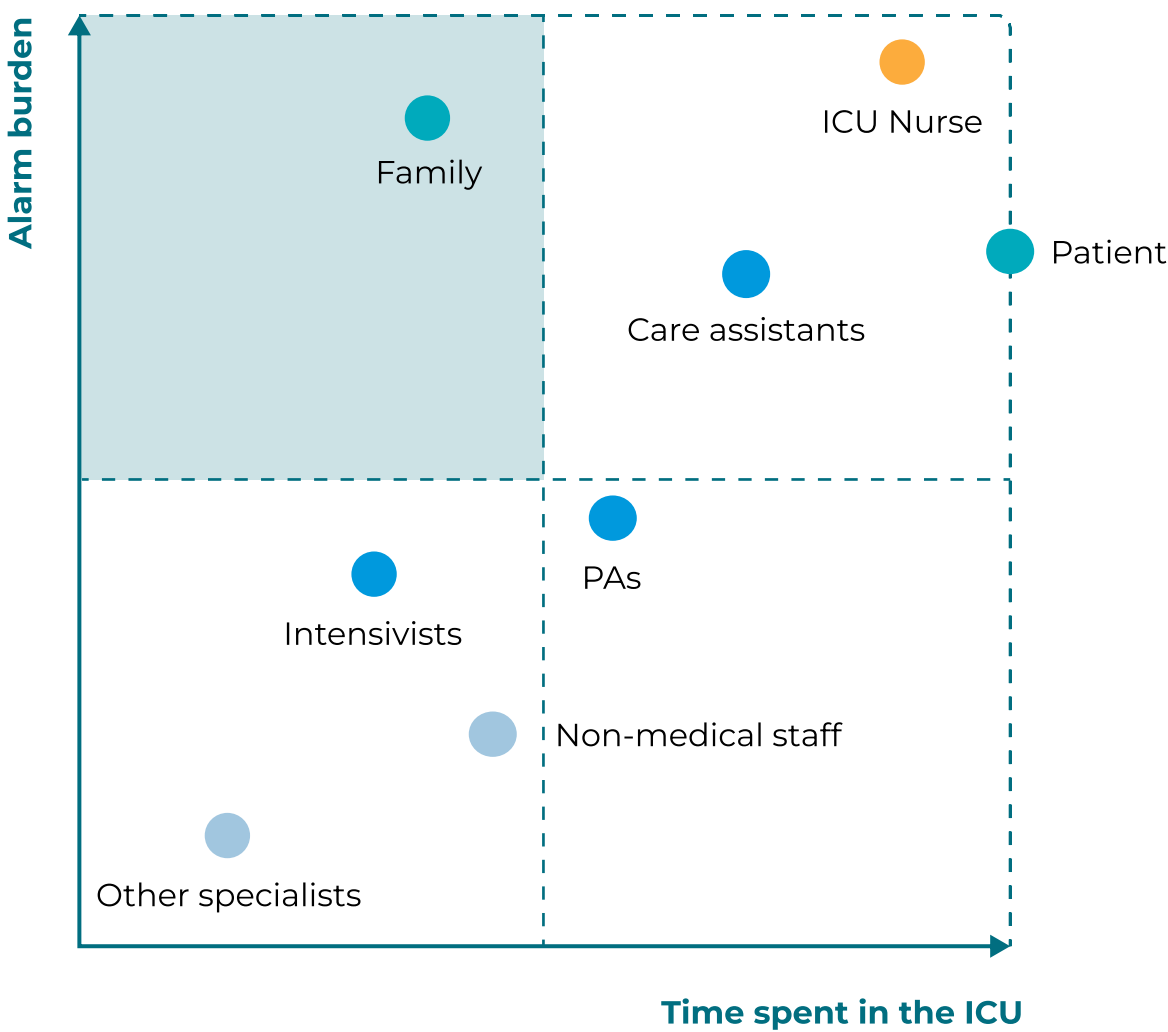


Figure 2.6: The relation between the time spent in the ICU and the alarm burden for the most important stakeholders, based on observations done in the three different units of UMC Utrecht.

Key Takeaways of chapter 2:

- The Intensive Care is a **high-pressure** and **rapidly changing** work environment.
- A new alarm system is not only valuable for the patient and nurses but will also help to **reduce stress for families**.

03

Alarms

The chapter aims to provide a comprehensive understanding of the alarm landscape within the ICU, examining not only their technical function and operation but also their impact on clinical workflow, staff well-being, and patient experience. It is based on fieldwork conducted at the NICU, PICU and adult ICU at UMCU, complemented by relevant literature. The fieldwork involved observations and unstructured interviews, shadowing nurses and intensivists during their day shift. The chapter concludes by looking ahead toward innovations which could create a smarter, quieter ICU environment.

3.1 Alarm Fatigue

3.2 The current alarm system at UMC Utrecht

3.3 Approaches to Alarm Configuration

3.4 The ICU nurse (fighting the alarms)

3.5 Towards a smart and silent ICU



3.1 Alarm Fatigue

To ensure patient safety, vital parameters are continuously measured. Vital parameters are, for example, heart rate, blood oxygen level, also referred to as oxygen saturation, and blood pressure. In the ICU, the condition of a patient can change fast. Continuous monitoring is essential for detecting conditional changes early and enabling timely medical intervention. To alert medical staff to these changes, the monitoring devices will generate an auditory and/or visual alarm when a parameter exceeds a predefined threshold, typically set with both upper and lower limits.

A single patient can generate approximately 950 alarm events over a 24-hour period, translating to around **40 alarms per hour** (Lu et al., 2024). Given that multi-bed ICU units typically care for more than one patient, it is easy to imagine how this could result in an overwhelming level of alarm noise and sensory overload for all stakeholders in the ICU. Visitors not only hear the alarms of their own loved ones, but they must also deal with the alarm noise of other patients. Considering that up to **90%** of these alarms are **not even clinically relevant** (Lawless, 1994), a single patient may generate as many as 36 unnecessary alarms per hour. This highlights the severity of the alarm burden issue in intensive care settings.

1 Patient = 950 Alarms / 24 hours

A technical report by Ruben Zoodsma, an MSc student in Medicine and PhD candidate, revealed that in just one year, nearly 6 million alarms were recorded in the NICU and PICU at UMC Utrecht (Zoodsma, 2024). In the PICU, this translates to one alarm every 20 seconds, in the NICU, even one alarm per every 6,5 seconds. With the average alarm duration around 7 seconds, this results in a never-silent NICU. The alarm load varies during the day, peaking during high-activity periods such as medication rounds and morning check-ups at the PICU. During these peak hours, a single healthcare professional may have to manage up to 59 alarms per hour (Zoodsma, 2024). During an unstructured interview, one nurse at the NICU said, "I'm glad I can unconsciously ignore a lot of alarms; otherwise, they would drive me crazy!"

This high alarm load in combination with the small number of relevant alarms results in a phenomenon called Alarm Fatigue: "Frequent alarms, many of which are avoidable, can lead to inadequate

"I'm glad I can unconsciously ignore a lot of alarms, otherwise they would drive me crazy!" - NICU nurse

responses, severely impacting patient safety." (Wilken Marc et al., 2017). Nurses are often interrupted during care tasks and lose trust in the alarm systems due to their excessive frequency (Lewandowska et al., 2020). This aligns with the observations done across the

"Frequent alarms, many of which are avoidable, can lead to inadequate responses, severely impacting patient safety"

Alarm Fatigue Definition

different ICU units at UMC Utrecht: it was frequently noted that nurses either ignored alarms or just did not respond. Once, a mother had to alert a nurse, who was seated just three metres away at the nurse station, about an ongoing alarm indicating that her daughter's sensors had become disconnected. While this may not have been a life-threatening situation, the example clearly shows the lack of response of nurses; they do not even look up from their computers to check what is going on. This could have serious consequences when the alarm would have been critical.

Beyond low response rates, the overwhelming number of alarms can also negatively affect the working environment of the ICU staff. The constant stream of alerts can lead to continuous stress among healthcare staff, unnecessary work, acute cognitive overload and noise pollution (Wilken Marc et al., 2017). But what is causing all these unnecessary alarms? The following section will explore the shortcomings of the current alarm system at UMC Utrecht.

3.2 The Alarm System in Utrecht

Alarms around the patient bed

Three primary devices generate alarms in the ICU setting: the physiological monitor, the ventilator, and the infusion pumps (see figure 3.1. The **physiological monitor** has three levels of priority: blue, yellow and red. A blue alarm indicates a technical issue, such as a disconnected sensor. Yellow alarms are of low priority and occur most frequently; red represents a high-priority, critical alarm. The **ventilator** is used when a patient needs artificial respiration. It operates with two priorities: yellow and red alarms. The **infusion pumps** provide the patient with medication and nutrition, generating alarms when the pumps are (almost) empty. A green signal indicates that medication is being administered correctly and that the supply flow is sufficient. A yellow alarm serves as a warning that the infusion will end within approximately ten minutes. If the medication has run out entirely, a red alarm is triggered, prompting immediate action.

According to nurses at the PICU and adult ICU, the urgency and perceived relevance of these alarms largely depend on the type of medication. For example, blood pressure medication must be delivered continuously, making such alarms highly important. In contrast, timing for antibiotics is less critical, so the same alarm may be considered unnecessary and even annoying. This suggests that a distinction may need to be made between different types of medication within the infusion pump system, allowing for more appropriate alarm responses based on clinical relevance.

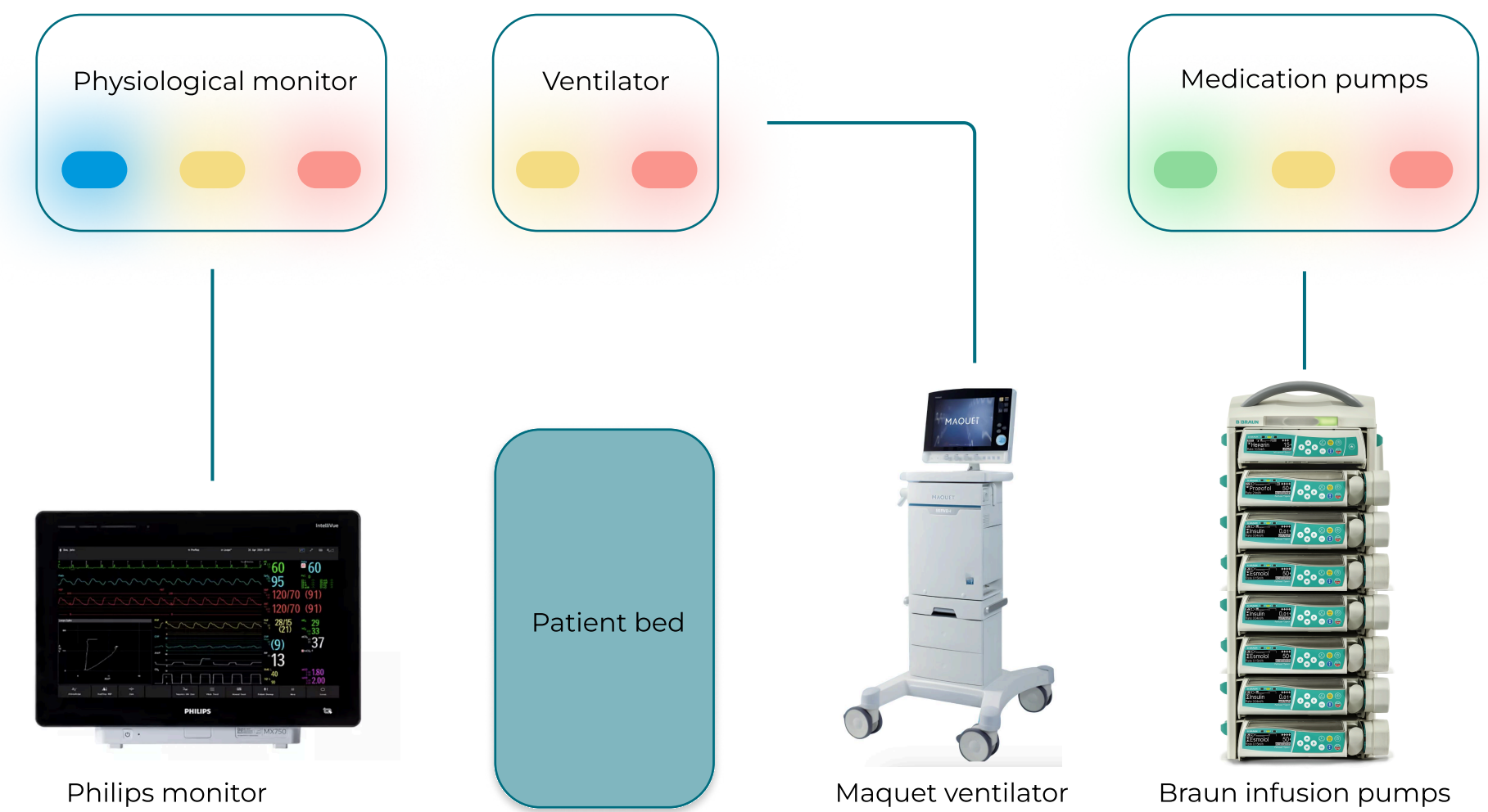


Figure 3.1: Overview of the alarm-generating devices surrounding a patient bed at the PICU at WKZ, including their associated colour-coded priority levels. The physiological monitor uses blue (technical), yellow (low priority), and red (high priority) alarms, while the ventilator uses yellow and red alarms. The infusion pumps use green (normal flow), yellow (almost empty), and red (empty) alarms.

Alarms beyond the patient bed

In addition to the devices around the bed, the monitors at the central nurse station will duplicate the alarms of the monitor. In the adult ICU, where single-patient rooms have been a standard practice for several years, nurses also rely on pagers, resulting in a slightly different alarm setup (see figure 3.2). Pagers are handheld devices attached to the nurses' clothing, which beep (and sometimes vibrate) to alert them when an alarm is triggered. These pagers have an old-fashioned appearance and provide only brief alarm messages, including the abbreviation of the alarm-generating device and the room number. Each pager is automatically linked to the nurse's assigned patient as well as their buddy's patient. However, this buddy assignment is anonymous and cannot be selected or adjusted by the staff themselves. Nurses have indicated that the current pager system is outdated, as it provides no clinical context, lacks flexibility and requires a time-consuming set-up at the beginning of each shift.

Procedures

During another observation in the adult ICU, two nurses were assisting each other in changing a patient's bed sheets. This task required the patient to be turned onto their side, a movement that logically affects the values of vital parameters and, consequently, triggers alarms. Despite the alarms not being critical, neither of them suppressed the sound. If the system could recognise that a routine procedure, such as changing bedsheets, was taking place, it could temporarily mute the alarm or adjust the settings. However, not all procedures are as low-risk as changing bedsheets. For example, during more critical interventions like intubation, nurses emphasised the importance of being alerted if some vital parameters change. Nonetheless, incorporating contextual information about the situation could enhance the accuracy of the alarm system.

Outdated Alarm System

The current method of alarming is outdated; there is a need for a new approach (Koomen et al., 2021). At present, the devices responsible for generating alarms are not 'talking' to each other. Each device is independent and triggers its own alarms. This leads to information overload and a significant number of unnecessary alarms in the ICU. We need to shift to a networked-device paradigm, where bedside alarms are first transmitted to a centralised network, which can prioritise and filter the alarms before notifying staff (Koomen et al., 2021).

Figure 3.3 presents a simplified overview of the current alarm system in the ICUs at UMC Utrecht. The orange arrows illustrate how the nurse is **flooded** with signals from the various monitoring devices. Alarms are delivered to the nurse through lots of channels, including bedside monitors, central nurse stations, pagers, and indicator lights both inside and outside the patient's room. This setup generates multiple, overlapping alarm signals for the same clinical event, resulting in noise and alarm overload.

In addition to managing these simultaneous alerts, nurses are also responsible for manually setting threshold values on **each device for every vital parameter**, such as heart rate, oxygen saturation, or infusion levels. While doing so, nurses must incorporate contextual information about the patient. These thresholds must be updated as the patient's condition changes. The current system requires numerous **simultaneous operations** and relies heavily on the nurse's ability to repeatedly (re)configure settings while also interpreting and prioritising alarms. There is no centralised network, as argued by Koomen et al. (2021), to help nurses maintain situational awareness of the patient and support them in decision-making processes.

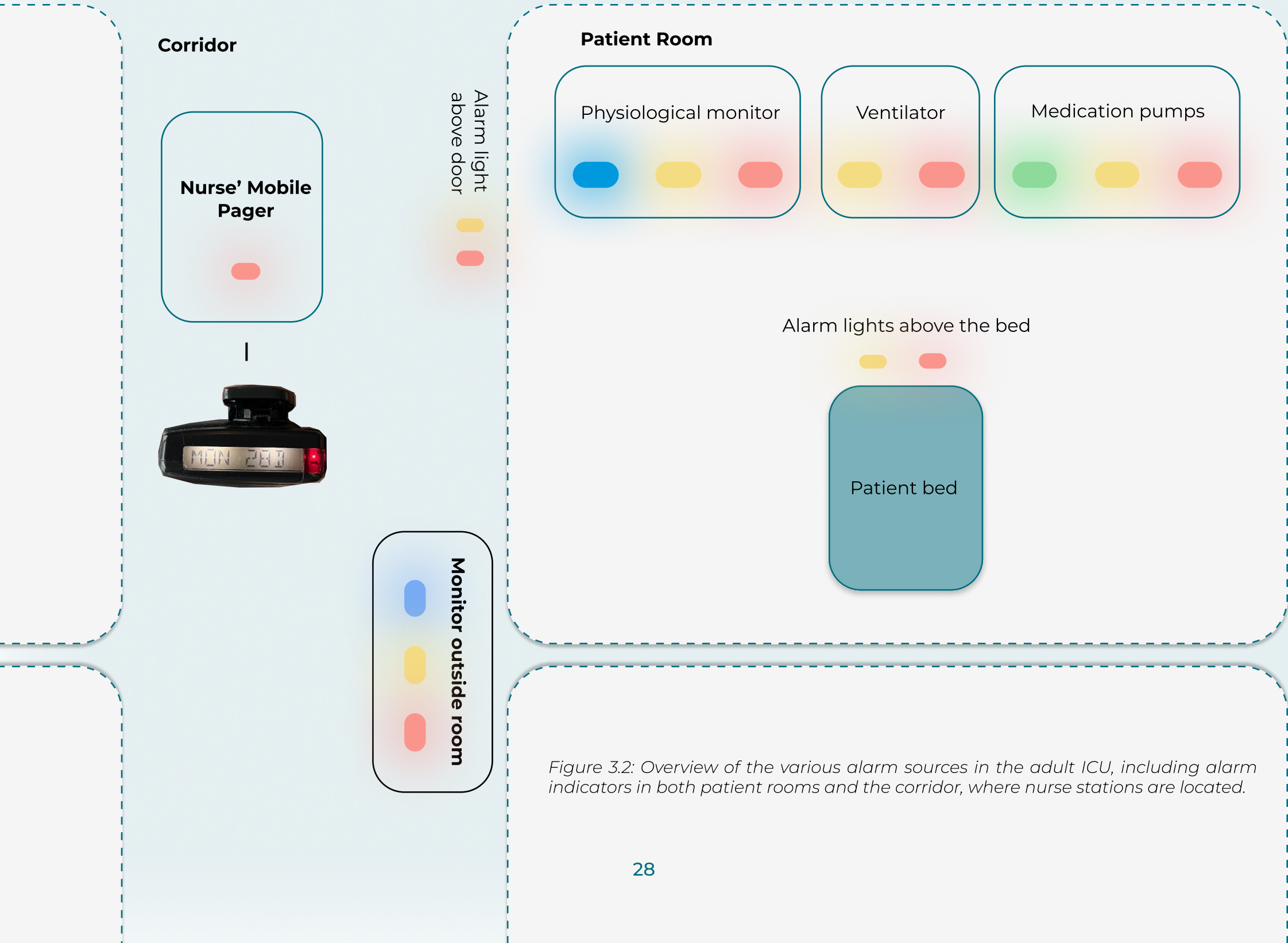


Figure 3.2: Overview of the various alarm sources in the adult ICU, including alarm indicators in both patient rooms and the corridor, where nurse stations are located.

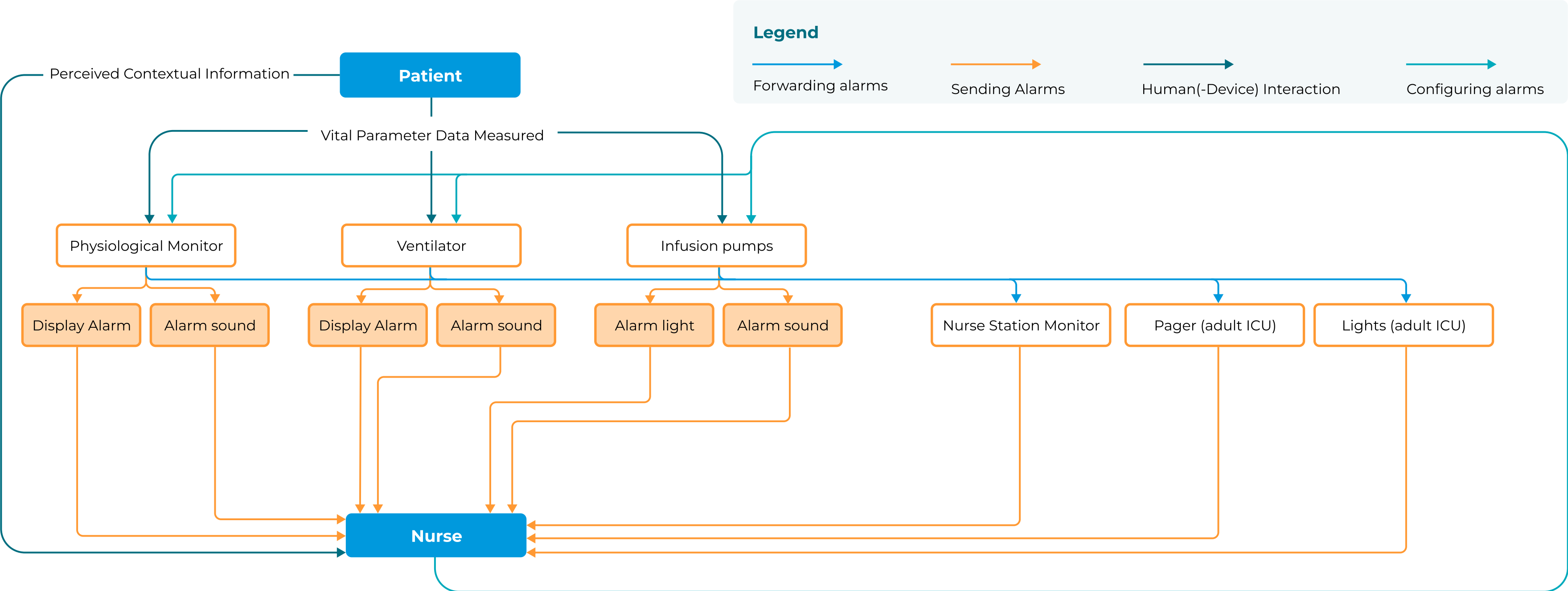


Figure 3.3: Simplified overview of the current alarm system in the ICU's at UMC Utrecht.

Key Takeaways of section 3.2:

- Currently, devices prioritise alarms without considering the specific condition or treatment needs of the patient. Without the right context and interpretation, the **alarms are almost meaningless**.
- The **paggers** used in the adult ICU are outdated and lack in meaningful notifications.
- Alarms are often not silenced or adjusted when appropriate.
- **Contextual information** during specific handlings could help to make the alarm system more accurate.
- **A lack of communication between devices** leads to information overload: there is a clear need for a centralised network to manage the alarms.

3.3 Approaches to Alarm Configuration

When a new patient is admitted to the ICU, the nurse is responsible for setting up the thresholds of **each individual** vital parameter. There are some default settings, but these are limited to basic populations: adults, children and neonates. Some units, like the NICU at WKZ, have standard protocols about the configuration of these thresholds. For some vital parameters, nurses are required to consult a physician before adjusting or widening alarm limits.

A patient with a cardiac condition may require different heart rate limits than a patient without a heart disease. However, the setting of each individual parameter can be time-consuming, and time is not always available in the ICU. This limits the customisation of patient-specific thresholds, while Konkani et al. (2012) highlighted the importance of personalised alarm settings to reduce clinically irrelevant alarms. Nonetheless, this customisation appears to be challenging. A study conducted in Korea found that only 19% of the patients' boundaries were appropriately matched to the patient's condition. At the same time, the nurses surveyed indicated that they had no struggles with setting the alarms properly (Cho et al., 2016). This suggests that a system which **guides** nurses through the settings of alarms for different patients could be valuable for the design of this project.

Setting Alarms at UMC Utrecht

During interviews, several nurses mentioned that they always try to check the thresholds of their patient:

“It’s not that I always change something, but I always check how they are set at the beginning of my shift.”

Nurses recognised variability between colleague nurses in how thresholds are set:

“Look, I might choose for 120, but my colleague would set it at 125. I don’t really care if I’m alarmed with 120 or 125, it’s about knowing that the heart rate is increasing.”

This quote suggests that nurses want to be informed about trends in patient conditions, but they are less interested in precise numerical values. In the NICU, the difference between nurses is less significant because they operate with standardised agreements about alarm settings. This may explain why the alarm load at the NICU is three times higher than at the PICU.

A NICU nurse explained how they hand over alarms:

“You can consciously set the alarms a bit wider, but you should clearly hand this over to your colleague or set back the limits to the original thresholds”.

One nurse at the adult ICU indicated that students or junior nurses sometimes monitor their patients very closely, which results in a lot of alarms. It can be particularly annoying to be the buddy of this colleague, whose pager then receives a constant stream of unnecessary alerts.

Personal Factors influencing Alarm Configuration

Several individual factors influence how nurses interact with patient monitoring systems. For example, their level of experience plays a role: more experienced nurses often tend to set wider thresholds. Other factors also contribute to alarm-setting behaviour, such as personality, sensitivity to sound, and risk tolerance (Bostan et al., 2024). For example, a nurse who is highly sensitive to noise and is not afraid to take a risk may choose wider boundaries and silence alarms more quickly. In contrast, someone with low risk tolerance may prefer stricter settings and respond to more alarms, even if they are non-urgent. Figure 3.4 summarises how these individual factors can lead to different approaches to setting up alarms.

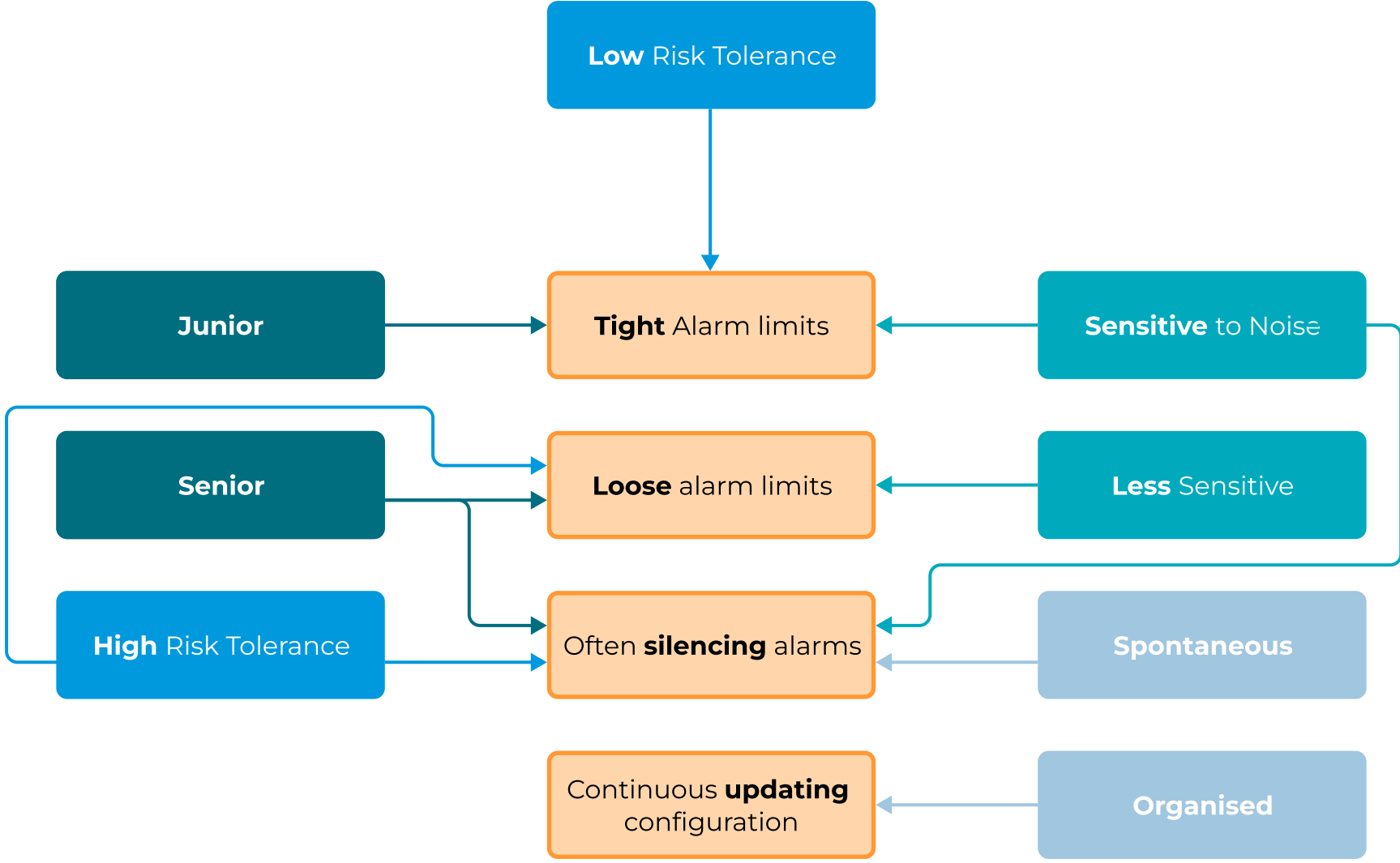


Figure 3.4: An overview of how individual factors could influence nurses' alarm setting strategies (orange boxes), based on factors identified by Bostan et al. in 2024.

Key Takeaways of Section 3.3:

- Nurses try to check and update alarm settings at the beginning of their shift, but this is sometimes **forgotten**.
- Alarm thresholds should be **patient-specific** to reduce clinically irrelevant alarms. Currently, this is often not the case due to time and system limitations.
- Nurses should be **supported or guided** through the configuration of these patient specific threshold.

3.4 The ICU Nurse

Among all the healthcare professionals, the ICU nurses have the most direct patient contact. Their daily tasks are to give medicine, do personal care such as washing, regularly check on the patient, discuss treatment plans with intensivists, assist physicians, support families and keep track of their vital parameters and therefore respond to the high volume of (false) alarms.

Nurse personalities

As every nurse is an individual, they will perform their tasks slightly differently due to emotional, contextual, and personal characteristics (Sanz-Segura et al., 2019). Recognising these differences is essential when designing a new alarm system. Bostan et al. (2024) identified four distinct nurse profiles based on personality traits, risk tolerance, stress sensitivity, musicality and level of experience. "The unique characteristics of profiles have the potential to provide new user insights for designing system features to match the natural tendencies, needs, and preferences of ICU nurses for ease of use and acceptability." Each group has different preferences and tolerances when interacting with alarm systems. Figure 3.5 shows an overview of the nurse profiles and their corresponding needs (Bostan et al., 2024).

Combining the needs of these profiles highlights the need for a system that is simple but allows for extra guidance for the experienced & short-tempered nurse and provides more advanced features for the sociable and flexible nurse. The nurse profiles serve as valuable inspiration to find a balance between different needs, indicating the need for a system that is adaptive and flexible (Bostan et al., 2024).

Cognitive Overload

The ICU is a cognitively demanding environment where nurses must deal with multiple critical events simultaneously, complete their regular tasks, process large amounts of patient data and continuously monitor their patients. On top of this, they have to deal with the constant stream of auditory and visual alarms, many of which are non-actionable. The alarms are often treated by nurses as stressors, rather than helpful cues (Sanz-Segura et al., 2019), contributing to alarm fatigue and negatively affecting task performance (Koomen et al., 2021; Sanz-Segura et al., 2019).

Cognitive load refers to the mental effort required to process information within our working memory, which has a limited capacity (Bannert, 2002). In the ICU context, nurses are asked to prioritise, filter, and

respond to a flood of alarm inputs while also maintaining situational awareness and making rapid decisions. When the input exceeds their cognitive capacity, it leads to cognitive overload, one of the reasons why nurses sometimes fail to respond to alarms (Sanz-Segura et al., 2019). To manage cognitive load, the information input should be controlled (Bannert, 2002). However, the current alarm systems fail to filter or limit the amount of incoming information. Therefore, it is essential to minimise the cognitive load of a new alarm system. This includes not only filtering and prioritising alarms based on clinical relevance, but also ensuring the user interface is intuitive, streamlined, and easy to use. "A simple user interface with a reduced number of steps required to complete tasks will help minimise the cognitive load induced by the use of the system." (Bostan et al., 2024).

Workflow Disruption

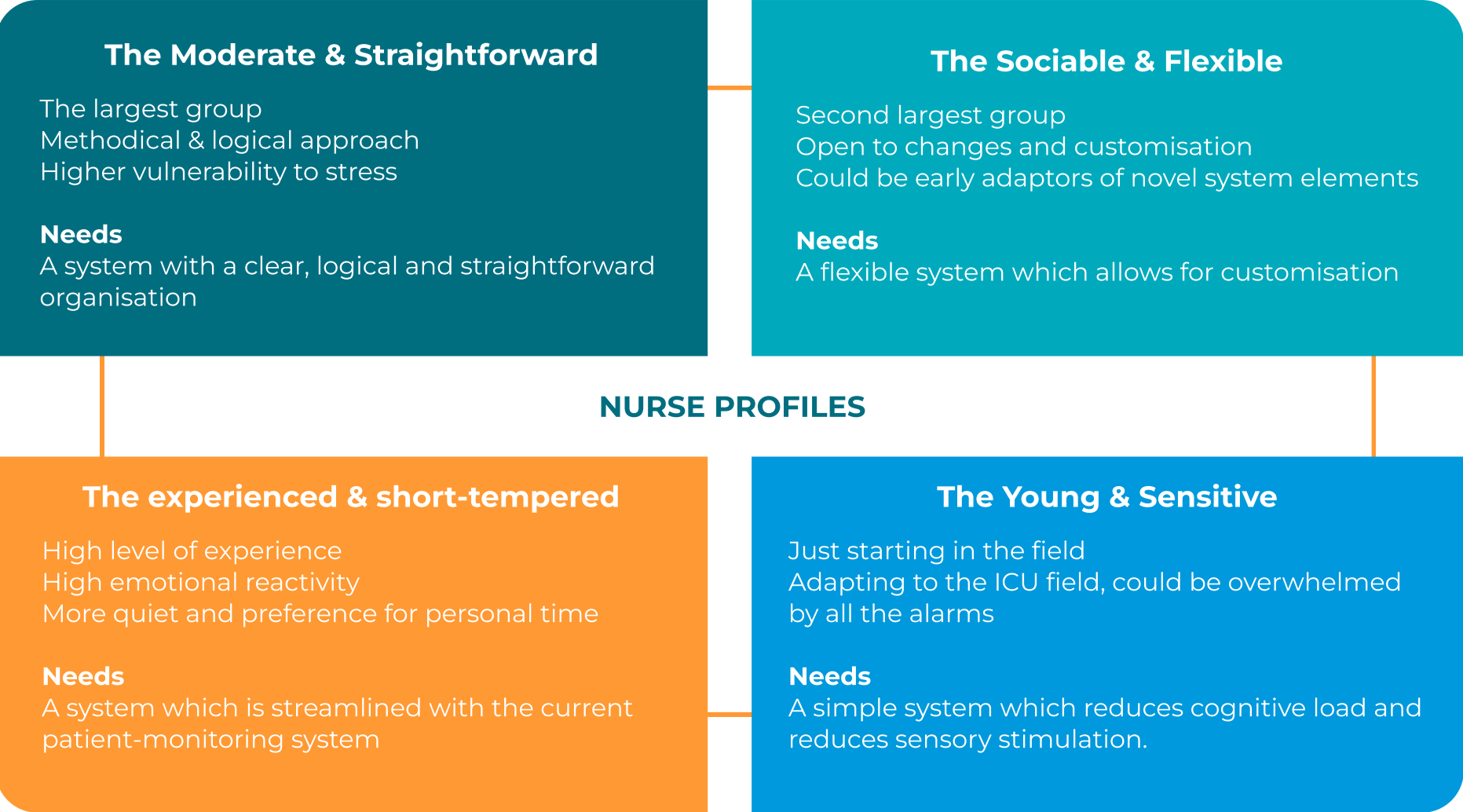
To better understand how alarms affect nurses in practice, a visual overview of the workflow of nurses was created, see Figure 3.6 on the next page. It is a so-called transitional journey map which shows transitions between activity categories due to (acute) events (Jansen et al., 2013). This journey map is based on observations conducted at the NICU between 7:30 and 9:30 AM, one of the busiest periods due to handovers and physician rounds. The NICU at WKZ is the ICU with the highest alarm load, with almost three times more alarms than at the PICU (Zoodsma, 2024), so this journey map clearly demonstrates the extent of the problem. The alarms and nurse responses were logged using digital notes; however, some events may have been missed due to the presence of only one observer. The activity categories in the journey map are arranged to best visualise the transitions between workflows, but a larger shift along the y-axis does not necessarily indicate that the transition required more effort than a shorter shift.

Although the nurses considered this morning quiet, around 53 alarms were recorded across five patient beds. Only **six alarms** resulted in a **workflow change** for the three responsible nurses, and those were all non-actionable alarms. Nurses just responded by silencing the alarm for 2 minutes, or they widened the thresholds.

The remaining 90% of alarms were ignored, as nurses explained they usually already knew the cause and did not consider them critical. This highlights the need for a better filtered and prioritised alarm system, as the nurses are not even using the current alarm alerts.

The one **actionable alarm** was also ignored. However, it was rather technical than critical: the sensors for measurement of some vital parameters were detached. The mother had to call the nurse before they responded. While the event was not critical, it shows a concerning desensitisation. Most oxygen saturation alarms kept going off continually, because the saturation value of patients showed minor fluctuations, for example, between 91% and 92%, and 92% was set as the lower alarm limit. Only a one per cent drop in saturation will not have severe consequences for the patient, while the monitor continues to make annoying sounds.

The map shows that most alarms did not interrupt the workflow of ICU nurses, because they were ignored, and nurses did not switch to another activity. However, this does not mean that they are not interrupted in their cognitive processes. The nurses indicated during the observations that most alarms were perceived as annoying and useless. A study by Cho et al. (2016) also found that nurses primarily experience fatigue not from acting on alarms, but from being constantly disturbed by them. (Cho et al., 2016). Thus, the cause of annoyance can be distinguished by the interruptions of their workflow or annoyance by the chaotic alarm sounds. The constant disruption results in cognitive annoyance: cognitive processes become more challenging to complete (Bostan et al., 2022). For example, when a nurse is preparing medicine, concentrating on an exact dose is way more difficult while simultaneously assessing if ongoing alarms are relevant. This highlights the importance of reducing alarm noise to support nurses and other healthcare professionals in performing their jobs effectively by minimising the cognitive load whenever possible.



Key Takeaways of Section 3.4:

- Nurse profiles are a valuable inspiration to serve **different user needs**.
- The **cognitive load** of the user interface should be kept as low as possible to increase task performance.

Figure 3.5: Four nurse profiles with their corresponding needs, adapted from and based on the study conducted by Bostan et al. (2024).

Transitional Nurse Journey Map

The influence of alarms on a nurse's workflow.

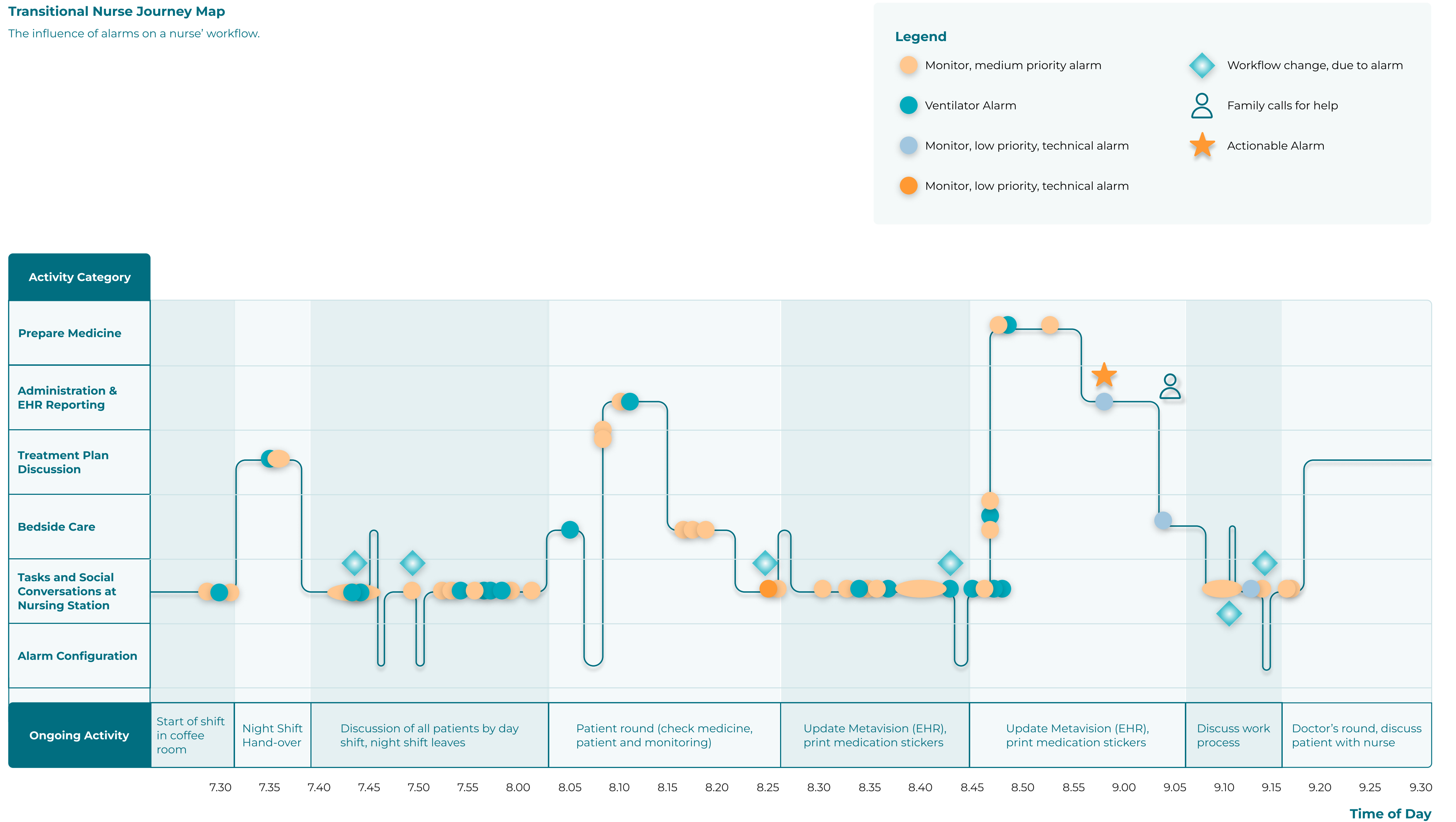


Figure 3.6: A transitional journey map which shows the influence of alarms on the work activities of nurses, inspired by Jansen et al. (2013).

3.5 Towards a Smart and Silent ICU

Already in 2001, researcher Marie-Christine Chambrin highlighted the need to reduce the number of false alarms in health monitoring systems (Chambrin, 2001). Nowadays, it is still a significant issue. Smart alarm management systems using machine learning are a promising direction to tackle alarm fatigue. But what exactly does **smart** mean?

*“... developing smart alarms, which were **easy to integrate** into existing systems to analyse **multiple clinical data input** of multiple patients, and to decide whether staff actions or clinical interventions were needed for specific patients. If staff actions were needed, **smart alarms** would inform possible clinical risks of the condition and **delivered this information to an appropriate, available staff member.**”*
(Bach et al., 2018, pp. 3 - 4).

So, within this new system, alarm messages would become more meaningful, instead of only informing about the priority and origin device. In short, it can be seen as an intelligent system which receives input from all different kinds of devices and then decides if and where an alarm should be sent to. Multiple hospitals and universities around the world are working towards a more silent ICU, using different approaches.

3.5.1 State of the Art: Smart & Silent ICU

Procedural and Workflow Optimisations

For instance, at Erasmus Medical Centre in Rotterdam, architectural, procedural, and cultural changes have resulted in a quieter ICU. In this case, new spacious rooms with automatic closing doors resulted in better sound isolation. The nurse stations were divided into smaller units, which affected the social activities and handovers of the nurses, and also reduced the measured sound level during specific times. (Özcan et al., 2024). However, these changes did not result in a reduction of the number of alarms.

It is essential to consider not only the measured sound level but also the perceptions of nurses regarding the sounds. A context mapping study indicated that nurses perceive alarm loudness differently during different activities (Özcan et al., 2025). Implementing a new alarm system requires an integrated approach that considers technical, organisational, and human-centred factors (Bach et al., 2018). Technological fixes alone will not solve alarm fatigue, without considering a user-friendly interface and workflow for ICU professionals.

At the NICU at Maxima Medisch Centrum in Eindhoven, the implementation of a new alarm system and the optimisation of workflows and alarm settings resulted in a reduction of alarms and an increased response from the nurses (Varisco, 2023). In

short, the new alarm system involved quicker delivery of alarms to handhelds and displaying waveform information of the vital parameters. The workflow optimisation included alarm delays, protocols for replacing sensors, regular checks and evaluation of alarm settings, guidelines on handling alarms and the pausing of alarms during caregiving moments. These workflow optimisations are organisational improvements which are relatively easy to implement for hospitals. This study showed the effectiveness of combining organisational and technical improvements in reducing the total number of red alarms. Nevertheless, the new alarms were not assessed for clinical relevance. A systematic review indicated that analysing multiple vital parameters simultaneously can help identify clinical deterioration earlier (Sun et al., 2020). For instance, when both heart rate and blood pressure exceed their normal ranges, this can trigger a high-priority, clinically relevant alarm, potentially indicating heart failure. Despite the fact that these studies were only conducted at non-intensive care wards, they show the potential of combining multiple physiological measurements into clinically valuable knowledge.

Technological Interventions

Technological developments, especially involving machine learning and artificial intelligence (AI), present promising solutions for alarm fatigue. For example, CalmWave, a company based in the USA, is developing an AI platform that uses historical bedside monitor data to generate unit-level default thresholds and updates them to patient-specific thresholds. Unfortunately, no academic review of this system has been found; however, CalmWave itself claims to have conducted a successful proof-of-concept pilot, which reduced non-actionable alarms by 58%, in collaboration with Wellstar Health System (CalmWave, 2024).

In Brazil, researchers have shown that a reasoning algorithm can help reduce alarm notifications by 99%. The reasoning algorithm developed consists of the grouping of alarms by queuing them for 5 minutes, and the algorithm decides which caregivers should be notified and how (Fernandes et al., 2019). However, the algorithm was not tested on security in a clinical setting, and it was only tested with one vital parameter: heart rate. This system only manages one input, while in the future, inputs from all different devices and manufacturers should be combined to create a smart alarm notification (Bach et al., 2018). Sometimes, different sounds from multiple devices are alarming about the same condition change of the patient. The devices should be coordinated by a system so that only one alarm is triggered when a patient's condition changes (Konkani et al., 2012).

Connecting multiple devices

Recognising the limitations of single-device technologies, German universities created a demonstrator of a silent ICU with a multiple-device management system at a conference in Chicago. This silent ICU consists of a distributed alarm system which is based on the IEEE 11073 SDC standards (Kasparick et al., 2023). IEEE 11073 is an international set of medical device and interoperability standards. SDC stands for Service-oriented Device Connectivity, which allows medical devices from different manufacturers to communicate bidirectionally with each other (OR.NET, n.d.). It can be seen as a common language for medical devices of various manufacturers to understand each other and share data, such as vital parameters, easily.

When the devices can communicate with each other, alarms with the same clinical condition can be

combined, to optimise the notification to the healthcare professionals on mobile devices. Nurses can also reject alarms on mobile devices and send this information back to the monitor. In this way, the bedside can remain (more) silent (Kasparick et al., 2023). Similarly, the company Ascom uses targeted alarm routing systems which keep the monitors, ventilators and pumps in a silent mode, while ensuring that the alarms are sent to the mobile device of the right caregiver (The Silent ICU, 2024).

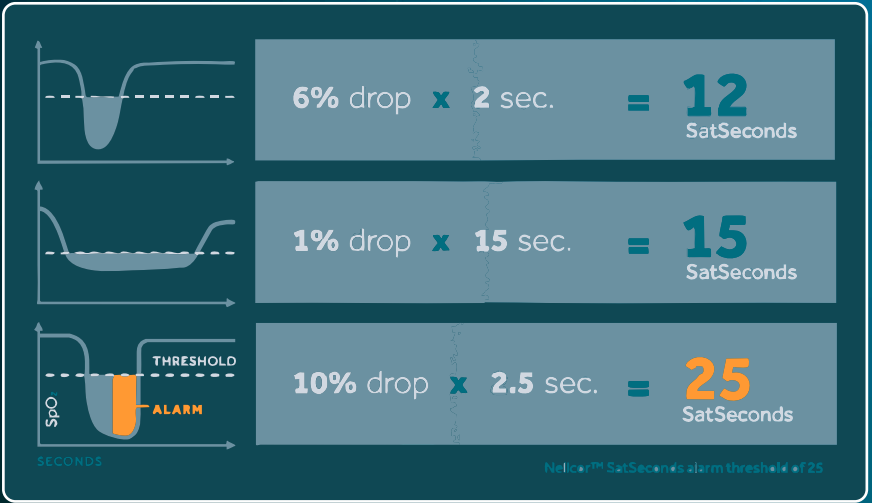
To conclude, there is a wide variety of strategies to reduce alarm overload in the ICU, which include human, organisational, architectural, and technological changes (see Table 3.1). This table attempts to summarise the strategies for alarm reduction based on the literature discussed in this chapter.

Table 3.1: State of the Art: Strategies to reduce alarm overload in the ICU.

Category	Strategy	Details
Architectural	Separate rooms for all patients	Individual patient rooms with automated doors for improved privacy and sound isolation (Özcan et al., 2024)
	Smaller nursing stations	Splitting large nurse stations into individual ones to reduce social noise (Özcan et al., 2024)
Technological	Meaningful mobile notifications	Alarms sent directly to nurses' handheld with more meaningful information about the alarm (The Silent ICU, 2024; Varisco, 2023)
	Multiple device connection	Alarms of the monitor, ventilator and pumps can be combined and regulated (Kasparick et al., 2023; Koomen et al., 2021)
	Multi-parameter alarm integration	Combining signals from multiple vital signs to create more meaningful alarms, outside the ICU (Sun et al., 2020)
	Machine learning	Grouping alarms, flagging false alarms, automated alarm thresholds, filtering non-actionable alarms (Fernandes et al., 2019; CalmWave, 2024)
Organisational	Alarm protocols	Customising alarm limits, delaying alarms, improving the settings, pausing alarms, timely replacement of sensors (Varisco, 2023)
Human-Centred	Education and training	Educating nurses on alarm management and setting patient-specific thresholds (Bach et al., 2018)
	Including perception of nurses on alarms	Designing alarms while considering nurses' perception on sound during different activities (Özcan et al., 2025)

What is missing?

At present, no existing alarm system integrates **contextual patient information** with measured physiological data. Without this integration, healthcare professionals, particularly nurses, must rely on their own judgment and clinical knowledge to interpret whether an alarm requires immediate action or can safely be ignored. This is not always possible due to cognitive overload (Bostan et al., 2022). **Machine learning can support nurses in this decision-making process**, but none of the algorithms described in the literature take into account the contextual information, such as the reason for admission, of the patient. How can algorithms filter on clinically relevant alarms if they do not even know the patient? To interpret the meaning behind vital measurement data, patient knowledge is required. In addition to contextual information, none of the technologies described considers the **duration** of a threshold exceedance. Duration can be an essential factor in determining clinical relevance. Currently, a brief increase in heart rate immediately triggers an alarm, which can be due to the patient's movement, a phenomenon that is not clinically relevant. Following such movement, the heart rate typically returns to normal levels quickly. If the duration had been considered, it would not have resulted in an alarm.



Although the recent technologies do not incorporate duration in the algorithms, this concept was already implemented over a decade ago in oxygen saturation monitors. The Nellcor brand introduced the Sat Seconds feature, which was shown in a study to successfully reduce oxygen saturation alarms by 40%. (Brostowicz & Rais-Bahrami, 2010). Figure 3.7 illustrates how SatSeconds™ works: hospitals can configure a specific SatSeconds threshold, 25 in this example, at which an alarm is triggered. A larger drop in saturation will cause the Sat Seconds to accumulate more quickly, resulting in an earlier alarm. This method filters out short fluctuations in saturation, helping to reduce non-actionable alarms.

3.5.2 Envisioned future alarm system of UMC

The SASICU project team of UMC Utrecht came up with the idea to include both contextual patient information and a depth-duration algorithm in a new system. All devices are connected and able to communicate with each other via SDC (see Figure 3.8). The system combines data (measured vital signs) with knowledge (contextual information of the patient) to make well-informed decisions about alarms. The system's main components are the **Brain**, the **Cerebellum**, and the **Smart Alarm Manager**.

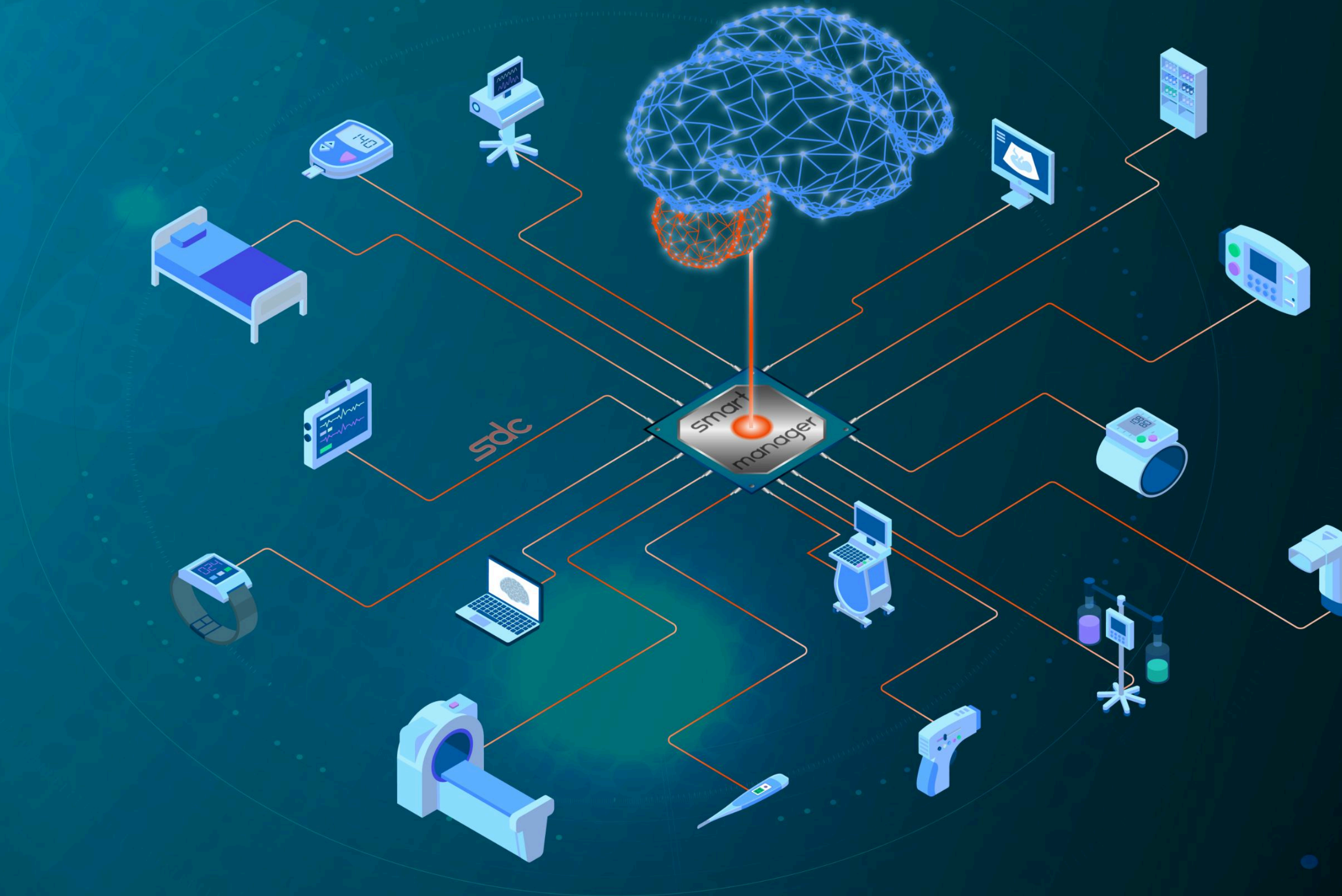


Figure 3.8: The envisioned future alarm system of UMC Utrecht, connecting all medical devices via SDC to the Smart Alarm Manager, which is informed by the Brain and Cerebellum to make smart decisions about alarms. Illustration by Teus Kappen.

Figure 3.9 shows the communication and technical operation of the system in more detail. The **Brain** has access to a wide range of data, including lab results, Electronic Health Record information and other hospital data about the patient. It communicates using PHIR (Fast Healthcare Interoperability Resources), a healthcare communication standard used to securely exchange structured patient data, such as medical history or lab results, between hospital IT systems. This type of communication is relatively slow. In contrast, the SDC communication (in orange) continuously streams data from the monitoring devices, which is essential for quickly detecting patient deterioration. The **Smart Alarm Manager** can make fast decisions with SDC input, but can be modulated (inhibited or excited) by the input of the Brain, which has situational awareness of the patient. The **Cerebellum** is standardising this modulation by writing templates which can apply an alarm protocol for specific patient groups.

Most likely, the Smart Alarm Manager will serve as the translation layer between the vital parameter data of the monitoring devices in SDC and the tuning and communication of the brain in FHIR. During this translation, the Smart Alarm Manager applies both **contextual patient knowledge and alarm protocols**, as well as alarm algorithms, such as the **depth-duration algorithm**, to assess whether an alarm should be generated and to determine where it should be sent. Initially, only the nurse's mobile device receives the alarm notification. If the nurse does not respond within a specified time, the system detects this and escalates the alarm: first to a colleague ("buddy") and, if necessary, ultimately to activate bedside monitoring devices and alert the central nursing station.

So, contextual information about the patient's **current situation** (such as risk level and clinical status) is needed, which is partially provided by the brain, but

also by the nurse, who is closest to the patient and familiar with their current condition. But how does the nurse's input reach the Smart Alarm Manager? This is where the design of a **graphical user interface** comes into view; there is a need for a medium that healthcare professionals can use to provide this contextual information. The brain can prepopulate the user interface with the existing contextual knowledge, which the nurse then reviews and refines based on the patient's current situation. The interface can be regarded as the front-end part of the Cerebellum.

This novel envisioned alarm system can **achieve situational awareness** of the patient's condition; it identifies what is considered 'normal' for that specific patient in the current situation and translates this into clinically relevant, personalised alarm settings. The whole system is complex and probably not even feasible within 5 years, so this project only focuses on

a specific part. Figure 3.10 shows the system elements within the **scope of this project**, specifically the design of the user interface that interacts with the Smart Alarm Manager.

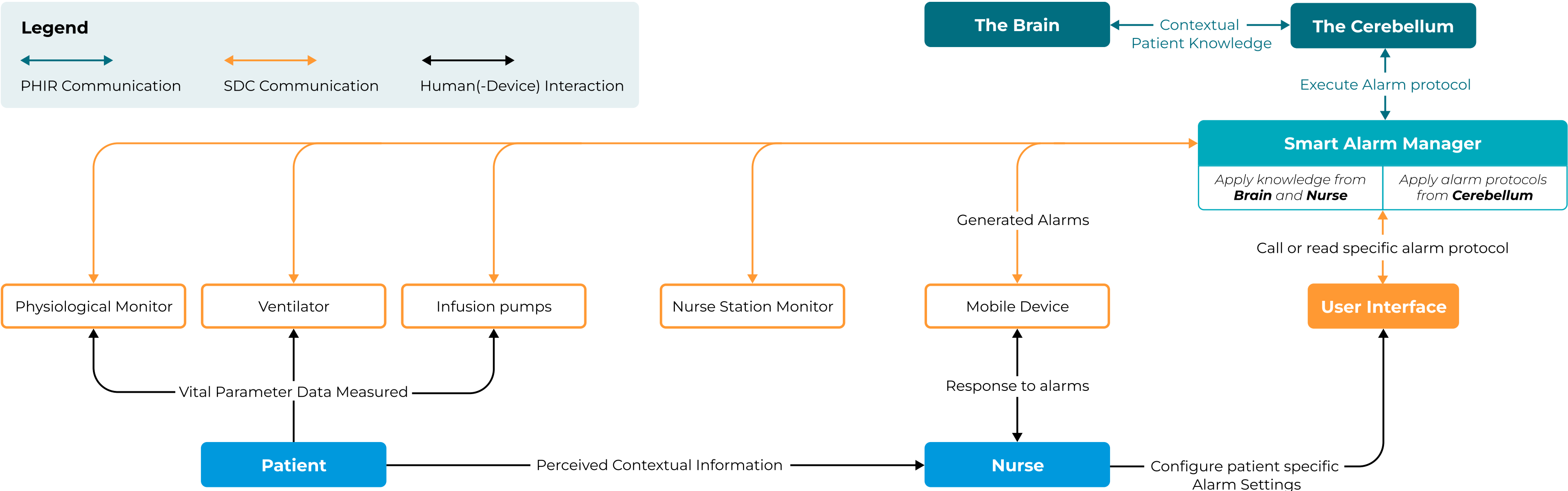


Figure 3.9: A simplified overview of the communication and technical operation of the envisioned future alarm system at UMC Utrecht.

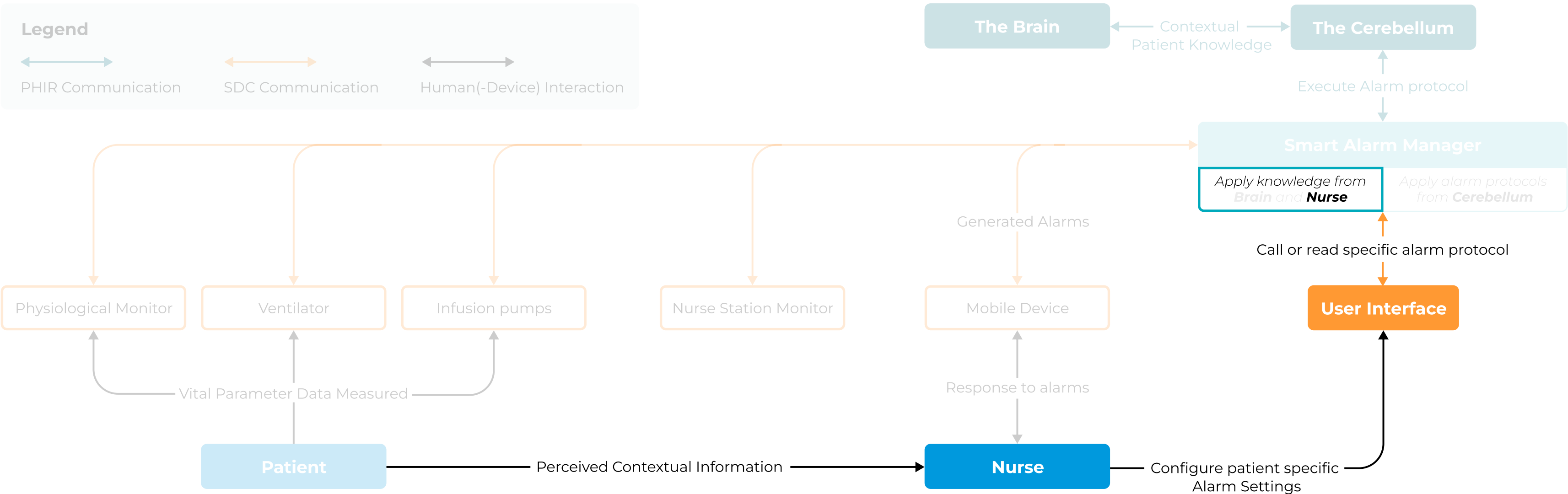


Figure 3.10: The elements of the future alarm system within the scope of this graduation project.

Depth-Duration Algorithm

The Smart Alarm Manager uses amongst others a depth-duration algorithm (developed by UMC Utrecht) to determine if an alarm is triggered: The duration of an exceedance, in combination with the depth (how far the parameter deviates from the target), is considered when determining if an alarm is triggered, similarly to the Sat Seconds feature described above. Figure 3.11 illustrates a simplification of this depth/duration algorithm. When a vital sign shows a deep deviation, an alarm is

triggered immediately. However, if the deviation is gradual and goes bit by bit deeper, it takes a while before an alarm is activated. The acceptable duration length and depth, defined by the area between the red lines in the figure, represent how long and how far a vital parameter may deviate without prompting an alarm. This range is configured based on the patient's clinical risk level. For high-risk patients, the red line becomes steeper, meaning that alarms will be triggered sooner.

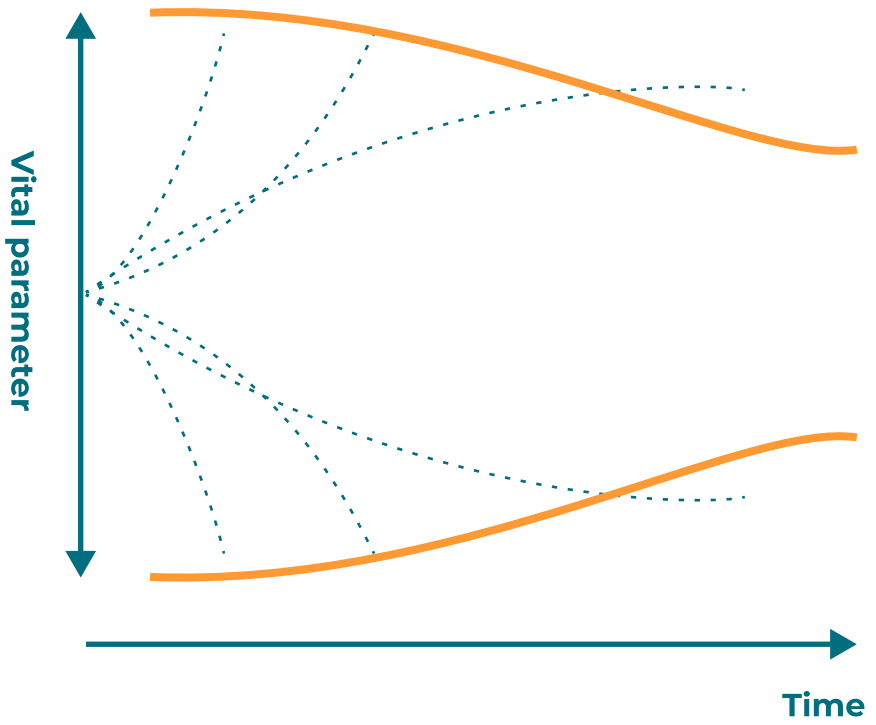


Figure 3.11: simplification of the depth-duration algorithm, illustration by Marijn Soeteman.

The depth/duration algorithm can also be explained using the metaphor of collecting stamps for a stamp card, conceived by Marijn Soeteman (see figure 3.5.6). Stamps are collected with exceedances of the target value; the deeper the exceedance, the faster you collect stamps. Once the card is complete, an alarm is triggered. This metaphor shows how the algorithm retains memory of recent exceedances. If a patient has just experienced a significant deviation, the next one will contribute more heavily to triggering an alarm. This is important because otherwise, **small recurring exceedances** would **not** be detected by the system, which could have consequences for the patient.

From threshold to target

This new approach requires a shift in how nurses currently manage alarm settings. At present, alarm thresholds are set for every individual alarm, as outlined in section 3.3. With this new system, they must set the alarms based on clinical profile and risk level of the patient, categorised as low, medium or high. Rather than setting **static thresholds**, nurses could **fine-tune** the acceptable **target range**. This change may require training and education. Therefore, as mentioned in the introduction, iterative testing is essential to design an optimal user experience that effectively supports nurses the set-up of the new system.

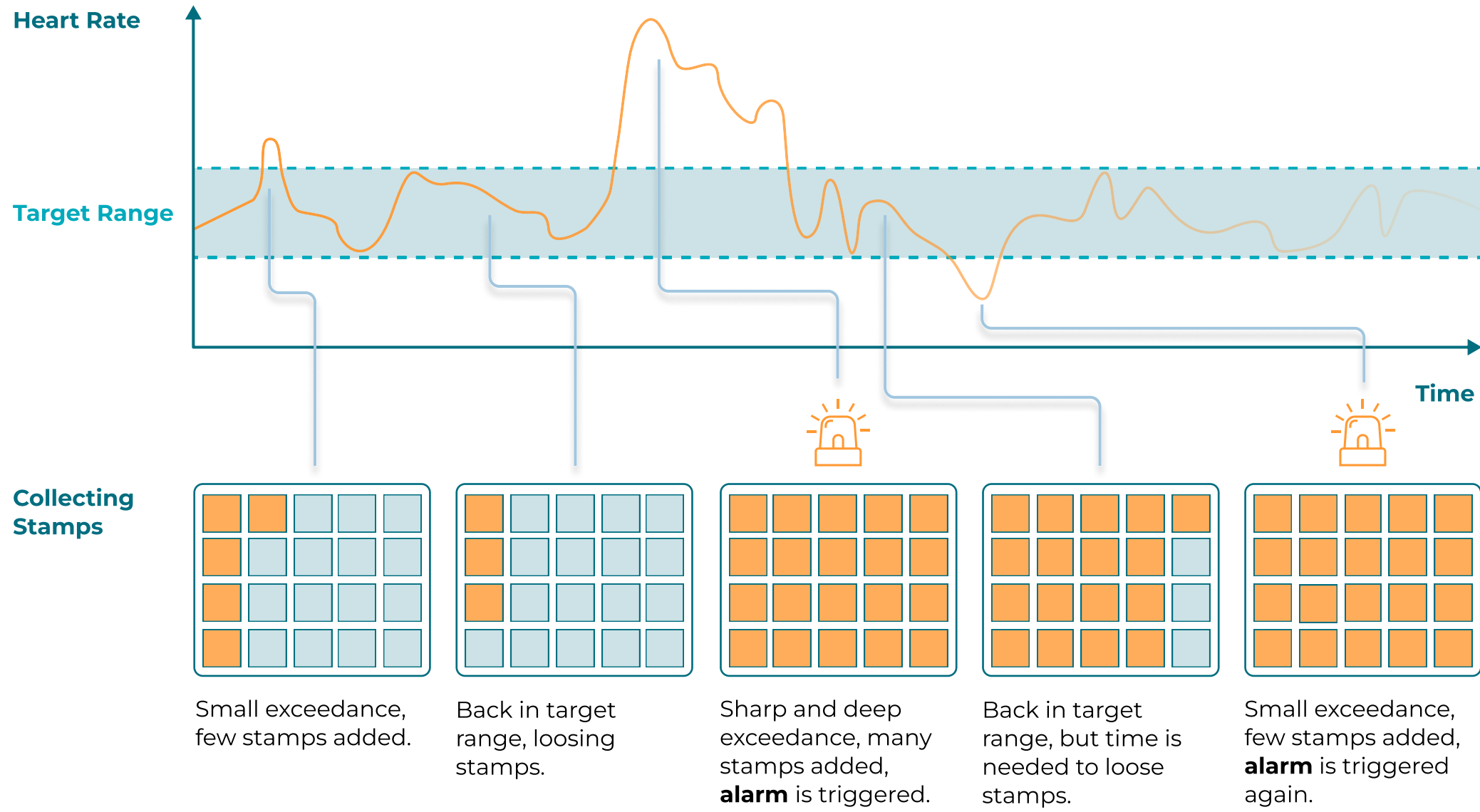


Figure 3.12: Visualised metaphor for the dept/duration algorithm; collecting a full stamp card to generate an alarm, conceived by Marijn Soeteman.

Key Takeaways of Section 3.5:

- A **smart alarm management system** processes input from multiple devices and patients to generate clinically relevant and meaningful messages, routed to the appropriate healthcare professional.
- Previous research has identified several successful strategies to reduce alarms in the ICU, including the use of algorithms. However, these algorithms lack **situational awareness** of the patient's current situation, which is essential to make meaningful decisions about alarms.
- A **graphical user interface** is needed to configure and test the novel envisioned alarm at WKZ.
- The interface should **help nurses** to shift from setting a static threshold to fine-tuning target ranges, which is required for the **depth-duration algorithm** to function properly.

04

Initial Prototype

This chapter presents the starting point of this project: an initial prototype of the configuration interface, developed by a medical doctor. Furthermore, this prototype is evaluated with nurses to gather input for the next design iterations, which will be presented in Chapter 6.

4.1 The prototype
4.2 Evaluation



4.1 The Prototype

From June to September 2025, trainee doctor Marijn Soeteman worked full time on the first design for this interface. Although she had no prior experience in design, her **clinical expertise** brought **significant value** to the project. The outcome is a low-fidelity prototype made in Figma, which serves as a promising starting point for the further development of this interface. Figure 4.2 shows an impression of this first prototype. The complete prototype is available in Appendix B. Additionally, an initial user flow was created based on this first design to provide an overview of the different screens, as shown in Figure 4.1.

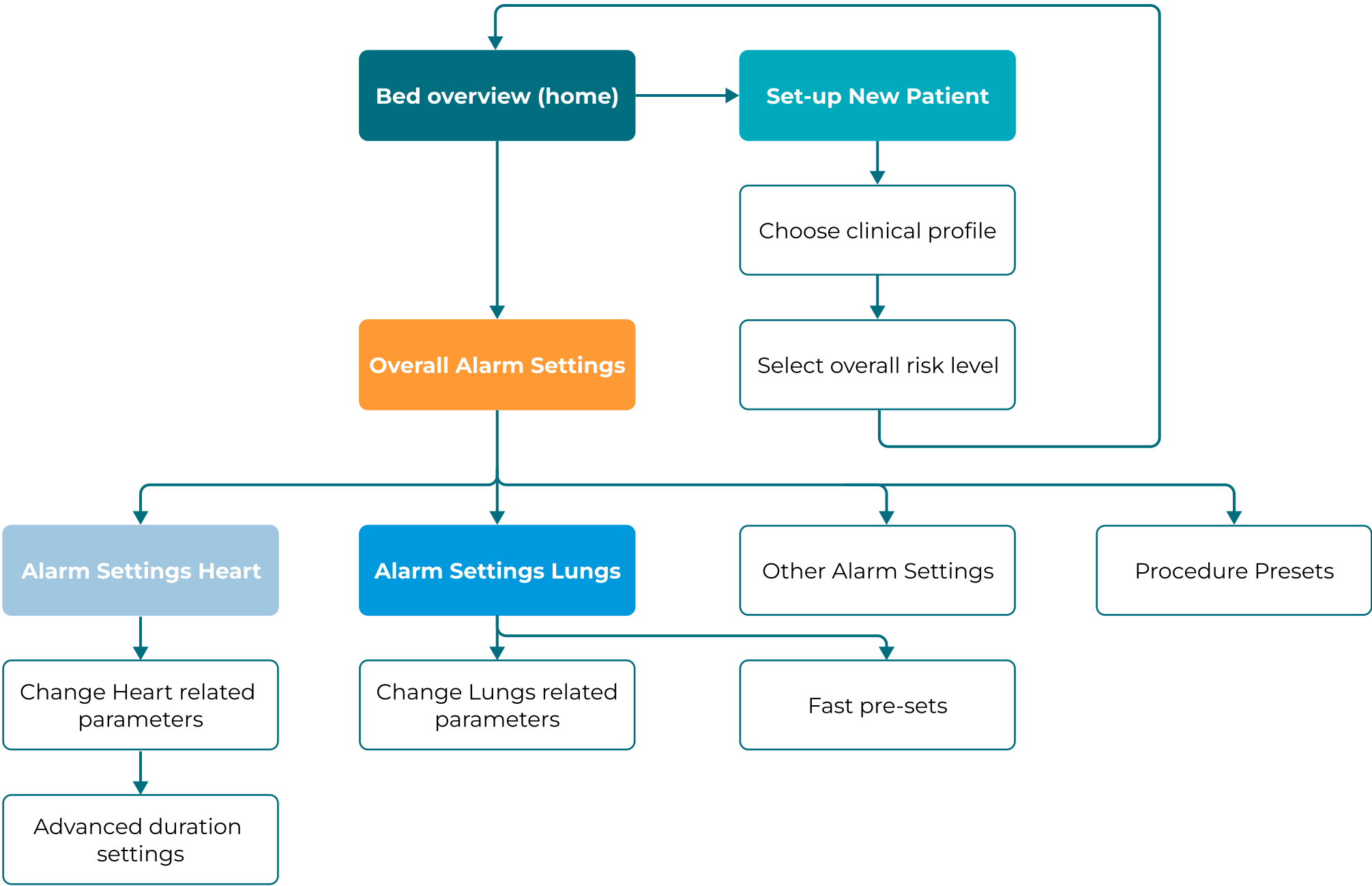


Figure 4.1: Initial user flow for the alarm configuration interface, based on the first prototype designed by Marijn Soeteman.

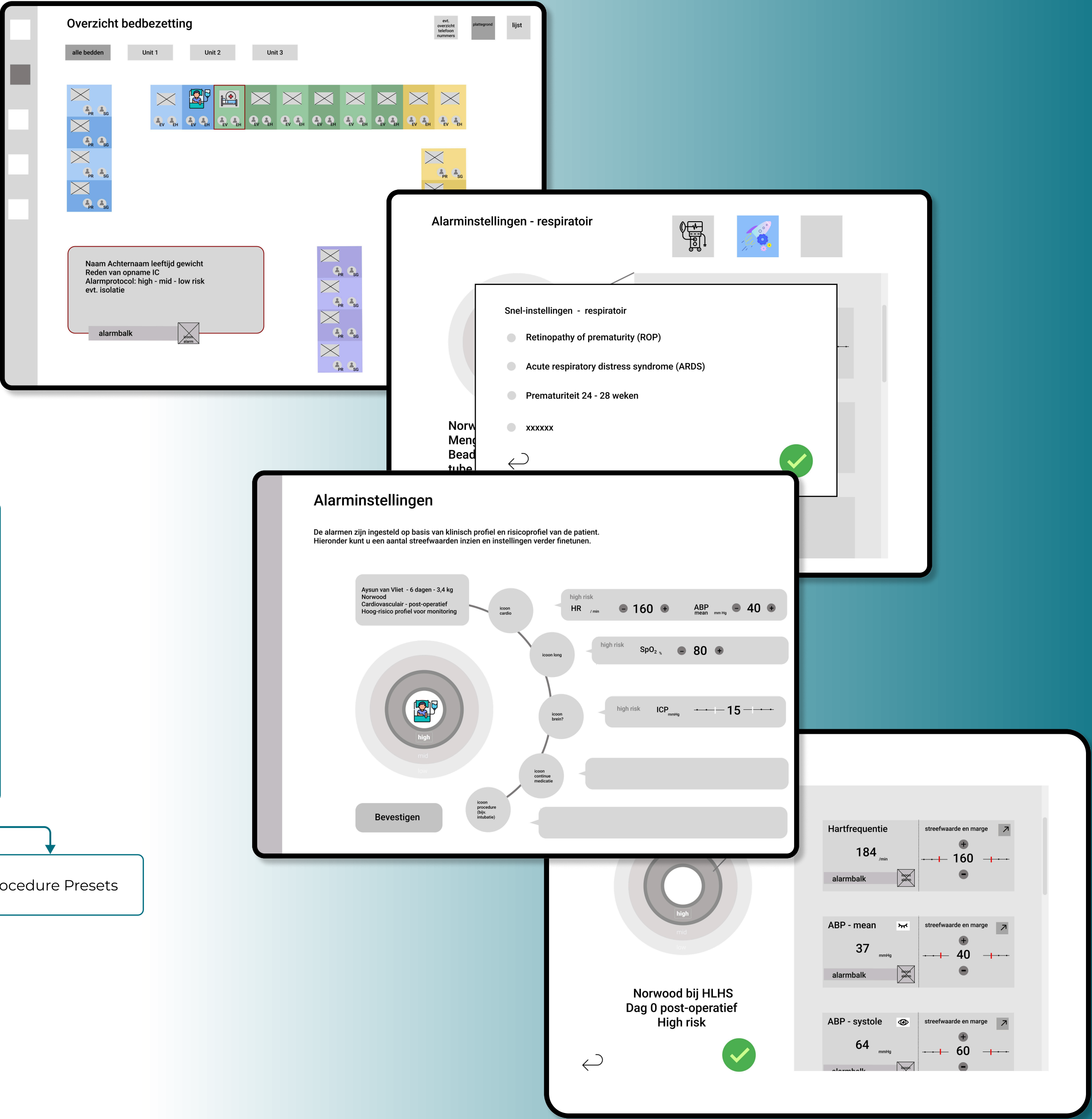


Figure 4.2: An impression of the first prototype to configure the new alarm system, designed by Marijn Soeteman.

4.2 Evaluation

This prototype had not yet been tested with healthcare professionals in the ICU. Therefore, an evaluation test was initiated before starting the iterative design process. The main research question of the evaluation was:

How do nurses perceive this new concept of setting alarms?

To gain more detailed insights, several sub-questions were explored during the evaluation:

- 1. What are nurses' opinions on the current alarm system?
- 2. Does the proposed system fit their existing workflow?
- 3. Is the navigation within the interface clear?
- 4. Do they understand how the duration-based algorithm works?
- 5. Would they see value in a 'procedure' functionality?

To ensure nurses could interact properly with the prototype during testing, several minor refinements were made in Figma. These included the addition of icons, adjustments to the scale of interface elements, and the use of colour. Finally, the prototype was made interactive (clickable) using Figma's prototyping tools.

Test Procedure

Three participants were selected by the intensivist of the SASICU project, based on their varying levels of experience and their openness to new developments (see table 4.1). Given that this is an early-stage evaluation, it was important to involve participants who are both open and collaborative to see potential improvements in clinical workflows.

The participants signed an informed consent form to participate in the test, see appendix C. This consent form is used for all evaluations described in this master thesis. Before starting the test, participants were provided with a short explanation of the test procedure, as well as an overview of the new alarm system. It was clarified that settings are not threshold based anymore, but instead the system uses a patient's clinical profile, risk level, and target values to set the vital parameters. The test took place in a quiet office or in the staff coffee room, see figure 4.3.



Figure 4.3: The three participants conducting interaction tasks with the prototype.

The test consisted of three main parts:

- **Initial interview:** Preliminary questions were asked regarding their experience with the current alarm system and how they approach the setting of alarms.
- **Interaction tasks:** Four tasks were given to interact with the Figma prototype:
 1. Imagine a new patient with a heart disease is admitted to the ICU. Connect the patient to a bed, select a clinical profile, and assign the highest risk level.
 2. Navigate to alarm settings and adjust the target heart rate to 170.

3. Imagine you must intubate the patient, so apply the default alarm settings for intubation.
4. The patient was born prematurely; use this preset for the respiratory alarm settings.

- **Post-test interview:** After completing the tasks, participants were asked several questions about their experience with the prototype and their understanding of its features.

The whole test procedure (in Dutch) can be found in Appendix D.

Results

All three participants were able to complete the four tasks, with one exception: the senior nurse was unable to find the correct screen for the last task. Some icons were unclear, and not all clinical information was aligned across the different screens, so participants began asking detailed clinical questions. These could not be answered during the session.

The full tests were recorded and transcribed to analyse their answers on open questions and find relevant user quotes. The quotes were clustered to create an overview and identify five **themes**: Alarm Fatigue, Thresholds, Workflow, Procedure, and UI elements (see Appendix E). All three participants acknowledged alarm fatigue as an issue with the current system. As participant 1 said:

“I hate it when loads of alarms are going off all the time and no one does anything about it.”

However, at the same time she highlighted the importance of not missing critical alerts:

“We don’t want unnecessary alarms, but we also don’t want to miss something important.”

Overall feedback on the new system was quite positive. Participant 1 said, “If this duration algorithm actually works, that would be great.” Despite this, they need time to get used to the new system, as participant 2 noted:

“You need to learn to trust alarms again. That if they go off, there’s really something going on.”

Participant 1 worried about the amount of extra work required when you must indicate problems for every separate organ. This is not the case, but the interface unintentionally gave that impression. On the other hand, other elements of the interface were seen as workflow improvements, as participant 3 mentioned: “The fast presets are really handy, we don't have to think so much anymore.”

The opinions about procedures, temporary default settings for specific interventions like intubation, were more mixed.

“I think procedures could be useful. Normally I wouldn’t change the lower limit, just because I’m afraid that I forget to put it back again.”

In contrast, another participant said:

“Procedures might make the workflow more complex; you don’t want to make an exception for every single thing.”

Discussion

As this was a low-fidelity prototype, some elements were missing or incomplete. The clinical scenario used for the tasks was not entirely accurate; this may have influenced how they experienced the prototype. For the next evaluations, the clinical information should be more consistent and corresponding with the interaction tasks given.

Additionally, the duration algorithm was not fully explained and visualised, making it difficult to assess whether participants understood how it works. This requires further evaluation in future tests, particularly to explore how nurses approach the detailed settings of vital parameters.

As expected, participants continued to show a preference for absolute threshold values. Changing their mindset will take time, as they need to become familiar with the new approach. Nevertheless, it was surprising to see that almost all tasks were completed successfully, despite the prototype lacking complete information and icons. This suggests that the navigation was intuitive. However, the limited content might also have made it easier to navigate through the interface. Procedure presets could be helpful, but they should be elaborated on first to ensure they are not making the system more complex.

It is important to note that the participants were selected for their openness to innovation and already had some prior knowledge of the new alarm system. This limits the generalisability of the results. However, their involvement was necessary to provide valuable early feedback. The variation in their professional experience contributed to making the test results more representative.

Table 4.1: Participants in the first prototype evaluation

Participant	Work Experience	Gender
1 - Senior Nurse	> 30 years	Female
2 - Physician Assistant	20 - 30 years	Male
2 - Junior Nurse	< 5 years	Female

Conclusion

To answer the main research question: all three participants responded positively to the new way of alarming and could imagine themselves using a system like this in future. Participant 3 commented:

“I think this could work really well. You can filter out useless alarms, and right now we have to change all the thresholds manually.”

However, several adjustments need to be made, and time will be needed to become familiar with the new workflow. As participant 1 said:

“Of course it would fit my workflow. All beginnings are difficult, so it’s about learning, settling in and starting to work in a different way.”

After the test, the prototype was discussed during the **SASICU project meeting**. One key insight was that procedure presets may not belong in this setup interface. Procedures are used while treating a patient at the bedside, so this might fit better within an interface which displays the alarms, which falls outside the scope of this project. Additionally, the meeting gave clarification about the set-up of the clinical profile: there should be two mandatory steps: choose the reason of admission and identify the overall risk level of the patient. An optional third step follows to fine-tune this risk level per organ, but no additional clinical details per organ are needed. Finally, it was clarified that alarm settings should be based on a target range, not a single target value.

Key Takeaways of Section 4:

- Overall, the three participants were quite positive about this new approach for configuring alarms.
- The ‘Procedure’ function falls outside the scope of this project.
- Further testing and detailing of this first prototype are needed to assess if nurses understand the new approach of adjusting target ranges and the implications of the depth-duration algorithm.

05

Design Brief

This chapter outlines the design brief that will guide the design conceptualisation phase. The design brief is informed by both literature and empirical findings discussed in Chapters 3 and 4. It concludes with clearly defined design requirements.

- 5.1 Design Goal
- 5.2 Design Requirements



5.1 Design Goal

As stated in the introduction, the initial assignment was quite clear and fixed: “Prototype a graphical user interface for ICU nurses to set up a new central alarm system which manages the alarm load at UMC Utrecht.” However, the research and analysis conducted throughout the project provided new insights and perspectives, leading to a refined design goal.

Explanation of the Design Goal

ICU professionals – Although ICU nurses will be the primary users of the interface, it must also be intuitive and comprehensible for intensivists, who can also be end users.

The design goal consists of three core elements:

Guidance – The interface should be designed to guide the nurse, keeping cognitive load to a minimum. It should support them in configuring the correct settings for a specific patient by presenting relevant information at the right moment.

Efficiency – Nurses often work under time pressure and cannot afford to spend hours configuring alarms. Therefore, the set-up process should feel quick, logical and straightforward, without unnecessary steps. The interface should be easy to use and navigate.

Confidence – ICU professionals should feel in control of the alarm system while interacting with the interface. When they walk away from the patient room, they must trust that the new system will warn them on time when the patient needs care again.

The design goal is:

“To prototype a graphical User Interface which *guides* ICU professionals to *efficiently* configure alarms for patients, which provides *confidence* that they can safely monitor patients from a distance.”

5.2 Design Requirements

To reach this design goal, specific requirements for the user interface were formulated. The clear design assignment from the SASICU team at UMC Utrecht has already resulted in certain specific design requirements and wishes. The other requirements are based on either literature, fieldwork, or the evaluation of the first prototype, all of which were executed during the research and analysis phase. The requirements and wishes are organised by four categories: context, functionality, experience, and technical specifications. The final design should at least fulfil those requirements, and the wishes are nice-to-haves.

- Legend**
- Proposed assignment by SASICU Team
 - Literature Review
 - Fieldwork (Interviews & Observations)
 - First Prototype Evaluation

Context

Requirements:

- The interface is suitable for the new PICU at WKZ. ●
- The interface is mainly made for nurses, but it should also be easy to use for intensivists and PAs. Family and parents do not interact with the interface. ●
- The interface is primarily positioned at the patient's bedside, close to the physiological monitor. It can also be accessed from the central nurse station. ●●

Wishes:

- The interface is suitable for all three kinds of Intensive Care Units: PICU, NICU and adult ICU. ●

Functionality

Requirements:

- The interface enables healthcare professionals to set-up a new patient within the new alarm system, based on clinical profile and risk-level. ●
- The interface enables healthcare professionals to fine-tune the risk-level on organ level. ●
- The interface enables healthcare professionals to adjust target ranges for the vital parameters. ●
- The interface allows for an **efficient** set-up. ●●
- The interface provides a quick overview of the patients within one unit, and their monitoring settings. ●
- The interface language should be Dutch. ●

Wishes:

- The interface is flexible and can be customised. ●

Experience

Requirements:

- The users should feel **guided** by the interface. ●●
- The cognitive load required to use the interface is as low as possible. ●
- The interface should provide **confidence** that healthcare professionals can safely monitor patients from a distance. ●●

Wishes:

- The interface is attractive; it is experienced as aesthetically pleasing.

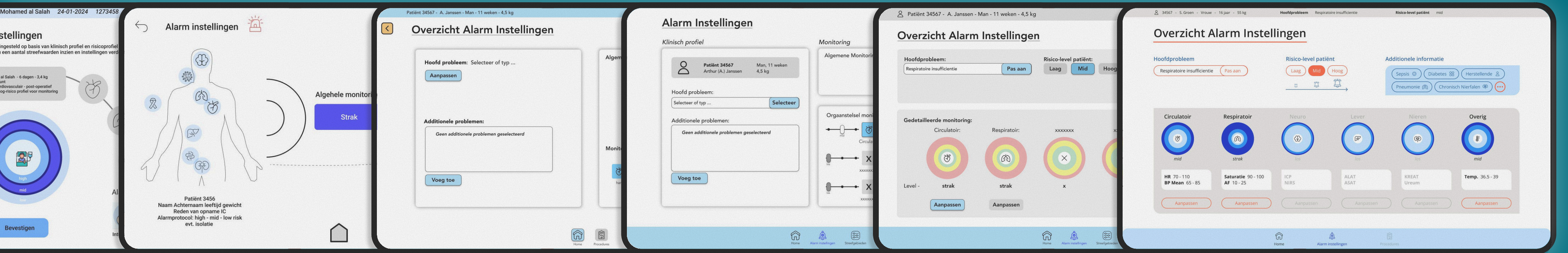
Technical Specifications

Requirements:

- The interface is developed for desktop use. ●●
- The size of the prototype is scalable between 17 and 22 inches. ●
- The interface can be controlled with a mouse and/or a touchscreen. ●●
- It is possible to connect the prototype to the digital patient simulation to test the effect of the new alarm system. ●

Wishes:

- The size of the prototype is scalable to iPad size or even mobile. ●
- The interface is (partly) developed in JavaScript or Python. ●



From a doctor's first prototype to a High-Fidelity design.

06

Conceptualisation

This chapter describes the iterative design process for evolving a user interface that meets the design goal and requirements. The design goal can be summarised in three keywords: **Guidance, Efficiency & Confidence**. To make the process manageable, each iteration focuses on cumulatively integrating one of these core elements. Each cycle consists of an ideation, prototyping, and evaluation phase. The chapter will conclude with the presentation of a first high-fidelity prototype and interviews with usability experts.

6.1 First iteration: Guidance

6.2 Second iteration: Guidance & Efficiency

6.3 Third iteration: Guidance, Efficiency & Confidence

6.4 Transformation to a High-Fidelity Prototype

6.5 Usability Expert Interviews

6.1 First iteration: Guidance

To minimise the cognitive load on nurses, it is important to guide them through the steps to configure alarm settings for a patient. Therefore, the interface should provide sufficient information without overwhelming the user. How can we achieve simplicity without withholding too much information?

6.1.1 Ideation & Prototyping

To explore different ideas, wireframes were first sketched on paper (see Figure 6.1). The ideation process was driven by the primary **design** question:

How can the interface guide nurses during alarm configuration?

This led to different design sub-questions:

- Sub-question 1:** What is the most minimalistic and simplest interface design that still meets the information needs of nurses?
- Sub-question 2:** Which and how many steps should the interface include?
- Sub-question 3:** How can the concept of monitoring based on target ranges (instead of absolute thresholds) be explained clearly, without making it too complex?

The initial paper wireframes were developed into a low-fidelity interactive prototype using Figma to gather feedback from nurses and gain insights for further iterations. The prototype was first reviewed during the weekly SASICU project meeting, resulting in several improvements. The initial prototype, with annotated comments from the client, can be found in Appendix F. The comments and suggestions led to the testable prototype shown in Figure 6.2, which is already annotated with results from the evaluation discussed in the following paragraph.

6.1.2 Evaluation

Test Procedure

The prototype was evaluated using a procedure similar to the one described previously (see Section 4.1). However, due to the high workload in the ICU, only two nurses were available for testing. Both participants (see Table 6.1) were recruited from the previous test group, which allowed for comparison between the first iteration of Section 4.2. Additionally, this participant selection saved time on explanations about the future alarm system. The main research question was:

Do nurses find this prototype guiding and informative enough to configure alarm settings for patients?

The participants were asked to complete **four tasks** with the prototype:

Table 6.1: Test participants of the first iteration.

Participant	Work Experience	Gender
1 - Senior Nurse	> 30 years	Female
2 - Junior Nurse	< 5 years	Female

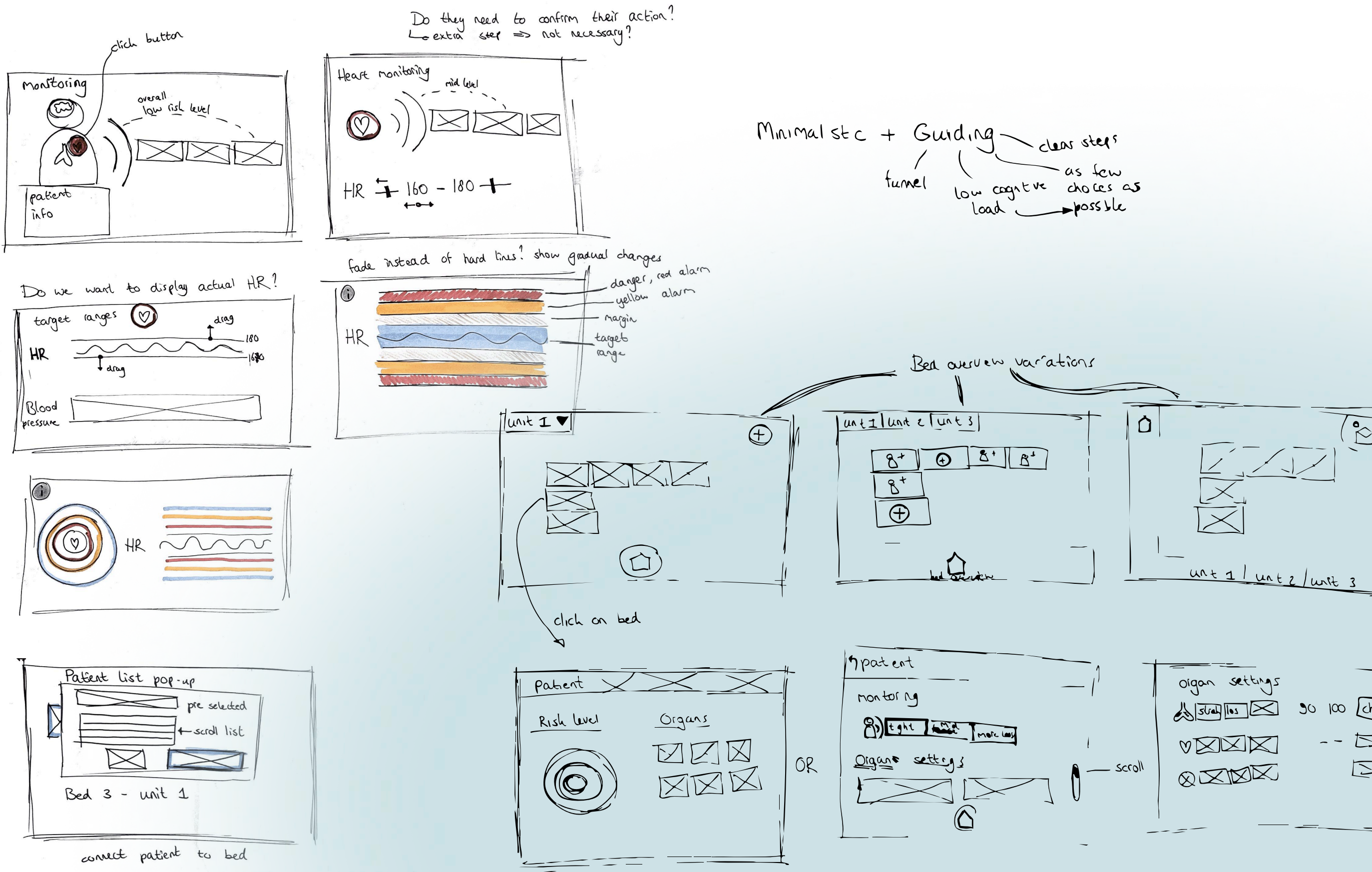


Figure 6.1: Initial wireframe sketches exploring ideas for guiding users through the interface.

1. Add a patient with heart failure and indicate a low-risk status.
2. Navigate to cardiac alarm settings and choose a tighter monitoring option.
3. Adjust the heart rate target range to 160-190 BPM.
4. Navigate back to the bed overview page.

Afterwards, several questions were asked regarding their experience and understanding of the interface, such as “Did you miss any information?” and “What is the meaning behind the target range graph?”

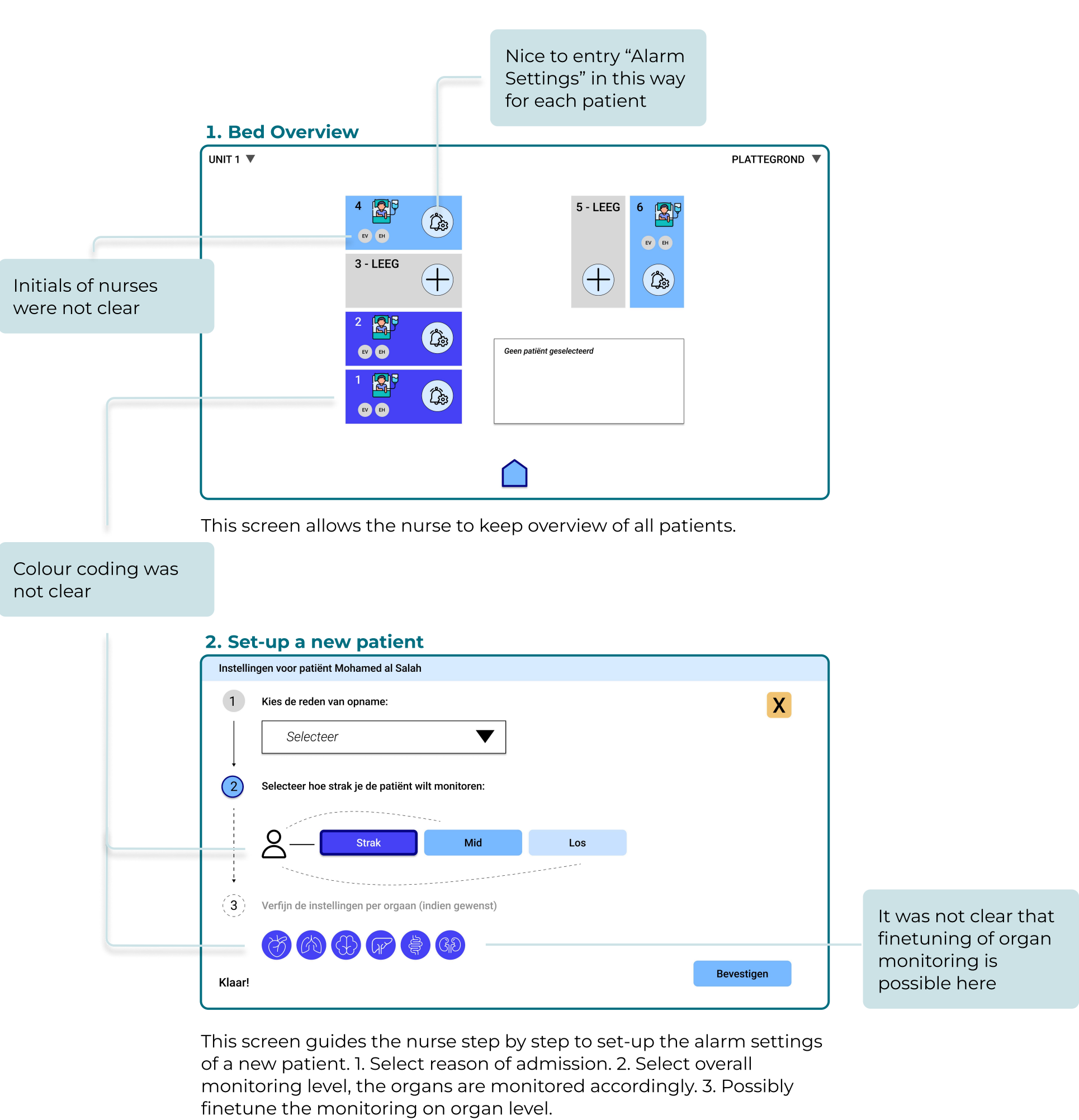
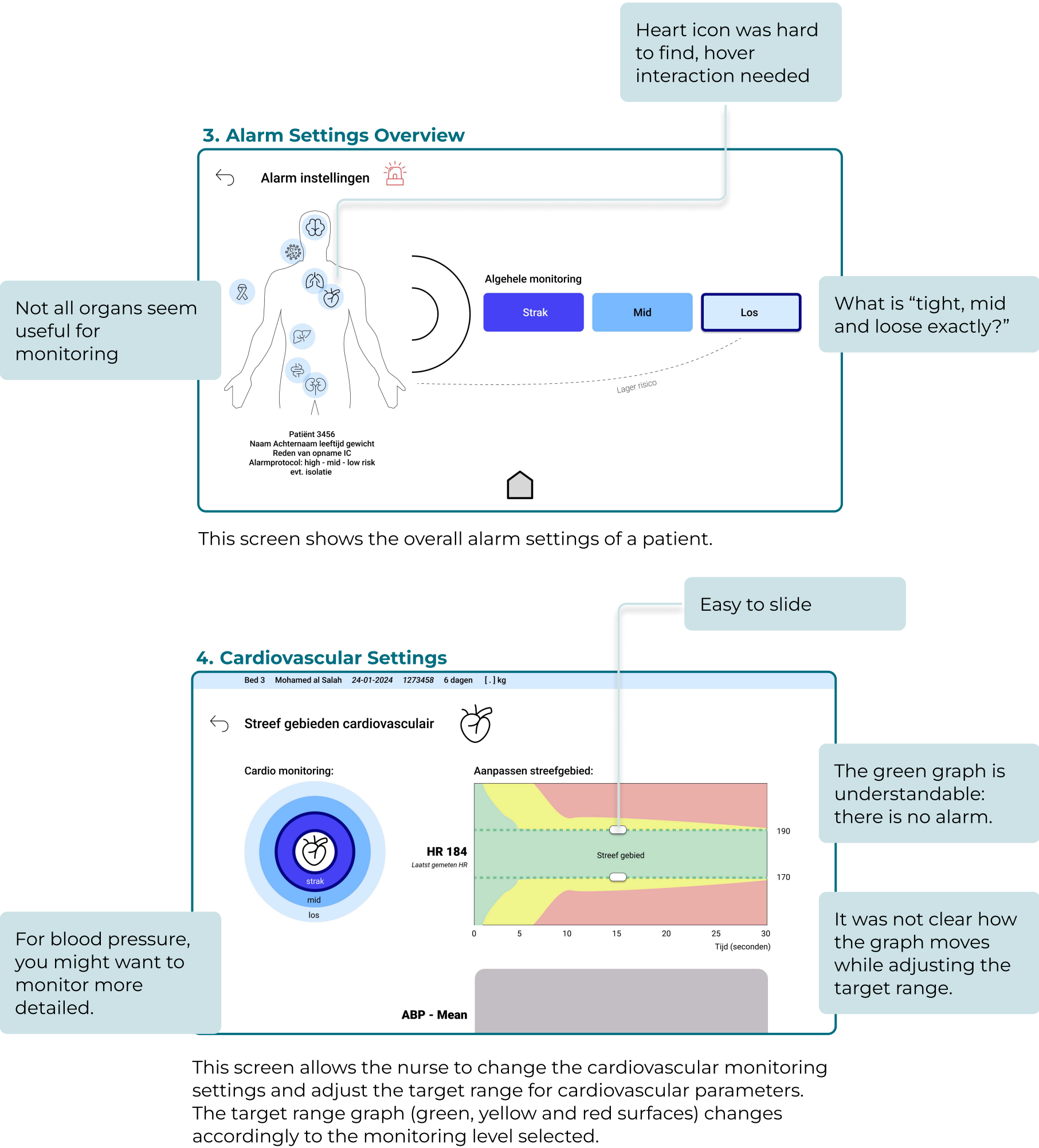


Figure 6.2: The testable low-fidelity prototype of the first iteration, including annotations with observations and remarks gathered during testing.

Results

Both participants successfully completed all four tasks within **2 minutes**. Figure 6.2 summarises their feedback about specific interface elements and observations made during task performance. Both participants indicated that they experienced the prototype as guiding, when the interviewer asked “Did you feel guided by the interface?” One participant said: “It was very easy, I didn’t need to

think like, what do I have to do? It’s easier than most apps.” The other participant said: **“It is neat and simple. You just need to know what and how you want to monitor. But it is clear where I have to click”**. However, there was also a need for clarification: “I would like some instructions about tight-mid-loose. What does tight exactly mean?”



Discussion

Due to limited nurse availability, this evaluation involved only two female participants. While they had different levels of experience, the small sample size restricts the generalisability of the findings. Additionally, both participants were already familiar with the new alarm system from a previous test. Although this allowed in depth evaluation of specific elements, such as the depth-duration visualisation, it also made the navigation easier.

It was encouraging to see that one participant immediately understood the depth-duration visualisation, despite the complexity of this principle. However, the other participant asked whether education would be provided about the interpretation of this graph. This suggests the need for further testing to **evaluate whether these visualisations are clear and intuitive for a wider group of users.**

The task completion within two minutes indicates for an efficient prototype. However, the prototype is simplified and lacks the complexity of this system in reality. While participants found the interface simple and guiding in this iteration, future evaluations should determine whether this feeling will remain when more clinical information and features are added.

Key Takeaways for next iteration

- Nurses continued approaching alarms with thresholds instead of **target ranges**. It is crucial that they clearly understand the concept of a target range.
- The practical implications of choosing different **monitoring levels** ("tight," "mid," "loose") were unclear and require a clearer visual explanation in the next iteration.
- The **navigation** style was clear and should be further explored in the next iterations.

6.2 Guidance and Efficiency

As discussed in Section 3.3, nurses often lack sufficient time to carefully configure patient alarms due to the high-paced ICU environment. Therefore, the alarm configuration must be as efficient as possible. This iteration explicitly addresses how the interface can enhance efficiency while continuing to provide enough guidance.

6.2.1 UX workshop with Ascom

The ideation process in this iteration differs slightly from previous approaches, as it builds upon insights gained from a three-day collaborative workshop with Ascom. This workshop was part of the SASICU project's existing schedule. As described in the introduction, Ascom (a healthcare technology company) received, together with UMC Utrecht, the European grant for the SASICU project. Eventually, Ascom aims to deliver the commercial product: a smart alarm system, including a User Interface, which can be sold to hospitals worldwide.

The workshop was organised to exchange knowledge, develop a shared understanding and terminology and brainstorm on UI/UX considerations. UMC Utrecht provided clinical knowledge and user needs, while Ascom contributed with their UX/UI expertise. Ascom was represented by two UX/UI designers and two technology specialists, while the entire SASICU project team participated from the hospital side. In particular, it was valuable to collaborate with the designers from Ascom and Marijn Soeteman, the trainee paediatrician who developed the first prototype (see Section 4.1). Marijn's contributions offered insights into her design process and choices made. Figures 6.3 through 6.5 provide an impression of the workshop days.

UX/UI brainstorm

After achieving a shared understanding, it was possible to brainstorm about specific user interface requirements. While previous iterations relied solely on the reason for admission and monitoring levels to configure alarms, it became clear that additional patient context is needed in some cases. For example, when the patient is an athlete or currently awake and moving, both of these "information pieces" could affect the "normal" values of vital parameters. Therefore, the user should have the option to select "additional problems", which are predefined clinical conditions or characteristics. These act as "shortcuts" that help users create the right target range and monitoring level for all organ systems for that **specific** patient.

The brainstorming session concluded with five **key functionalities** required to make the smart alarm system work, as shown in Figure 6.6. However, in alignment with the SASICU team, it was decided that functionality four falls outside the scope of this project. This feature will probably be more relevant to the (mobile) interface responsible for delivering alarm notifications.



Figure 6.3 The second workshop day at WKZ in Utrecht.

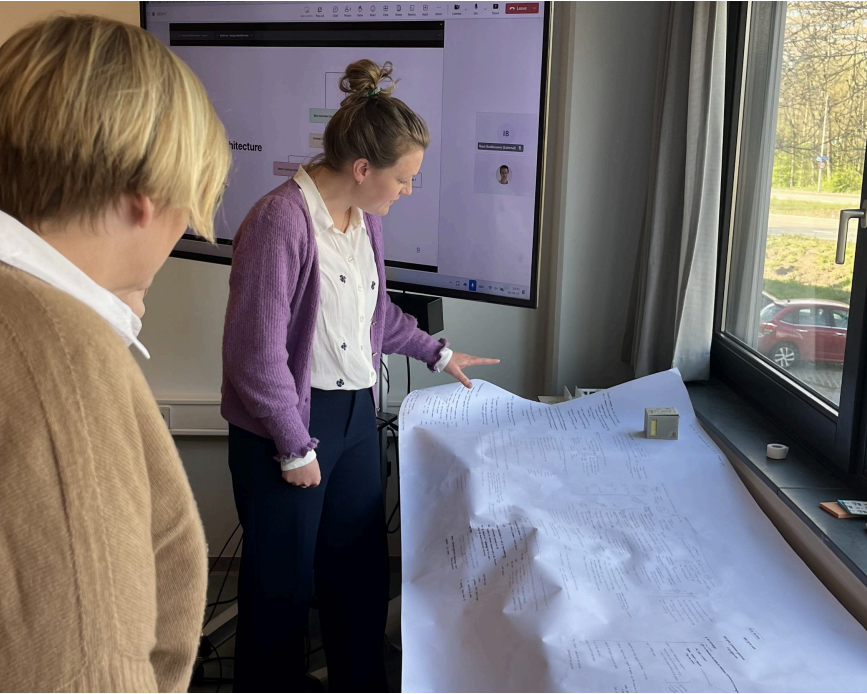


Figure 6.4 Paediatrician Marijn Soeteman showing her design process for the first prototype.



Figure 6.5 Discussing the required functionalities and hierarchy of the UI.

The 5 key functionalities

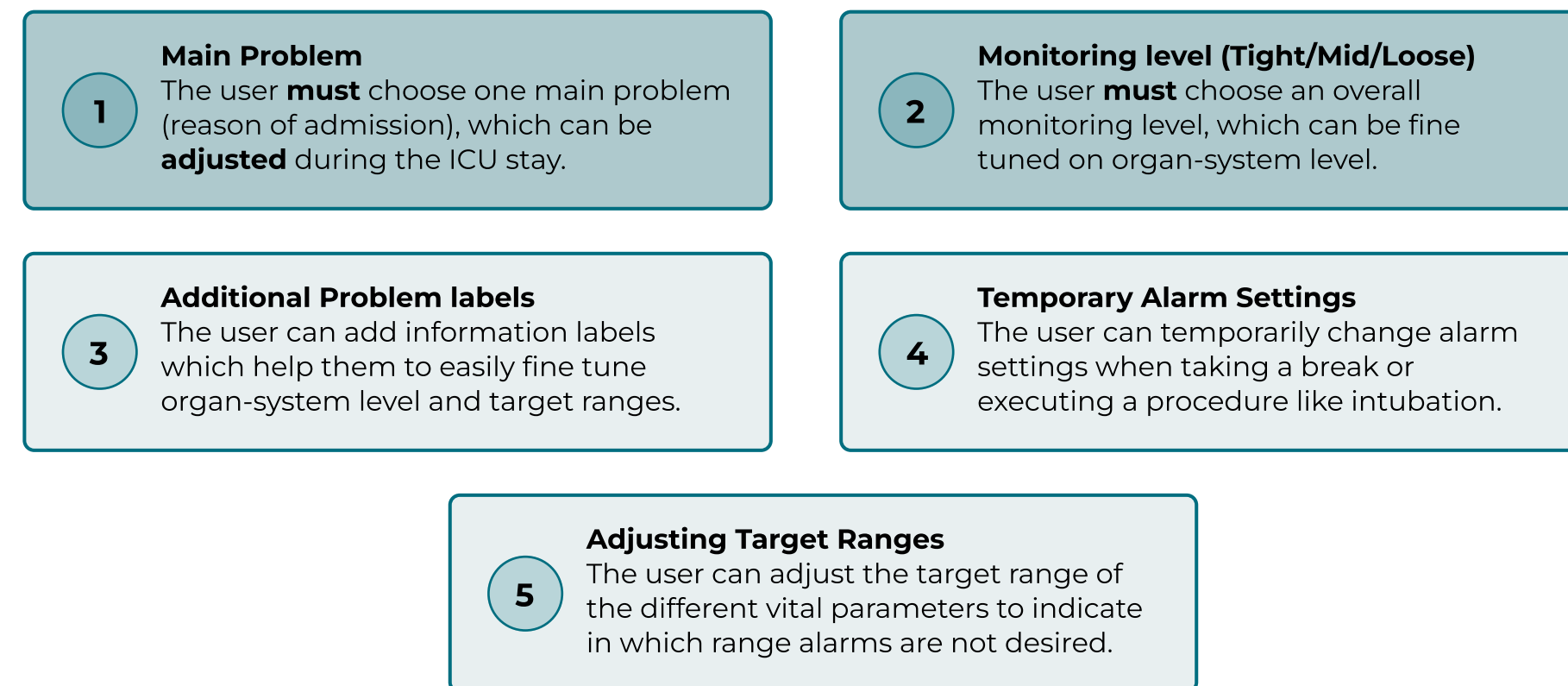


Figure 6.6: The resulting key functionalities from the UI workshop with Ascom.

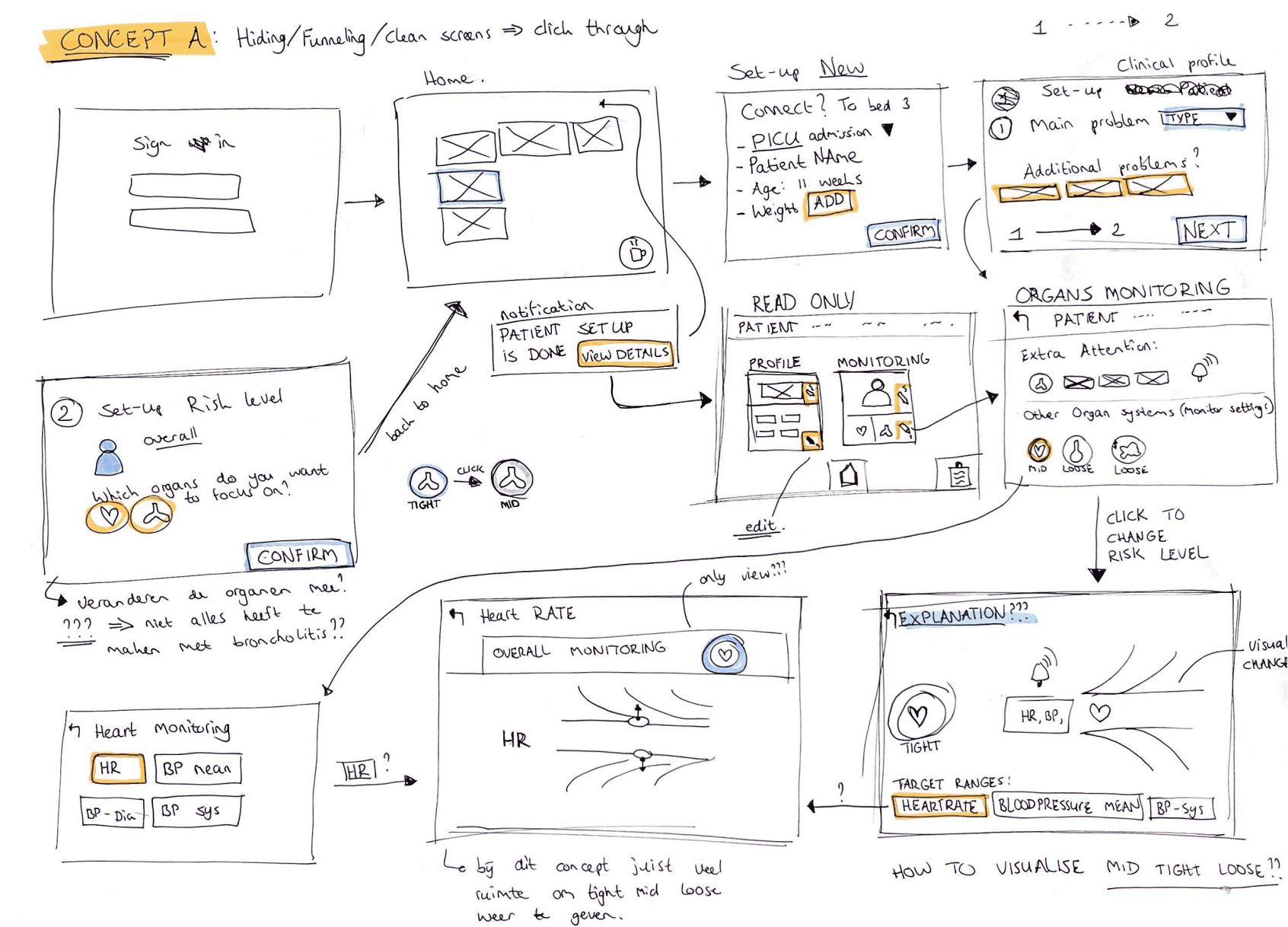


Figure 6.7: Wireframe sketches of concept A.

6.2.2 Ideation and Prototyping

With the key functionalities defined, the following design question was raised:

How can we organise all information and features into a logical hierarchy to enable the most efficient alarm configuration?

To explore different approaches for structuring the interface, two different concepts were developed; their wireframes are shown in Figures 6.7 and 6.8. Additionally, multiple concepts can hopefully encourage test participants to think more creatively when expressing their preferences during evaluation tests.

Concept A: The clean funnel

Concept A is a step-by-step funnel design, with every step displayed on a separate clean screen. The clean layout creates more space for explanation and reduces cognitive load.

Concept B: The pop-up overview

In contrast, concept B is more information-dense, using a pop-up format. This offers a more comprehensive overview of all settings in one place, but it limits space for details and explanations.

The wireframes were developed into two low-fidelity prototypes, shown in figure 6.10 and 6.11 in section 6.2.3.

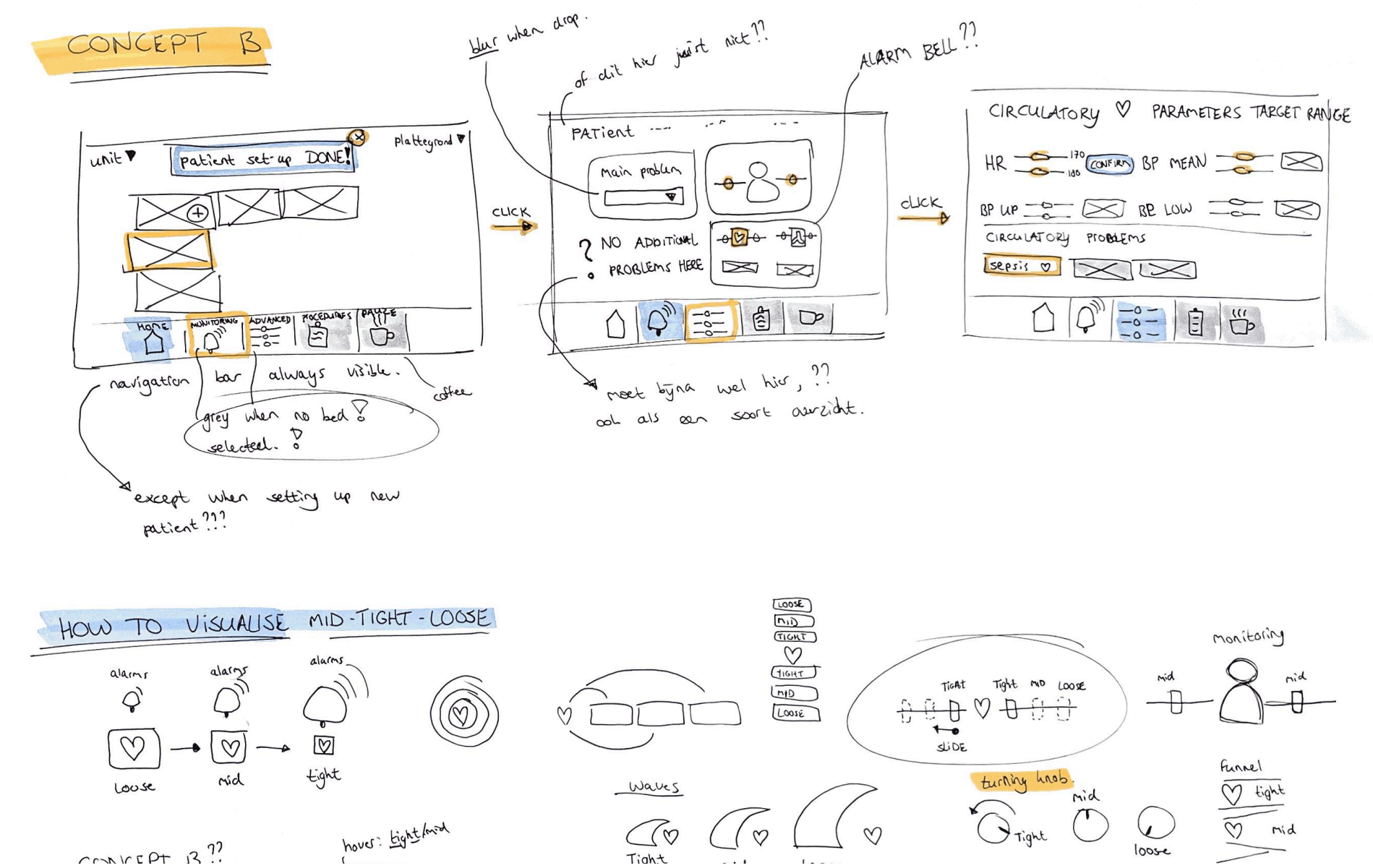


Figure 6.8: Wireframe sketches of concept B.

6.2.3 Evaluation

Test procedure

To evaluate both prototypes, a similar procedure was followed as in the previous evaluations (Section 4.2 and 6.1.2), including some additions. Four participants were involved: three clinical staff members and one Ascom employee, all selected by the Paediatrician Intensivist of the SASICU team (see Table 6.2). Participant 2 was new to the project, while Participants 3 and 4 had participated in one or more previous tests.

The participants were given a clinical scenario consisting of 4 steps, during which they were asked to configure the alarm settings accordingly. Both prototypes were tested using the same tasks, but to avoid bias from familiarity, the testing order was alternated: Participants 1 and 2 evaluated Prototype A first. In contrast, Participants 3 and 4 began with Prototype B.

The Clinical Scenario:

- 1. A new patient (male, 11 weeks old, 4.5 kg) with bronchiolitis is admitted to the ICU.
- 2. There is suspicion of pneumonia.
- 3. More deterioration: suspicion of sepsis.
- 4. One week has passed, and the patient shows signs of recovery.

To compare the usability of both concepts, participants completed the **System Usability Scale (SUS)** after using each prototype. SUS offers a quick and reliable measure of perceived usability on a scale of 1-100, even with a small sample size (Brooke, 2013). Additionally, open-ended questions were asked to gather qualitative feedback on specific interface elements. At last, they were also asked which concept felt the most guiding and which concept felt most efficient.

The two main research questions were:

Which interface elements contribute to a sense of efficiency and guidance?

Do participants understand the displayed information and the implications of their settings?

Results

Table 6.3 summarises some performance metrics. The tasks with concept A were completed in about 12 minutes by participants 1 and 2, while concept B took participants 3 and 4 about 6 minutes. In general, concept A was experienced as more guiding, while concept B was perceived as more efficient. Concept A received an average SUS score of 68, compared to 59 for Concept B. Most participants preferred visualising monitoring levels using circular icons rather than sliders, and they made use of the Additional Problem labels.

Figures 6.10 and 6.11 provide detailed feedback and observations made during task completion. Given the limited timeframe of this project, it is not feasible to address *all* feedback. In agreement with the SASICU team, a backlog has been created to document input that falls outside the current scope, but should be considered for future development (see Appendix G).

Participants were still focused on thresholds:

“I can’t see the thresholds right? Because I have no idea what my values are with tight or mid.” - P2

The target range visualisations were not clear:

“I find it unclear. I don’t see precisely when I get alarmed, there is no upper and lower threshold.” - P3

“I don’t get why this is a circle?” - P1

“I am not sure what the green edge is.” - P2

There is need for a better explanation about the impact of configuration choices:

“I cannot see what the implications of my adjustments are. If I add ‘sepsis’, what are the consequences?” - P1

“How tight is tight? I find it hard to imagine what it means” - P3

Table 6.2: Test participants of the second iteration.

Participant	Work Experience	Gender
1 - Clinical Implementation Specialist of Ascom	-	Female
2 - Junior Nurse	< 5 years	Female
3 - Physician Assistant	20 - 30 years	Male
4 - Junior Nurse	< 5 years	Female

Table 6.3: Results of various test elements of evaluation of second iteration.

Performance	P1 (Ascom)	P2 (Nurse)	P3 (PA)	P4 (Nurse)	
Test Order	AB	AB	BA	BA	
Completion Time <i>first tested Concept</i>	11 minutes	14 minutes	7 minutes	4 minutes	
Using Additional Problems	Yes	Yes	No	Yes	
Most <i>Efficient</i> Concept	B	A	B	B	
Most <i>Guiding</i> Concept	A	A	A	A en B	
Preference for circles/sliders	Circles	Circles	Sliders	Circles	
SUS Concept A	73	60	40	62.5	59
SUS Concept B	78	50	65	80	68

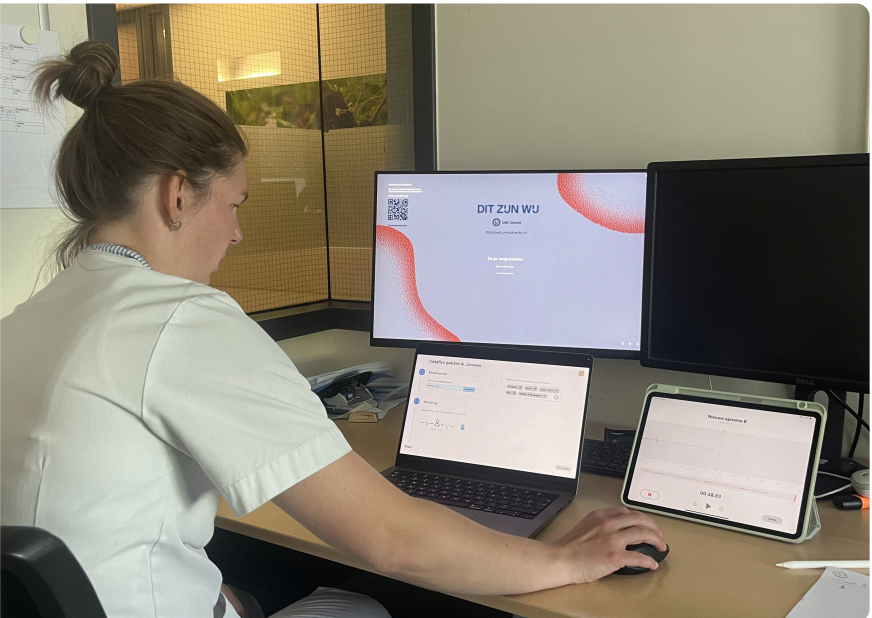
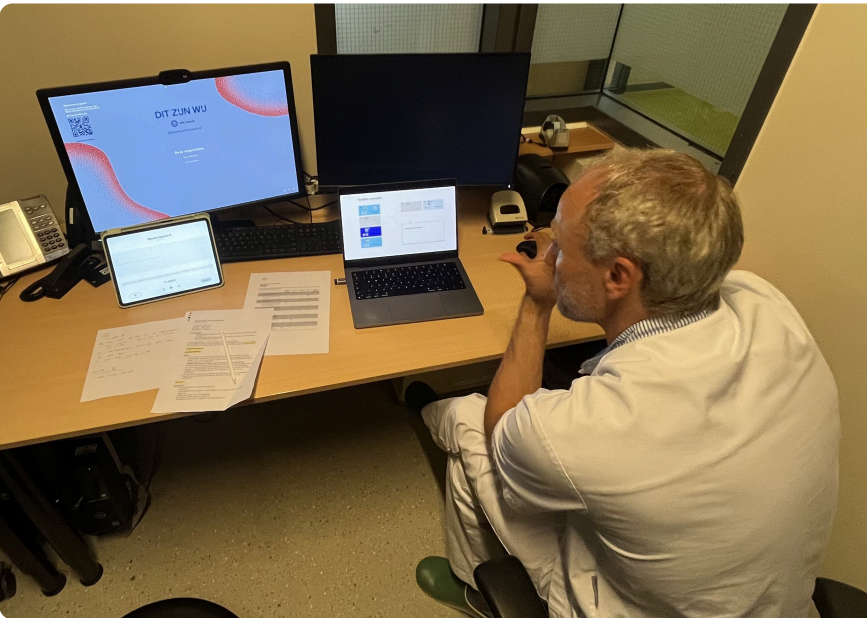


Table 6.9: Participants completing the tasks with the two prototypes.

Concept A - The Clean Funnel

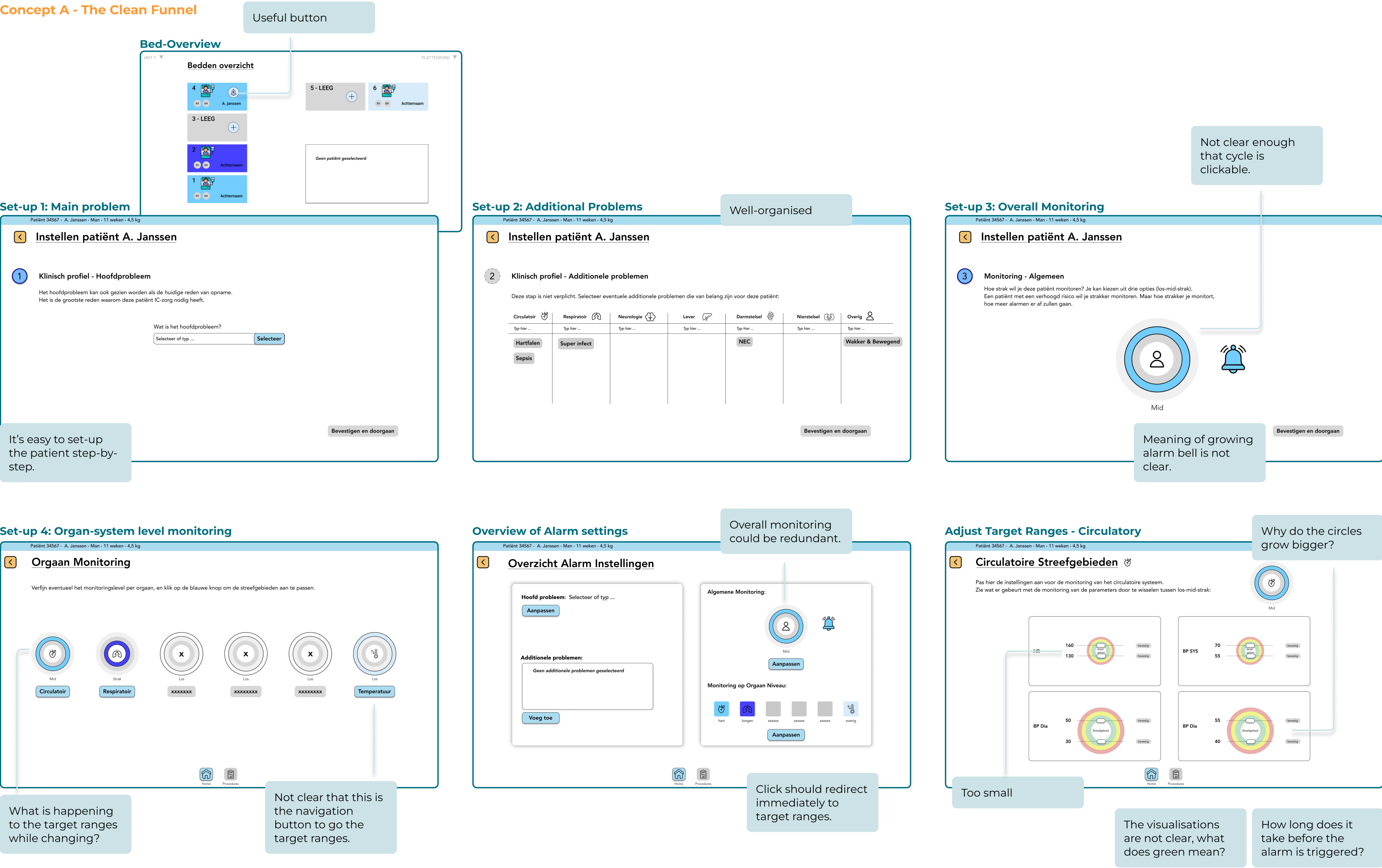


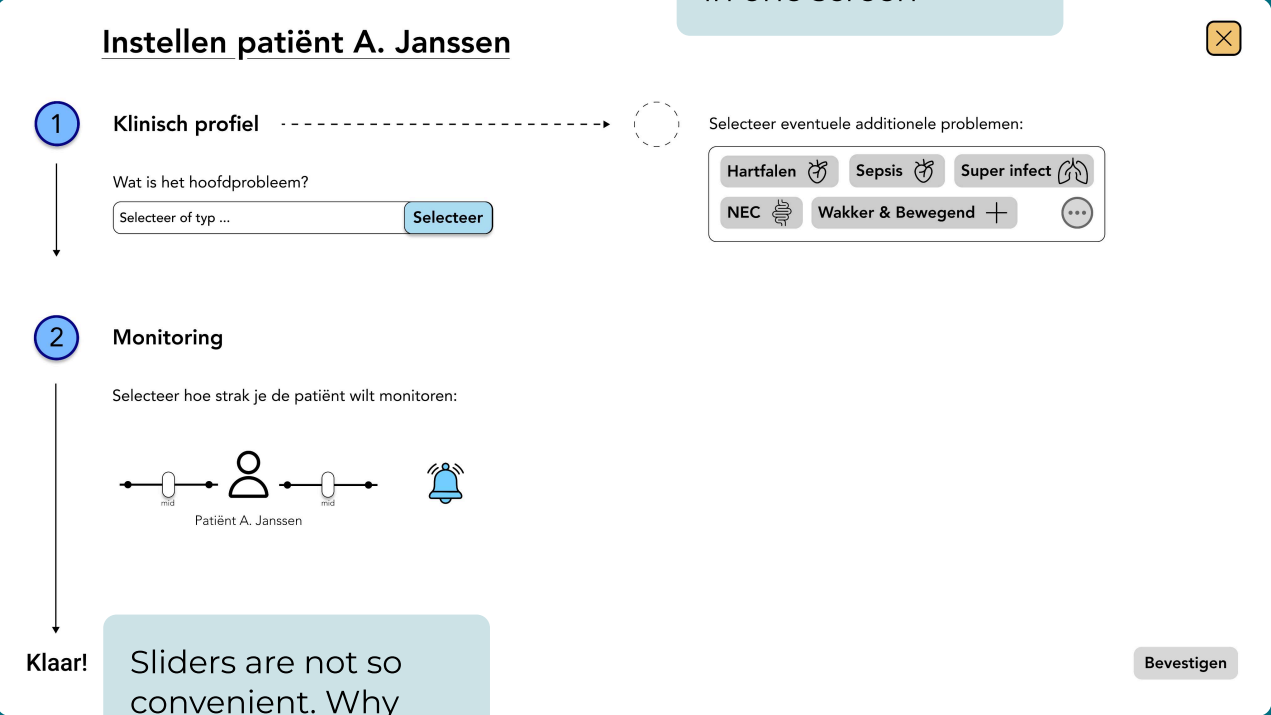
Figure 6.10: The low-fidelity prototype of concept A, including annotations with observations and remarks gathered during testing.

Concept B - Pop-up Style

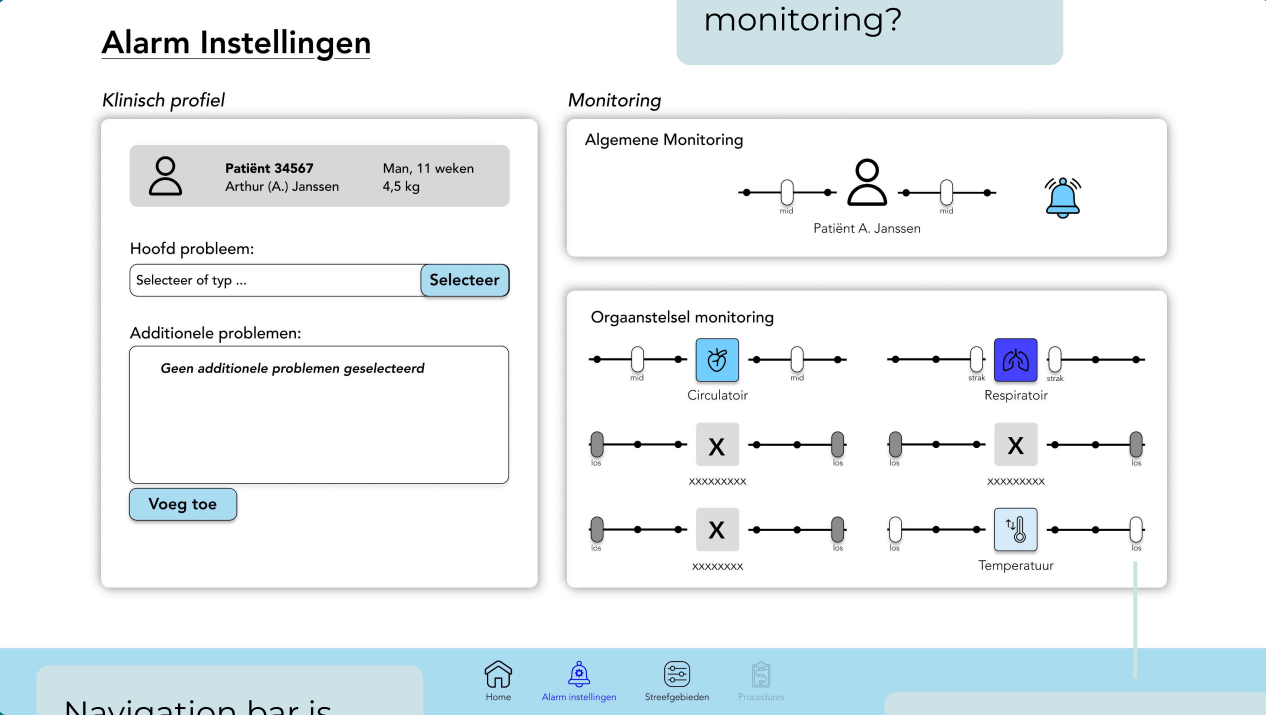
Bed overview



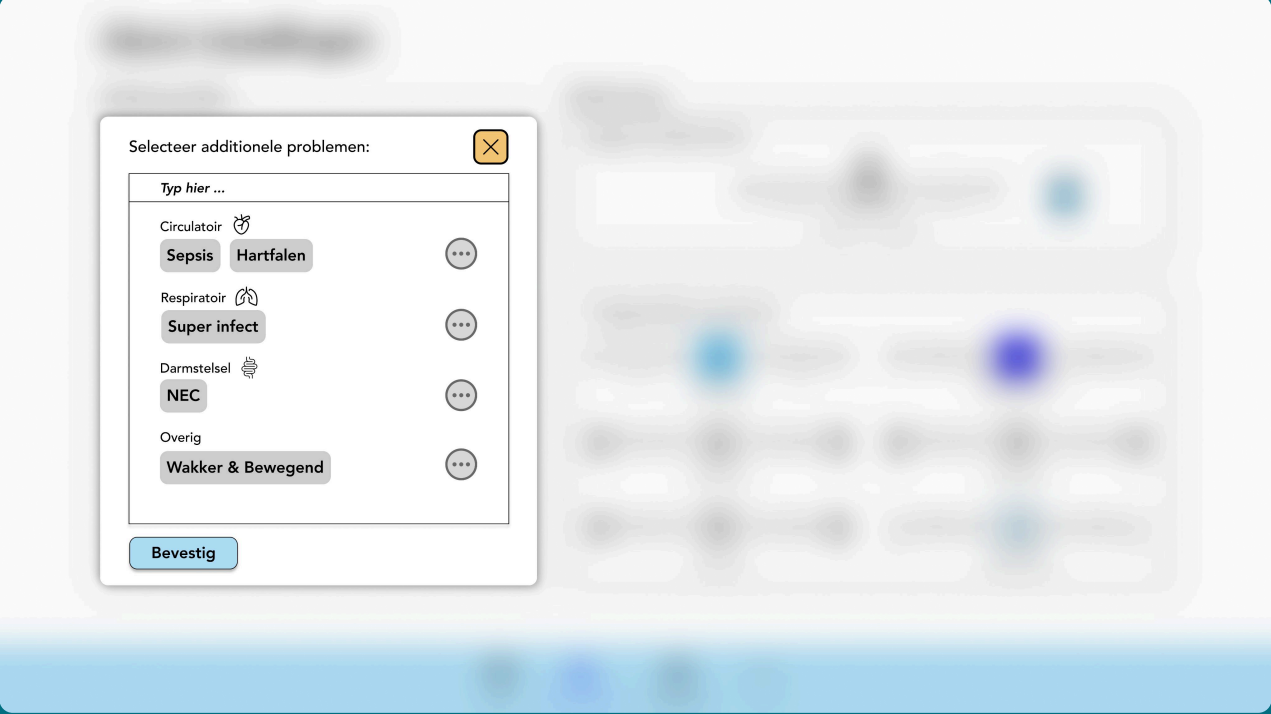
Set-up a new patient



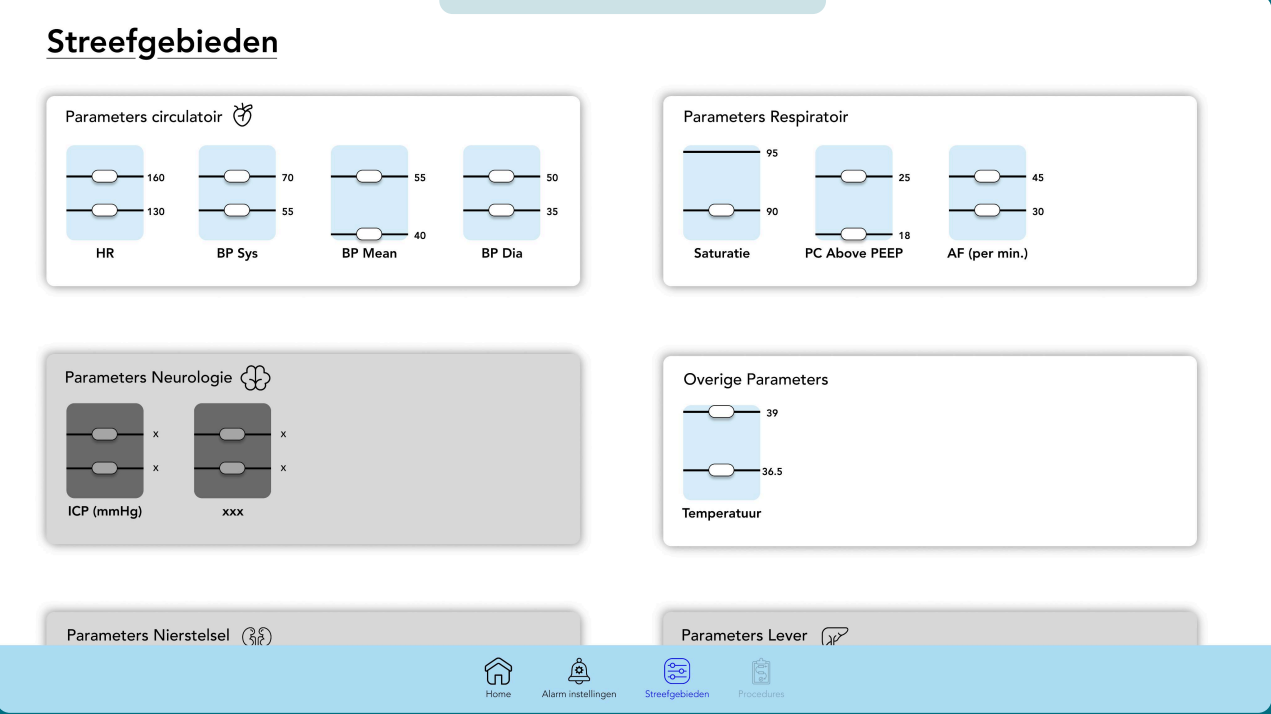
Overview of alarm settings



Additional Problems pop-up



Adjust Target ranges



Adjust circulatory target ranges

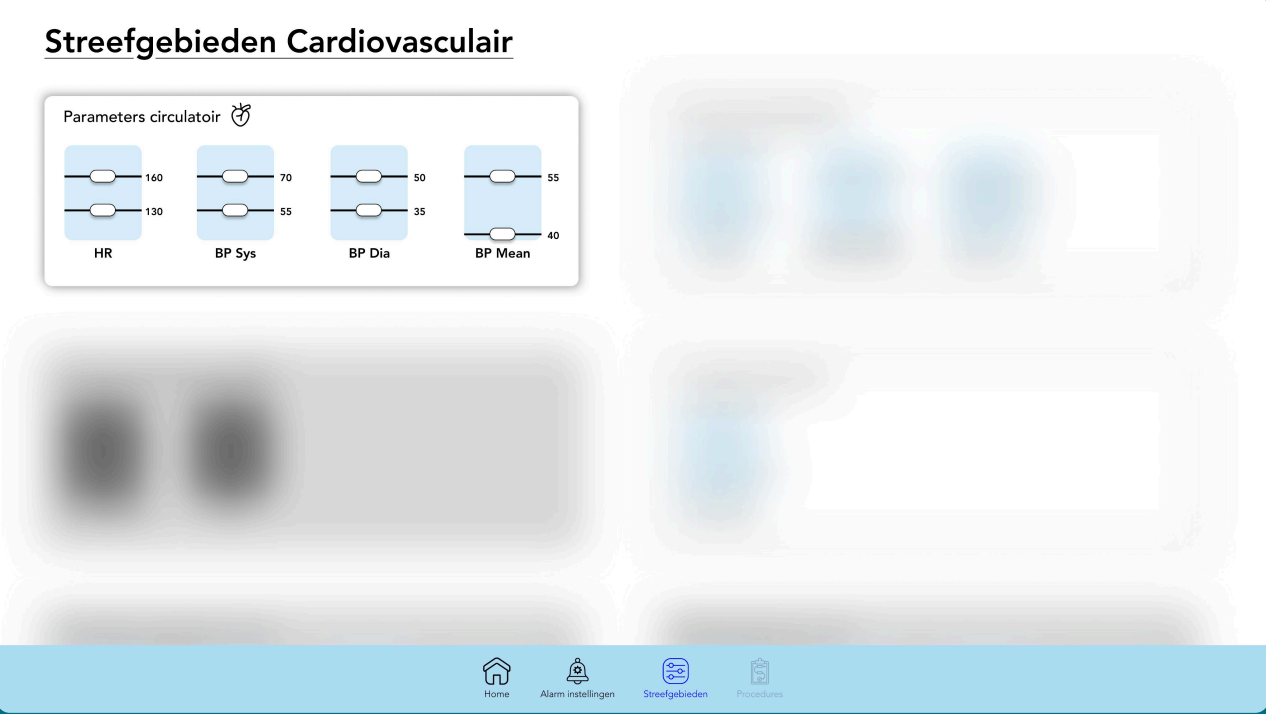


Figure 6.11: The low-fidelity prototype of concept B, including annotations with observations and remarks gathered during testing.

Discussion

6.3 Guidance, Efficiency & Confidence

SUS scores for both concepts ranged around or below the average usability benchmark of 68, indicating an acceptable usability, but this could definitely be improved. With appropriate training and onboarding, users may become more comfortable with the terminology and structure, particularly with concepts like "tight/mid/loose."

Concept B was considered more efficient, likely due to its navigation bar and overview-oriented layout, which made the target ranges easier to find. In contrast, Concept A offered a more structured, step-by-step experience, contributing to a stronger sense of guidance. The task completion times should be interpreted with caution, because participants were asked to think out loud. Differences in how participants verbalise their thoughts have a significant influence on timing.

Interestingly, participants were still asking for absolute thresholds, despite earlier research (see Section 3.X) showing that nurses frequently ignore alarms in practice. Why do they want to know the exact alarm value in advance, when they are eventually not acting on it? This contradiction highlights the clear need for a shift in how nurses approach alarm management.

However, some participants started to understand the way of working and see the potential of the new smart alarm system:

“When the patient deteriorates, I would monitor tight, but adjust the target range, else the alarms will drive you crazy.” - P2

“I am satisfied with the proposed settings of the system” - P4

“A combination of the two concepts would be perfect, then you’ll be getting close!” - P4

Although participant 4 was already more involved due to two previous tests, this shows the importance of continued exposure and education to facilitate the adoption of this new alarm approach.

The envisioned alarm system discussed in section 3.X will only be effective when nurses understand what they configure and feel confident in doing so. They should **feel in control** to ensure that they can adequately work with the system and respond appropriately to its alerts. This iteration specifically focuses on providing that sense of control, while continuing to build a structure that is both guiding and efficient.

Initial sketches were created to explore potential solutions to the design questions (see Figure 6.12). One early idea involved a summary screen that shows the effect of the chosen main problem and risk level on organ monitoring. However, after discussion with the SASICU team, it was determined that an interactive, real-time overview would be more effective, allowing users to switch between settings and immediately see their impact.

6.3.1 Ideation and Prototyping

The primary design question during this iteration was:

How can the interface give the nurses a feeling of control about alarm configuration settings?

An important sub-question is:
Can visualising the impact of configuration choices enhance this perceived sense of control?

This concept was then developed into a low-fidelity prototype, shown in Figure 6.13. Due to time constraints, this low-fidelity prototype was not tested with ICU nurses. Instead, it was directly translated into a high-fidelity version to execute usability expert interviews.

Key Takeaways for next iteration

- Both concepts offered valuable elements which contributed to either a sense of guidance or efficiency. The next iteration should explore how to **combine** the strengths of both concepts.
- All participants expressed a need for more insight about what the **monitoring levels** actually entail. The upcoming design should focus on providing intuitive feedback or visual cues to help users understand the **impact of their configuration choices**.

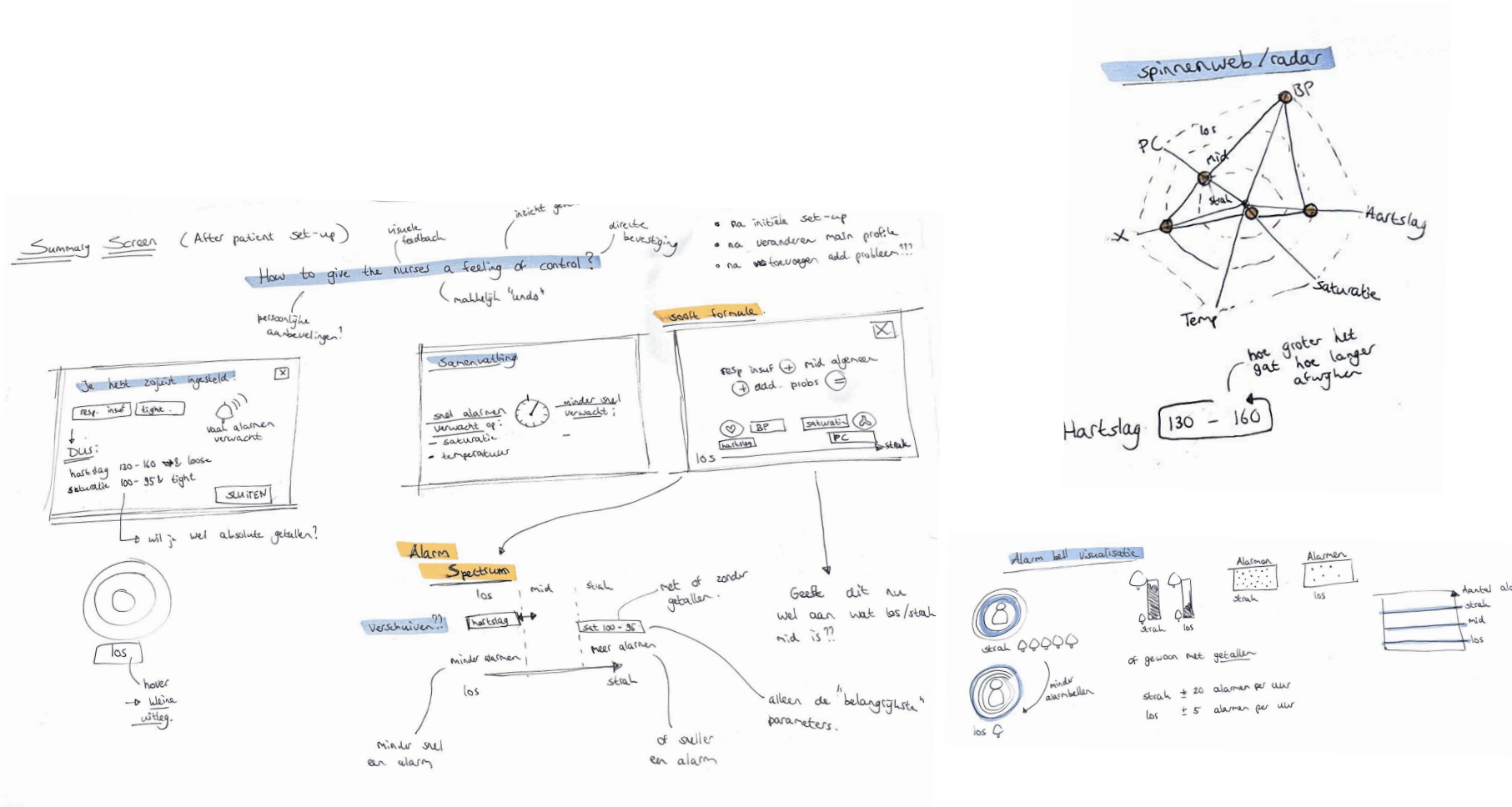
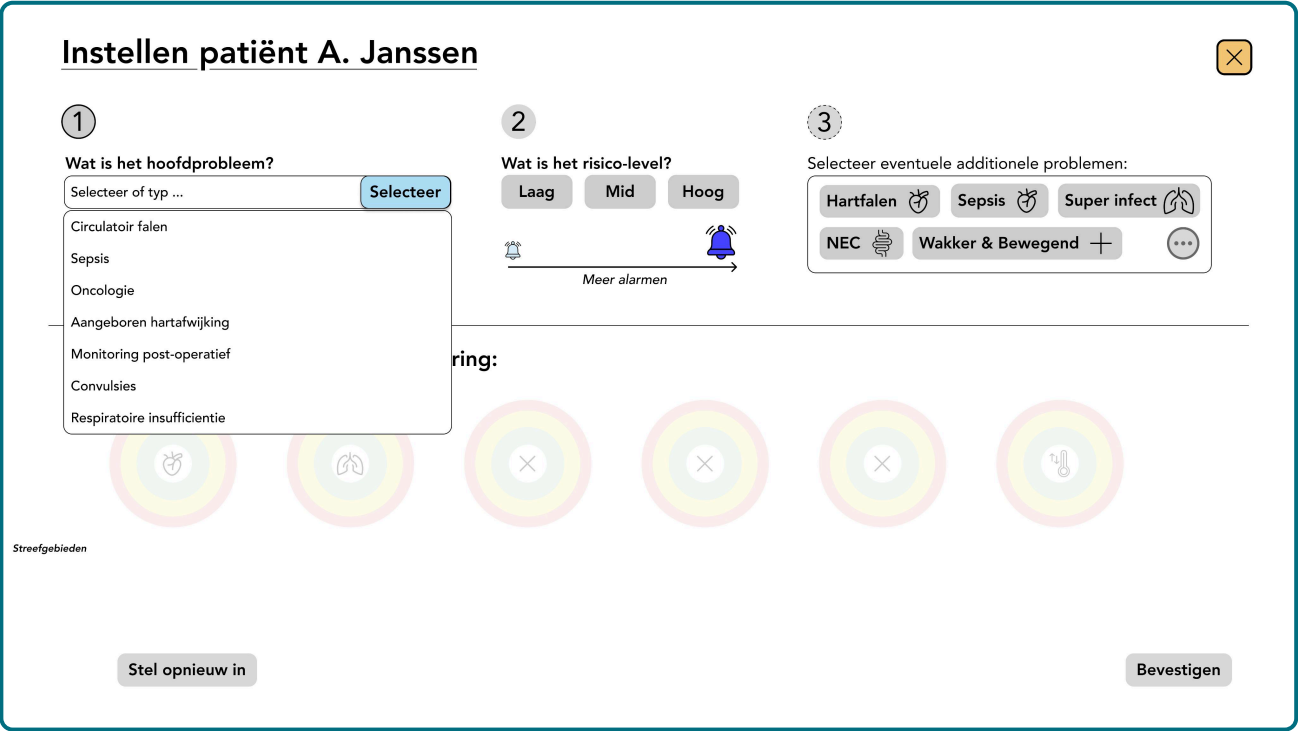


Figure 6.12: Exploring ideas for iteration 3.

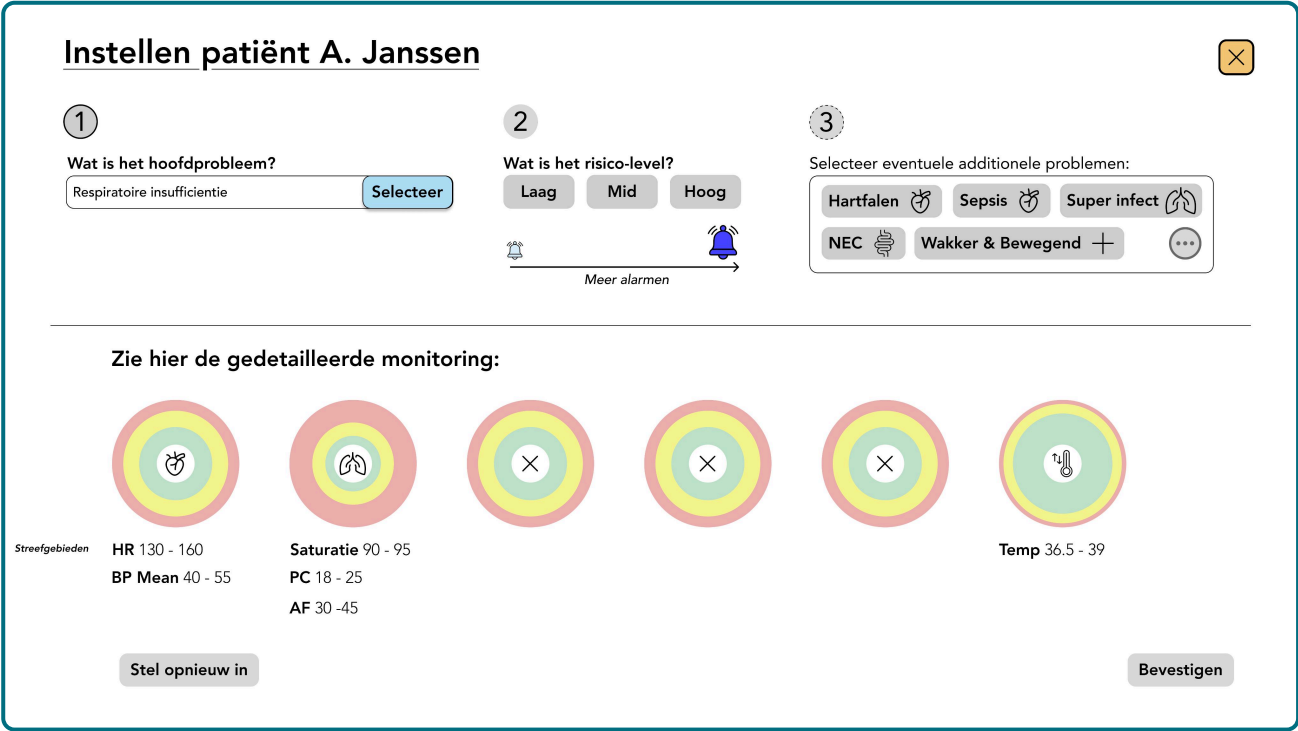
Low-fidelity Prototype - iteration 3

Set-up 1.1: Select the Main problem



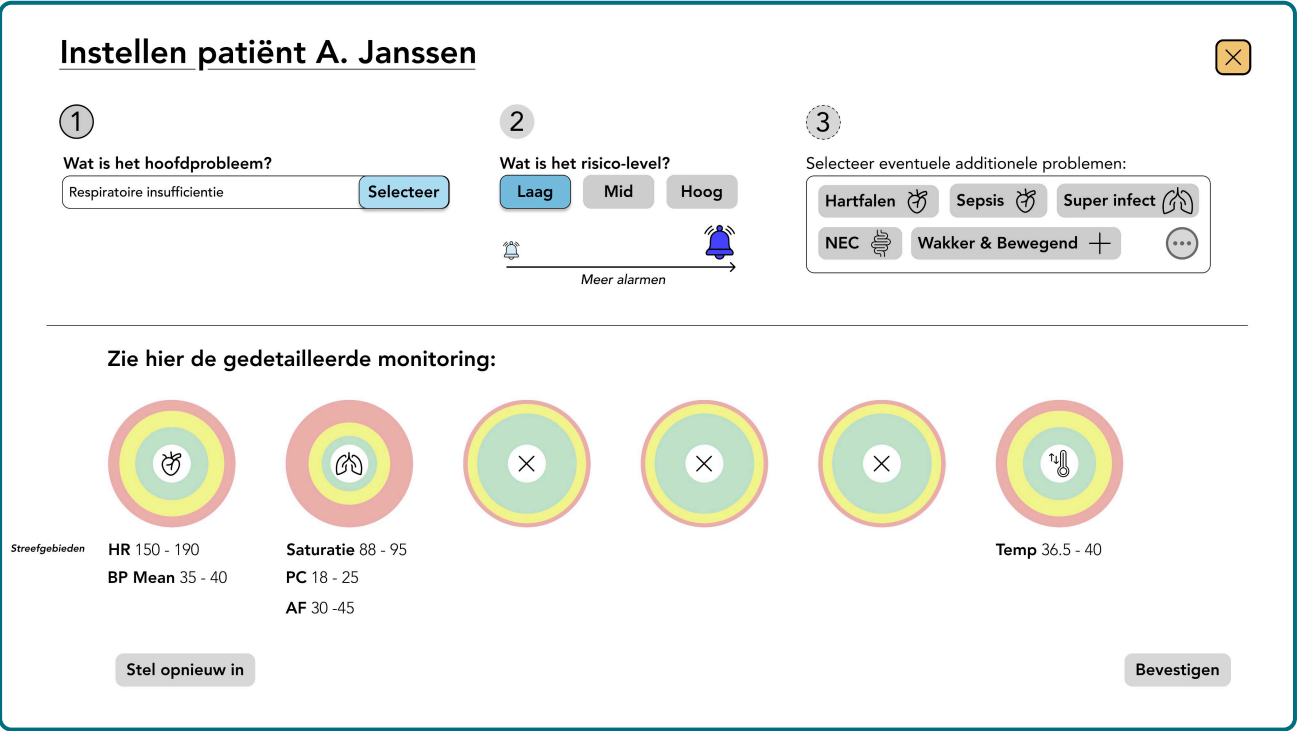
The user must select a main problem from the dropdown.

Set-up 1.2: See the effect of your choice



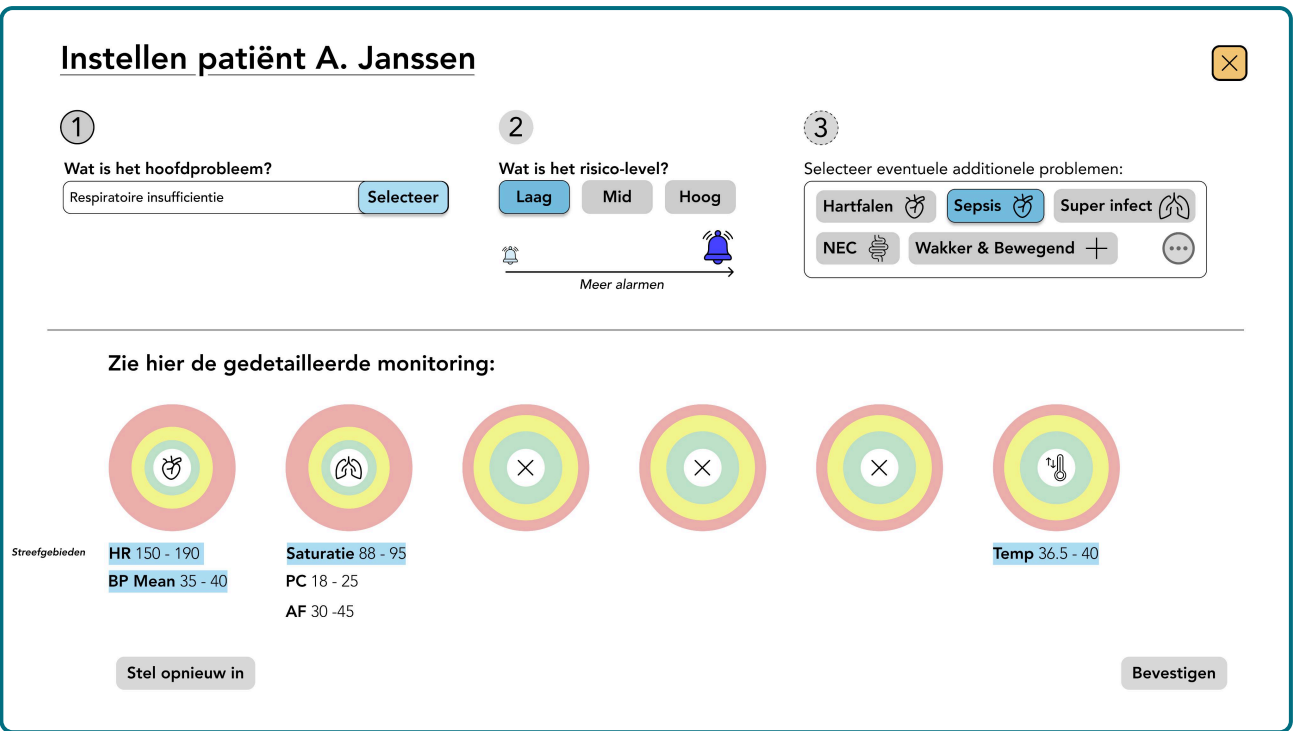
The user can see how the problem “Respiratory Insufficiency” influences the detailed monitoring below: the monitoring levels of organs and the target ranges for important parameters.

Set-up 2: Choose the risk level



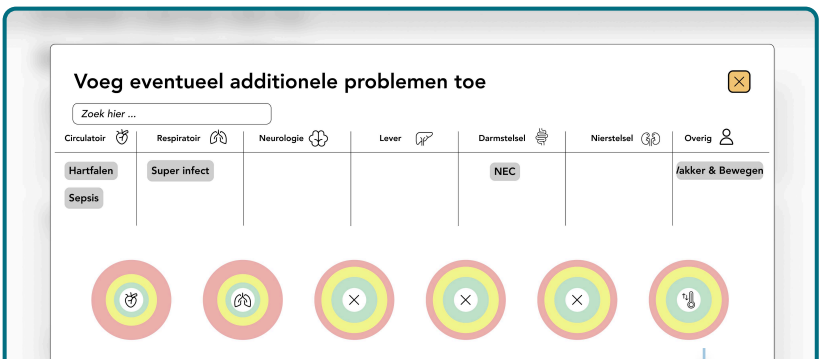
The user must select an overall risk level for the patient, for example “low”, and the monitoring levels change along real-time.

Set-up 3: Select optional additional problems



The user has the option to select additional problems, for example “sepsis”. As can be seen, the monitoring levels and target ranges change along real-time.

Pop-up Additional Problems



Overview of Alarm Settings



When the condition of the ICU patient changes or the user does not agree with the settings determined by the system, the user can change the settings immediately in this overview, or go more in depth by changing parameters.

Adjust circulatory target ranges



The user can fine tune the target ranges, and see how the monitoring level of the organ-system influences the target range graphs.

Figure 6.13: The low-fidelity prototype of iteration 3.

6.4 Transformation to a High-Fidelity Prototype

User Interface Design may seem like an easy task, especially when it is executed well. A successful interface may look very simple; however, the challenge lies in making a complex technical system intuitive and accessible to all its users.

To ensure the configuration interface developed in this project was as user-friendly and accessible as possible, UI design principles were consulted. Ben Shneiderman, an American Computer Scientist and professor, developed the Eight Golden Rules of Interface Design (2016). The principles are derived from his own experience and have been iterated over three decades.

These eight golden rules, as shown in Figure 6.14, serve as inspiration for the development of the high-fidelity prototype for this project's configuration interface. While every interface has its unique context and requirements, these guidelines provide a helpful starting point as they are relatively easy to apply. However, some rules, like those related to notifications and easy reversal of actions, would require too much time to prototype in Figma and, therefore, fall beyond the scope of this phase. The rules are intended to support the design process rat.

1

Strive for **Consistency**

• Terminology

• Buttons

• Colours & Fonts

2

Seek **Universal** usability

• Recognise diverse users

• Explanations for novices

• Shortcuts for experts

3

Offer **Informative** Feedback

• Visual feedback

• Results of the user's actions

• Also for minor actions

4

Design **Dialogs** to yield closure

• Confirm notifications

• Use of text

• Gives satisfaction of accomplishment

5

Prevent Errors

• Minimise the risk for errors

• Gray out unavailable elements

• Instructions for error handling

6

Permit **Easy Reversal** of actions

• Undo button

• Always possible to navigate back

• Go back to default

7

Keep users in **Control**

• Customisation

• Close notifications / pop-ups

• No undesired surprises

8

Reduce Short-Term **Memory Load**

• Avoid users having to remember information between two screens.

• Provide implicit help

UMC house style

The existing UMC/WKZ house style was selected as the style guide for the high-fidelity prototype to ensure alignment with UMC Utrecht's internal standards and facilitate further development and communication about the interface.

Primary colours:



Secondary colours:



Shapes:

Shapes are combined from sharp and round edges. Sharp and clear elements in the visual style reflect UMC's forward-thinking approach and decisiveness, while soft, rounded shapes express empathy, understanding, and a personal, attentive attitude.

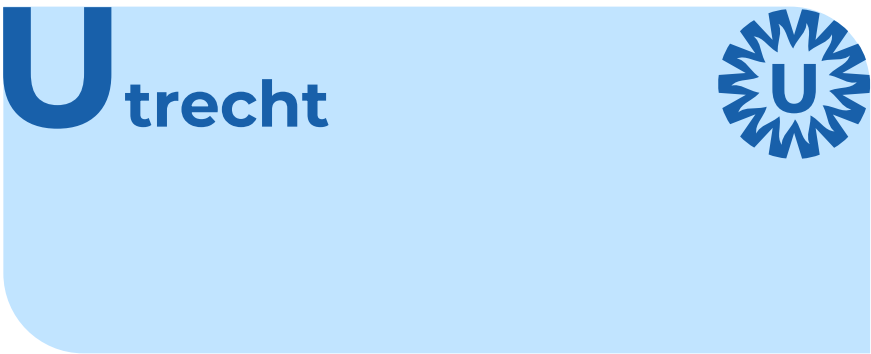


Figure 6.14: The Eight Golden Rules of User Interface Design (Shneiderman, 2016)

6.5 Usability Expert Interviews

Expert insight is essential when assessing the usability and effectiveness of a user interface design. Therefore, two interviews were conducted with usability experts from Ascom. Their input was especially valuable, as they not only have professional UX/UI experience but also understand the smart alarm system and clinical context, which is required to assess the interface content meaningfully. The research question of this evaluation was:

"How do usability experts perceive the usability and layout of the interface?"

Since Ascom's UX department is based in Sweden, the interviews were conducted remotely via Microsoft Teams. The first expert was both a UX/UI designer and a registered nurse, while the second held a senior UX designer role. Each expert was asked to complete four simple tasks (comparable to those described in Section 6.1.2) to interact with the prototype. Afterwards, seven open questions were asked, which can be found in Appendix H.

Results and Discussion

Figure 6.15 illustrates the annotated high-fidelity prototype incorporating expert feedback. During the weekly SASICU meeting, the most critical and feasible improvements were prioritised for implementation before the final evaluation with ICU nurses. While other remarks were acknowledged, they could not be addressed within the current project's timeframe and are therefore documented in the backlog (Appendix G).

General Impression

In general, both experts found the interface quite clear and simple. It provides a good overview by showing all the organ systems side by side, but it lacks the possibility to compare previous settings with current settings.

"It's quite clear to the point, I managed to do most of the tasks. Overall, this is a good way of trying to show the complexity of the system." - Expert 2

"I think it's quite simple. I like that I can see the changes when I select a setting, but I miss that I can compare them next to each other." - Expert 1

Navigation structure

The experts were able to navigate through the interface with ease, but the navigation structure was slightly ambiguous. Suggestions included avoiding redundant paths and adding clearer hierarchical cues such as a breadcrumb trail.

"You can dig deeper or go back to level one to have an overview, that's good." - E2

"It doesn't make sense to have two buttons which navigate to the same overview" - E1

"A general navigation bar might be redundant, because you will never configure two patients at the same time" - E2

Appearance and lay-out

The visual hierarchy should be improved. Buttons that perform different functions should not appear identical. Interactive elements such as sliders should offer a clearer call to action.

"I would rather keep less additional information labels on the screen, to get not blurred with options." - E1

"Do the headings need to be this big?" - E2

"I think I could have used the application for long time without understanding that it was draggable." - E2

Other Remarks

The experts highlighted the need for a 'save' or 'confirm' button. At the same time, the real-time feedback appears to support users in understanding how the system behaves, which is really important.

"I would like to play around first, to make sure that what I apply is actually what I want happening. You might want to add a save button to decrease the risk of someone setting something accidentally" - E1

"It's not an easy task, this is a really complicated interface to design." - E2

Key Takeaways for final design

- The prototype was perceived as clear and simple, but some improvements on visual hierarchy and navigation structure could enhance the usability of the prototype:
- The **navigation structure** can be improved by providing clear indicators of the user's current position within the interface.
- The **visual hierarchy** can be improved by sizing headers appropriately and ensuring interactive elements have clear, distinct appearances.

High-fidelity Prototype

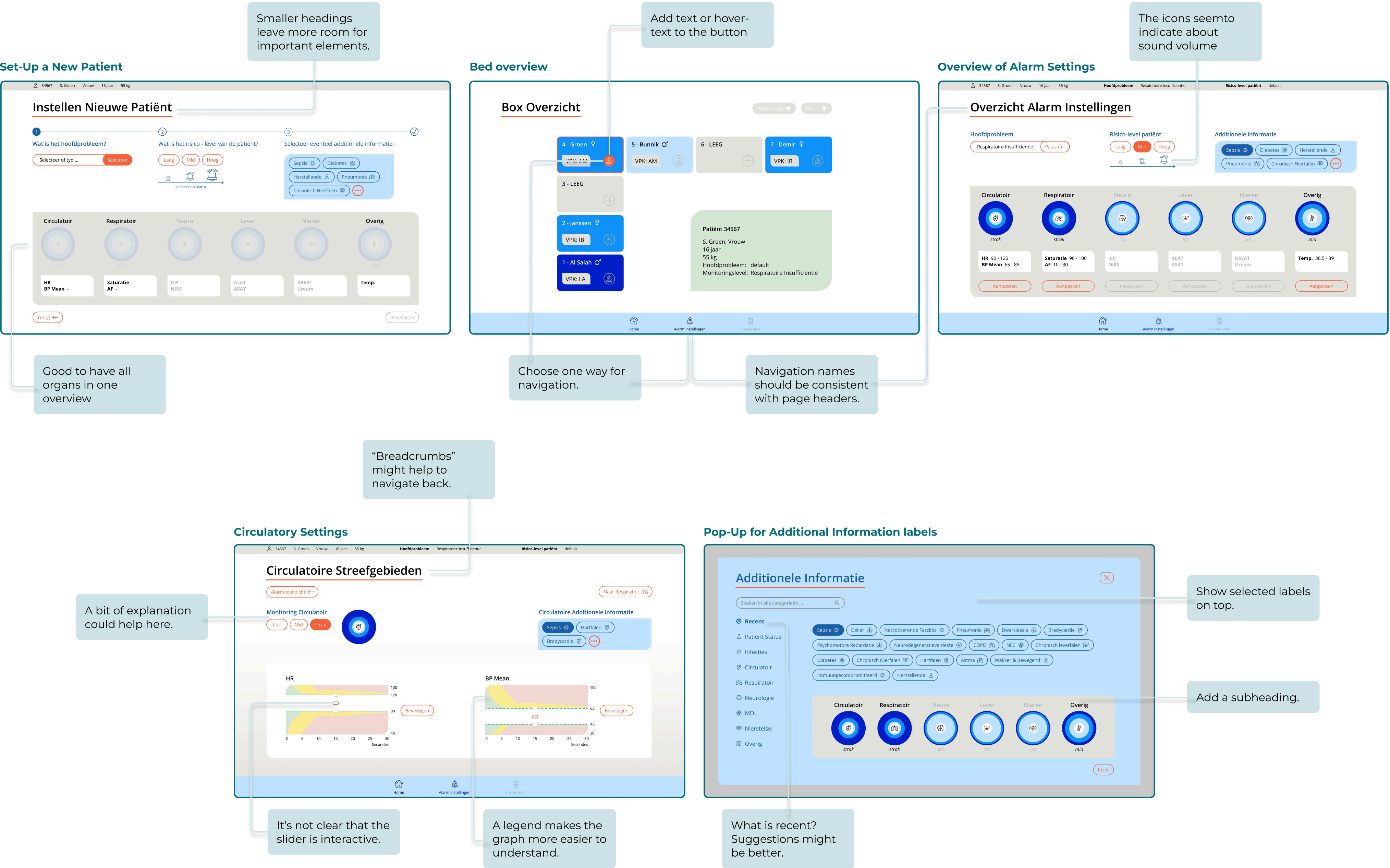
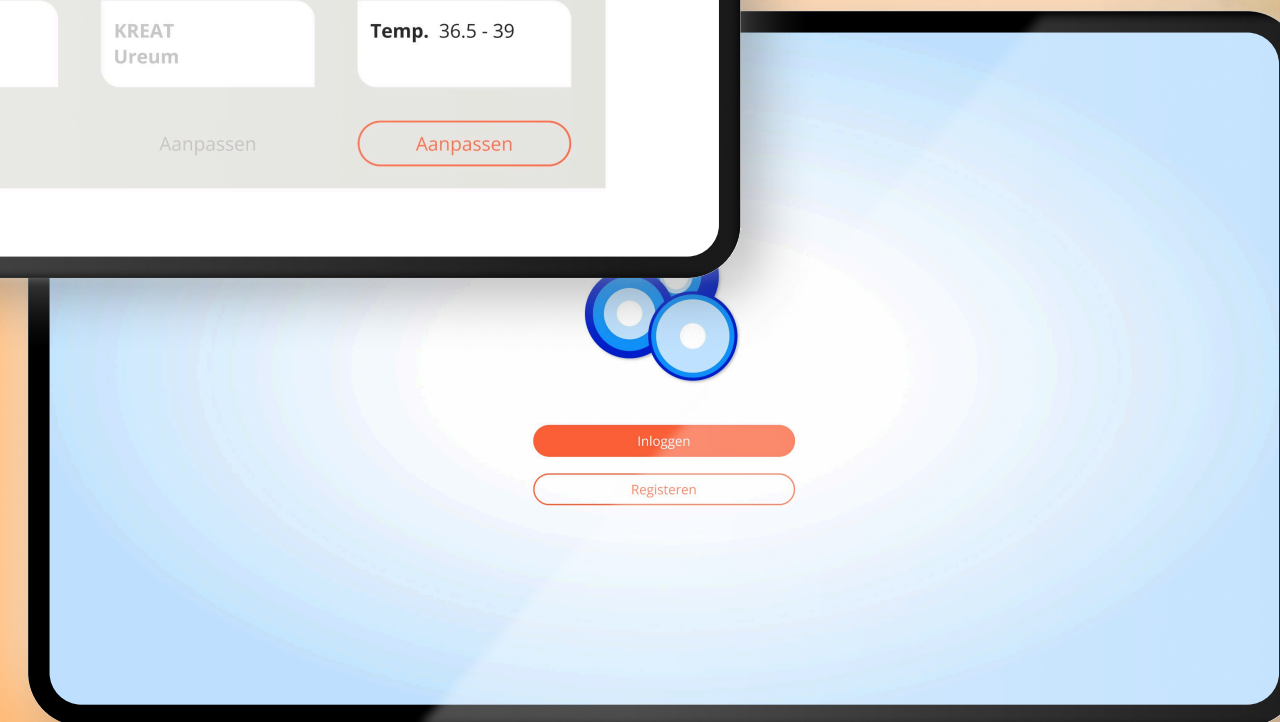
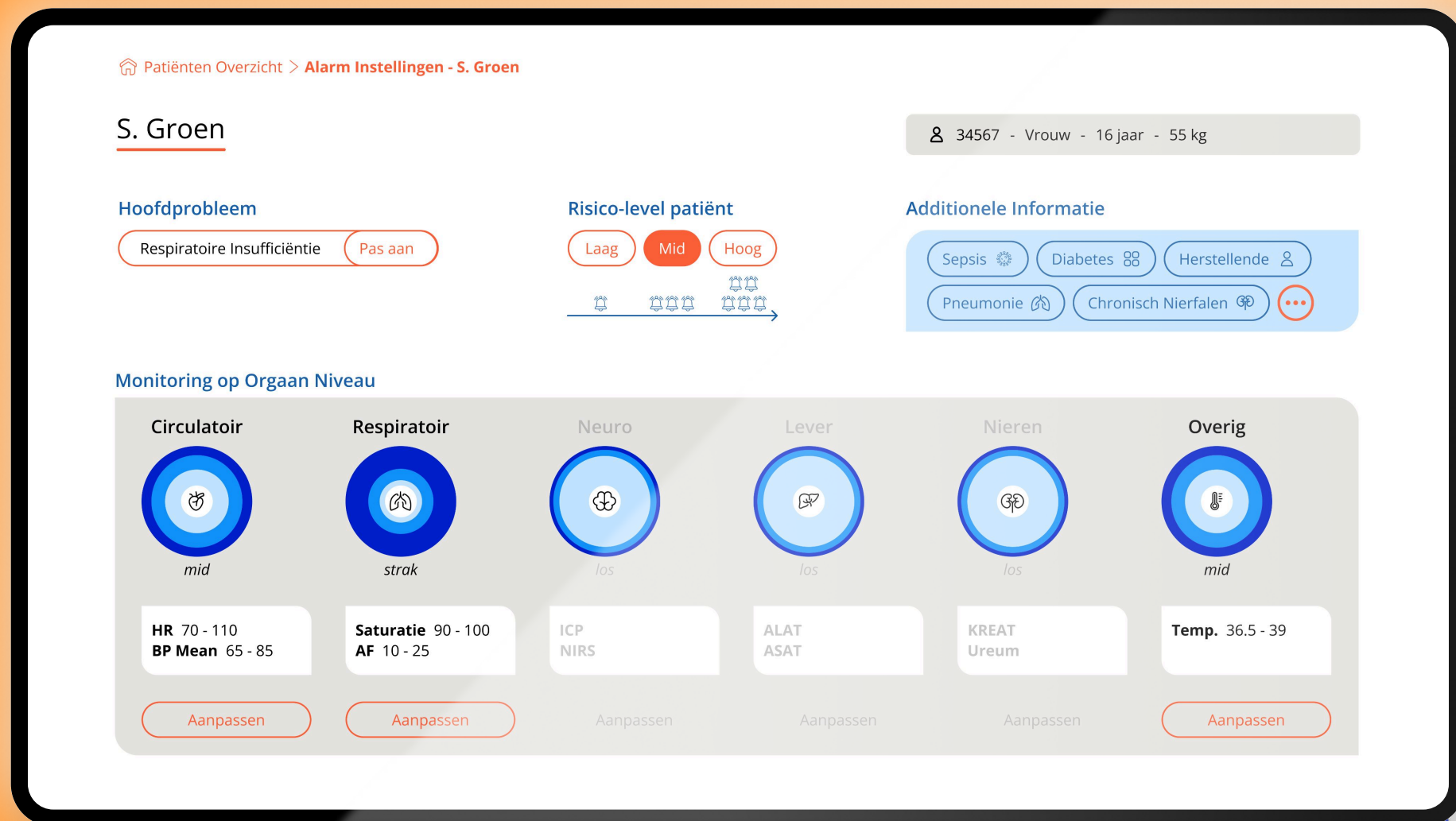


Figure 6.15: The high-fidelity prototype deriving from the low-fidelity prototype of iteration 3, and including expert feedback.



Make Alarm Configuration
easy. 

07

Final design

This chapter presents the final design: SetWise. Initially, an overview of the final design is provided, followed by a detailed walkthrough of each interface screen, including the key features. The chapter concludes with an explanation of how SetWise fits into the broader system architecture, including an explanation of the underlying algorithms.

7.1 The Design: SetWise

7.2 System architecture



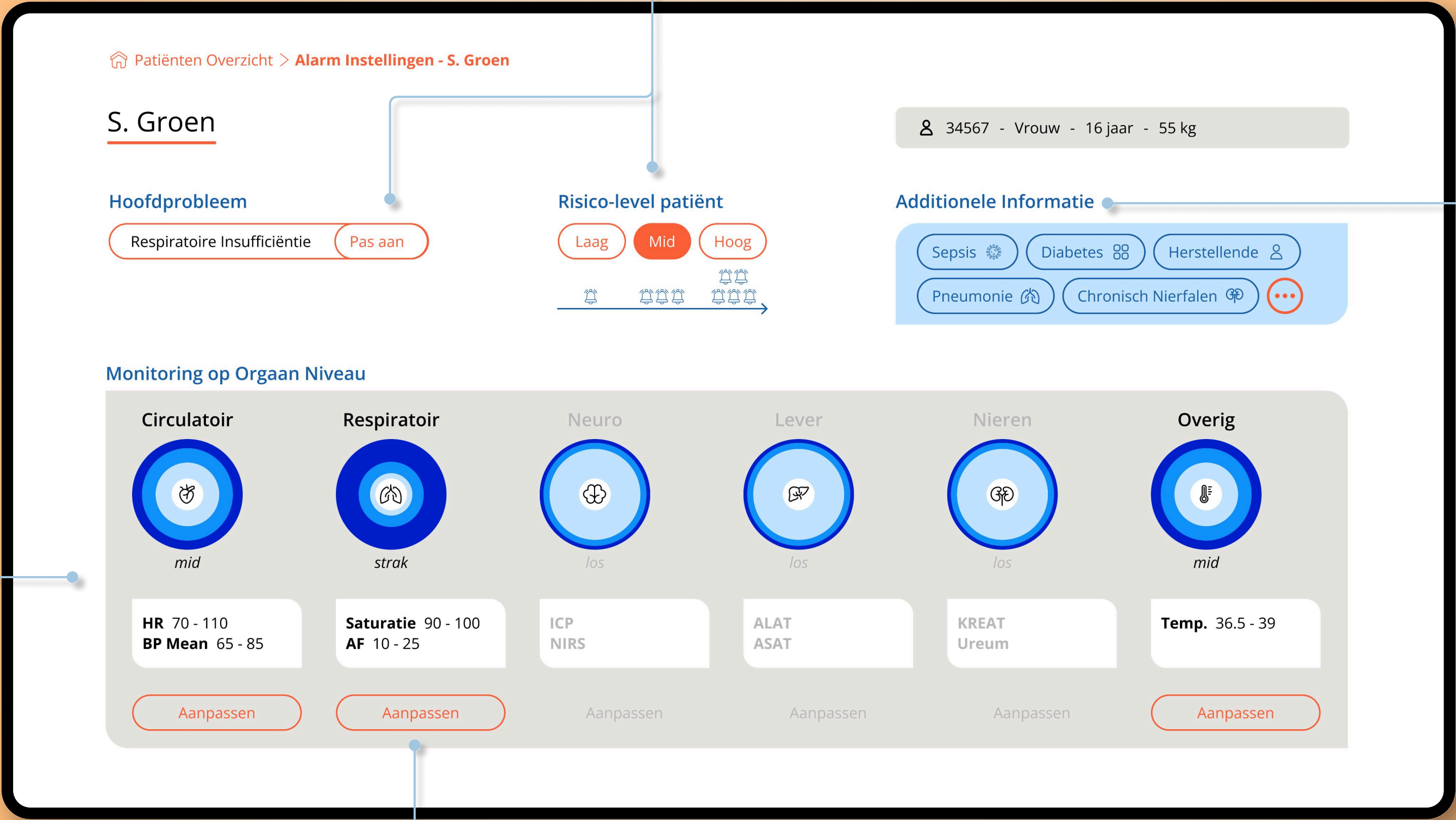
SetWise

SetWise is a **configuration interface** designed to support nurses in creating a personalised set of alarm rules for each patient, intending to reduce the overall alarm load in the ICU. While simplifying the configuration process, SetWise generates alarms that are both clinically relevant and context-aware. The interface acts as input for multiple algorithms to create the personalised alarm rules. SetWise is located next to the patient bed and can also be accessed from computers at the central nurse station.

[Click here to interact](#)

Two-Step Configuration

SetWise simplifies the setup process by guiding nurses through just two essential steps. Select the patient's primary clinical problem and risk level, and the system automatically configures detailed monitoring settings.



Clear overview

SetWise provides a comprehensive overview of the configured monitoring settings across all organ systems. This layout enables nurses to quickly verify or adjust settings without losing sight of the bigger clinical picture.

Context-Aware Shortcuts

Use the predefined additional information labels to add contextual details about the patient easily. These inputs further refine the configuration of target ranges and detailed monitoring levels, ensuring that the alarm settings accurately reflect the patient's current situation.

Dive deep, if desired

The proposed detailed monitoring settings can always be fine-tuned.

Patient Overview - Home

The patient overview serves as the landing page of the interface. It is the starting point for configuring a new patient, and acts as the home page to return to for an overview of all patients in the unit.

Add a new patient
To add a new patient, click the plus button of an empty bed.

Keep Overview

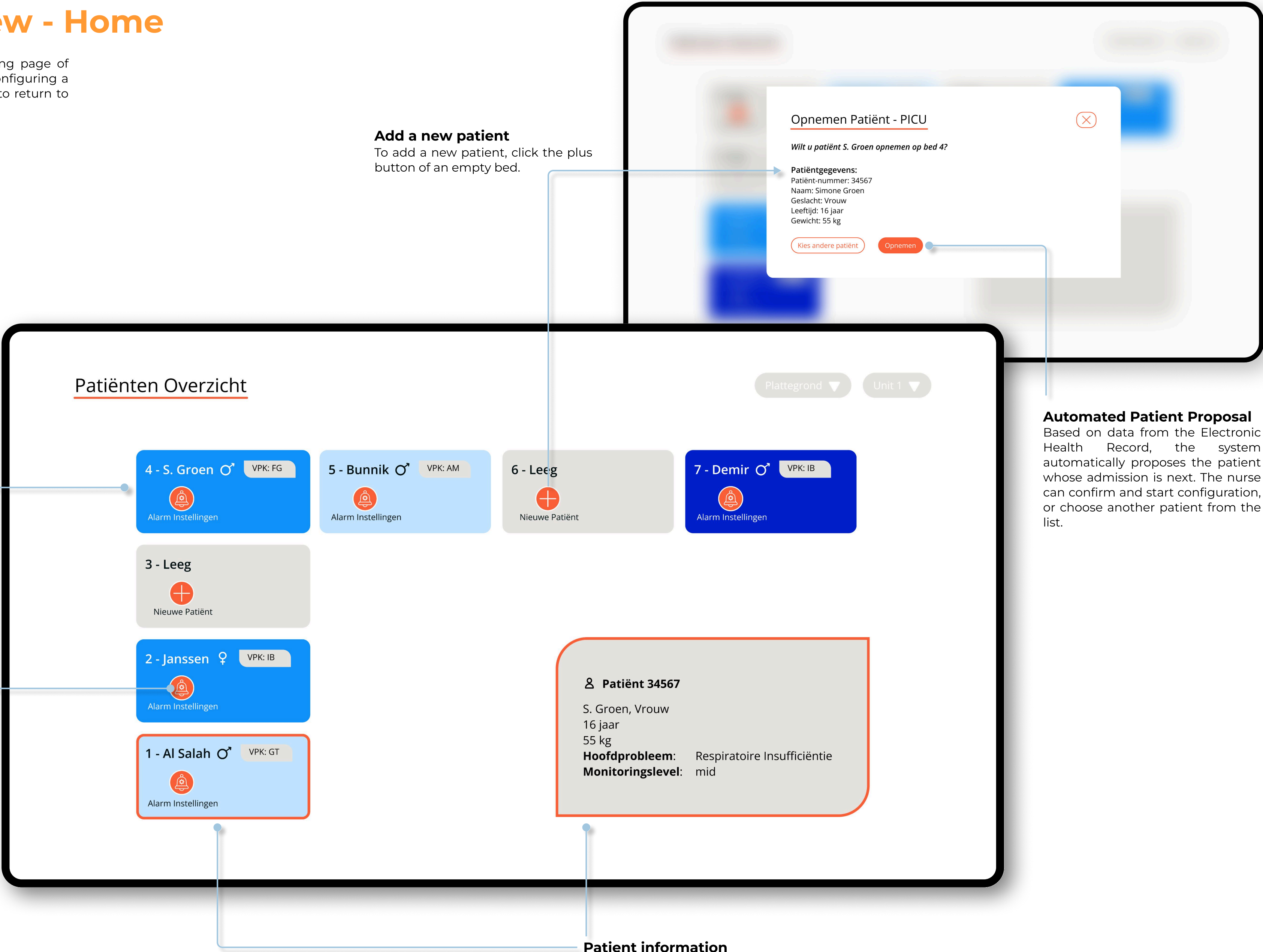
The home page enables an overview of all patients and their configured risk level, indicated by the colour of the beds.

- High Risk Level
- Mid Risk Level
- Low Risk Level

Patient Specific Settings

Easily navigate to the alarm settings of a specific patient by clicking the 'Alarm Settings' button.

Automated Patient Proposal
Based on data from the Electronic Health Record, the system automatically proposes the patient whose admission is next. The nurse can confirm and start configuration, or choose another patient from the list.



Patient information
View detailed patient information by clicking on the patient bed. This contextual information helps nurses make informed decisions about configuration.

Configure a New Patient

New patients are configured in just two mandatory steps. As the user progresses through the configuration, the detailed organ-system monitoring settings adjust in real-time, allowing for immediate insight into the **implications** of **each configuration choice**.

Step-by-step Guidance
The progress bar guides the user step-by-step through the configuration process.

The Higher the Risk, the More Alarms
The second step is to assign a risk level to the patient. This classification is used by the system's underlying algorithms to determine the sensitivity and frequency of alarm triggers.

The main problem

The first step is to select the patient's main clinical problem, which reflects the **main** reason for admission. This can always be updated in the general alarm settings overview if the patient's condition changes during the ICU stay.

Real-Time Adjustment

Once the main problem and risk level are selected, the system automatically adjusts the monitoring levels and corresponding target ranges for each organ system in real-time.

34567 - S. Groen - Vrouw - 16 jaar - 55 kg

Instellen Nieuwe Patiënt

1

Wat is het hoofdprobleem?

Respiratoire Insufficiëntie

Selecteer

2

Wat is het risico - level van de patiënt?

Laag

Mid

Hoog

sneller een alarm

3

Selecteer eventueel additionele informatie:

Sepsis

Diabetes

Herstellende

Pneumonie

Chronisch Nierfalen

Monitoring op Orgaan Niveau

Circulator

mid

HR 70 - 110

BP Mean 65 - 85

Respiratoir

strak

Saturatie 90 - 100

AF 10 - 25

Neuro

los

ICP

NIRS

Lever

los

ALAT

ASAT

Nieren

los

KREAT

Ureum

Overig

mid

Temp. 36.5 - 39

Terug

Bevestigen

Additional information

ICU patients can have complex pathologies and medical backgrounds. Nurses can further refine the configuration by selecting additional clinical information labels, and the detailed monitoring will automatically adjust.

Target Ranges

Each parameter displays a target range, which represents the values considered "normal" for a specific patient's condition, based on the main problem, additional information, and patient details.

94

95

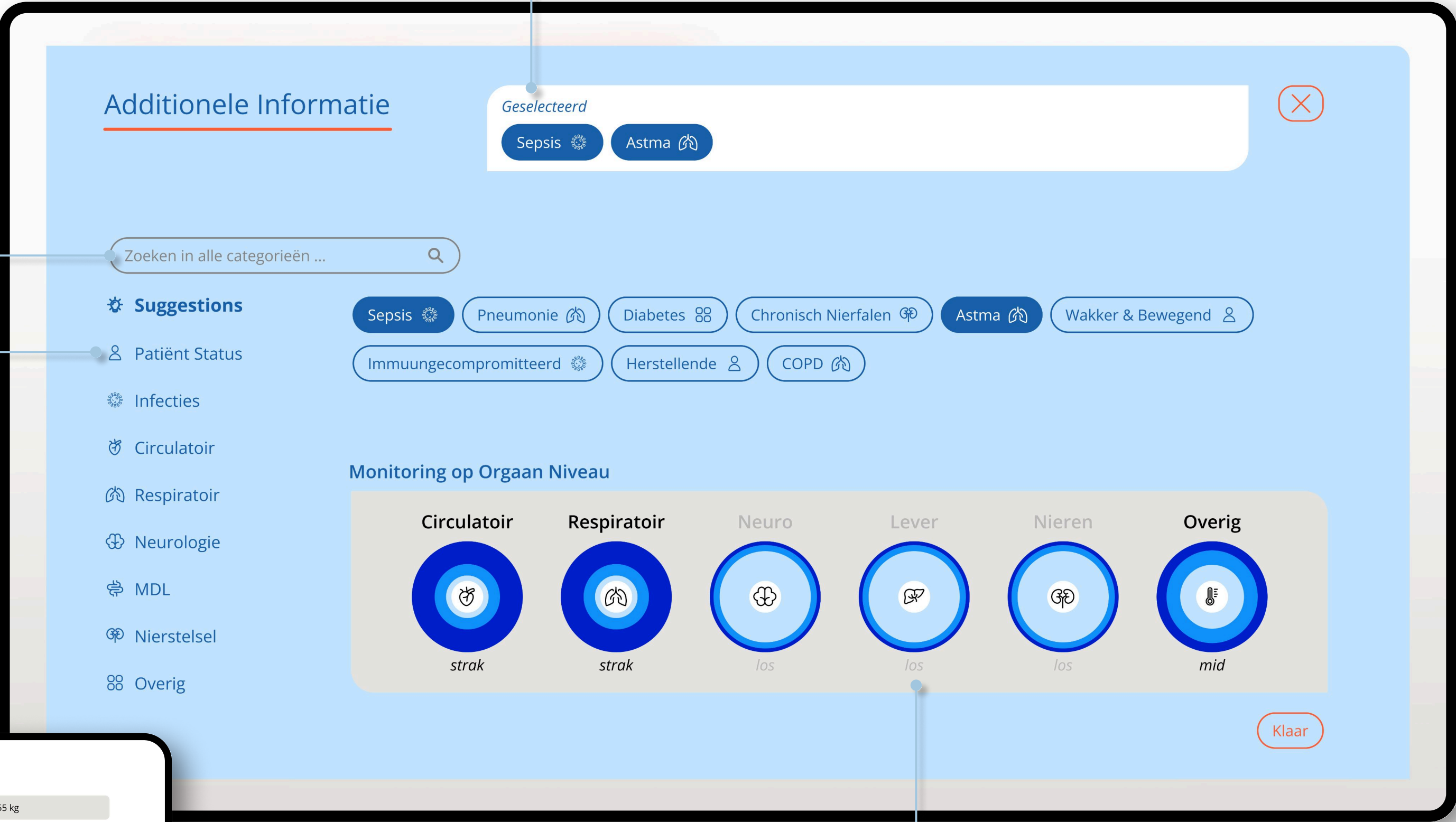
Additional Information Labels

After a new patient is configured, the user is redirected to the patient overview screen. From there, the alarm settings can be accessed and refined, such as the Additional Information Labels. These features enable users to add detailed clinical information, allowing for more precise configuration of individual patients.

Search all
Search across all categories using the general search bar.

Filter on organ system
The categories help to find the right information.

Selection on top
Selected labels are shown at the top of the screen, offering a clear overview of all applied labels.



Suggested Labels
Because the database of available labels is extensive, the interface shows only a limited set of suggestions based on the selected clinical problem and patient background. Users can expand this list by opening the pop-up.

Real-time Feedback
As additional labels are added, the system updates the monitoring levels and target ranges immediately to show the impact of each label.

Circulatory Settings

By going one level deeper into the settings, users can adjust the target ranges of vital parameters for the circulatory organ system.

Fine Tune Organ Monitoring

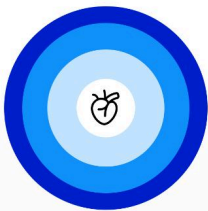
Although the system initially determines the monitoring level based on the patient's overall risk and clinical context, nurses can still manually adjust this level (loose, mid, or tight). These levels determine the system's sensitivity to deviations in vital parameters, which is visualised by the real-time adjustment of the target range graphs.

Patiënten Overzicht > Alarm Instellingen - S. Groen > Circulaire Monitoring

Circulaire Monitoring

Monitoring Level

Los Mid Strak



Never out of sight

The patient's information remains visible at the top of the screen to ensure that changes are always made for the right patient.

34567 - S. Groen - Vrouw - 16 jaar - 55 kg
Respiratoire Insufficiëntie - Risico: mid

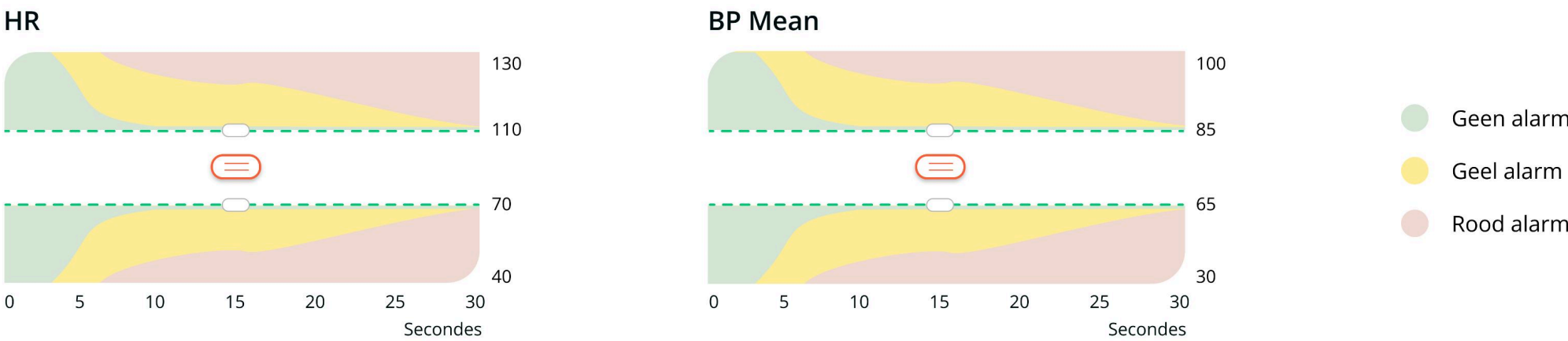
Circulaire Additionele informatie

Sepsis Hartfalen Bradycardie

Tailored Additional Information

Only relevant additional information labels that affect circulatory monitoring are shown.

Circulaire Streefgebieden Aanpassen

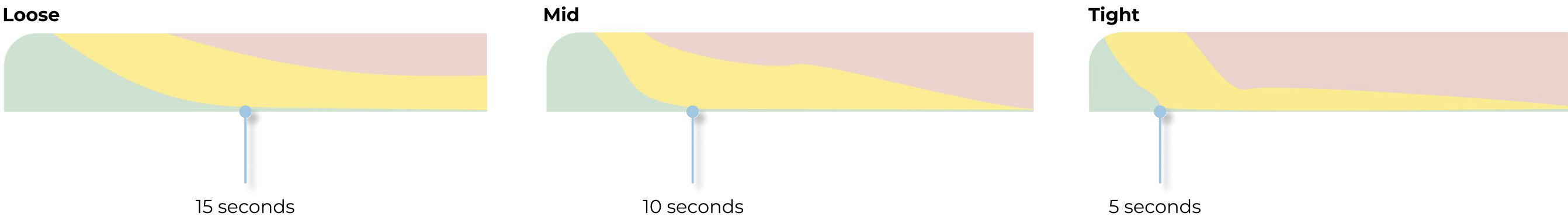


Alarm Instellingen ←

Naar Respiratoir

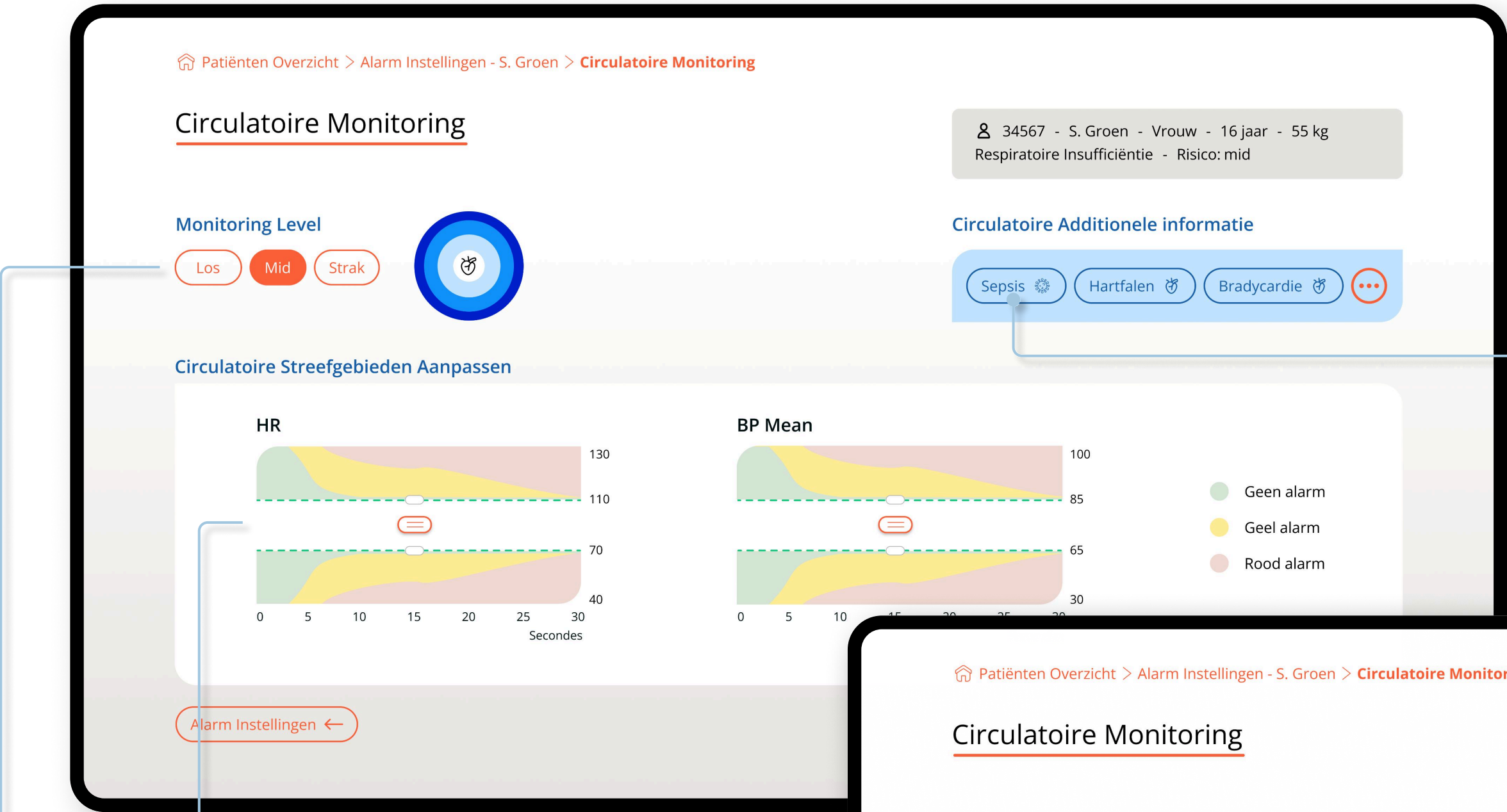
Next Organ System

Directly navigate to the other organ-systems.



Target Range Graphs

The graphs show how long it takes before a vital parameter exceedance will trigger an alarm. For example, if the monitoring level is set to loose, a small deviation will trigger an alarm after approximately 15 seconds. **Note:** if the deviation is large, the alarm may be triggered sooner.



See what you Set
Selecting an additional information label instantly updates **both** the target ranges AND the monitoring level, to show the implications of the label.

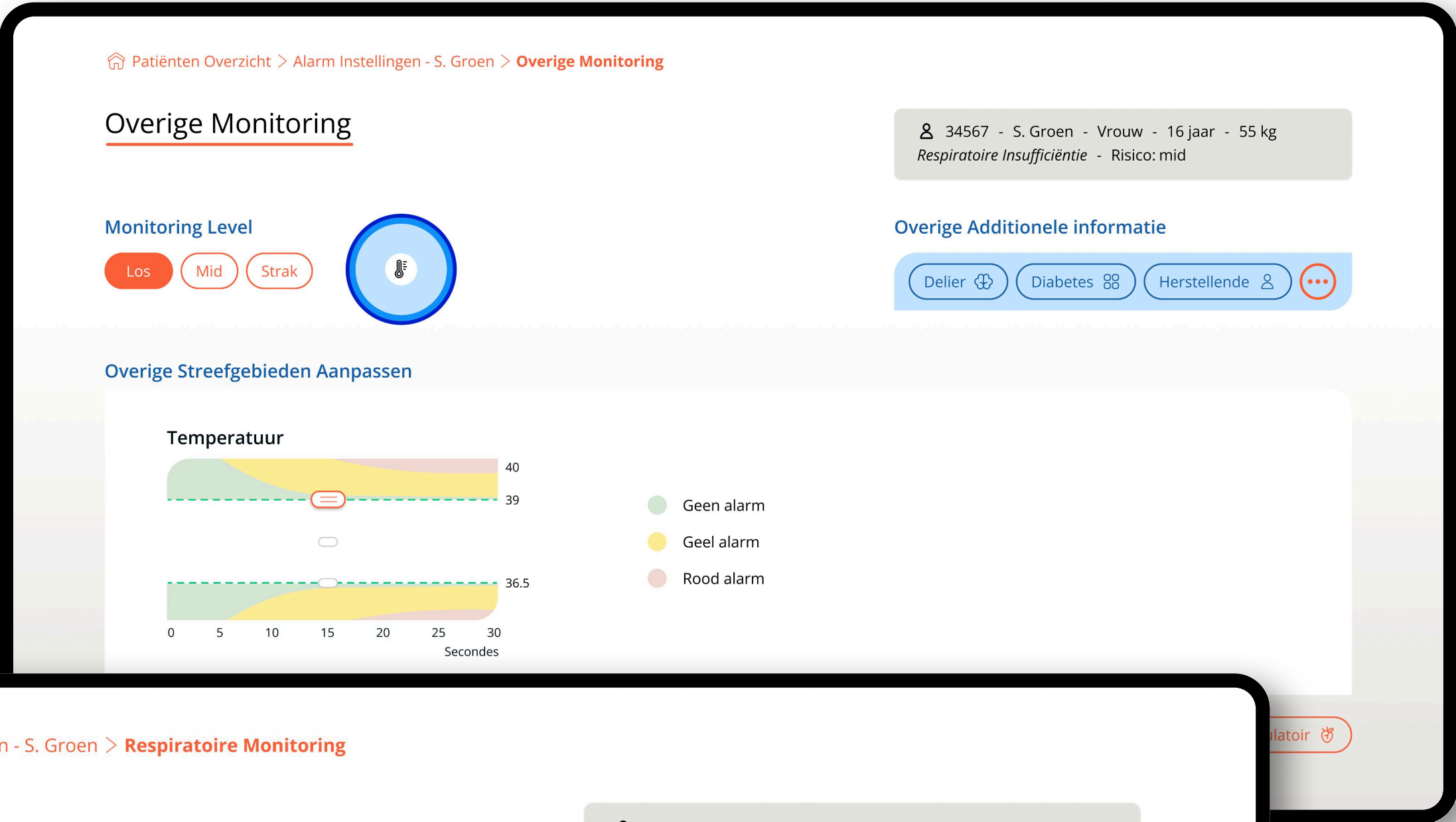
Automatically adjusted



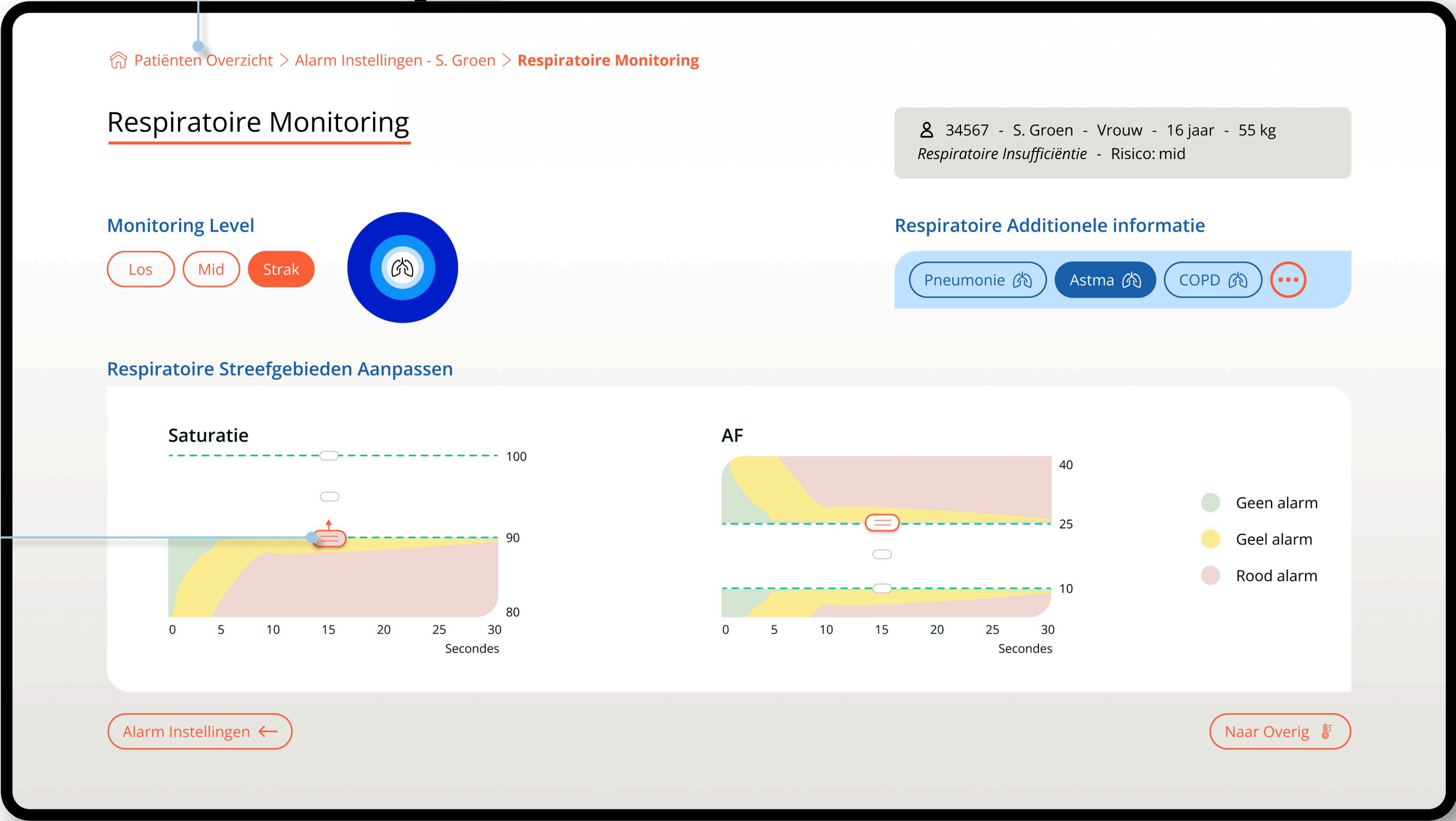
Respiratory & Other Settings

The Respiratory and Other settings follow the same structure as the circulatory settings to ensure a streamlined experience.

Keep track of where you are
The “breadcrumb” navigation helps to stay oriented and return to the patient or alarm overview with ease.



Hover & Slide
By hovering over the slider, arrows appear to guide the user to adjust to the desired target range.



7.2 System Architecture

The interface is part of a larger ecosystem, namely the envisioned future alarm system of UMC Utrecht (see Section 3.5.2). Figure 7.1 illustrates how the interface integrates with the other components. The system is not yet ready for deployment; the Smart Alarm Manager software still needs to be developed by Ascom, and the Brain module is still several years from completion. Nonetheless, this user interface enables UMC Utrecht to test the envisioned system with nurses, which is essential for deployment.

Component Functionality

The brain automatically populates the configuration interface with the patient's contextual information, the nurse only needs to verify and/or adjust this information. Using this context, the cerebellum then applies the appropriate alarm protocols; for example, it will allow a lower heart rate for patients with bradycardia. **The nurse stays in control, and may always fine tune** these target ranges. For an initial deployment, the system could also function without the Brain component. The configuration interface can directly request the Cerebellum to select the right alarm protocol, using the main problem and additional information provided by the nurse. In either scenario, the contextual data, configuration settings, and chosen protocol are forwarded to the Smart Alarm Manager software, where the core algorithms are executed.

The primary purpose of these algorithms is to generate a set of patient-specific alarm rules, which the Smart Alarm Manager then uses to determine whether an incoming alarm should actually be raised. The algorithms use the input of the configuration interface (and Brain) to create these alarm rules. The depth-duration algorithm combines contextual information with the risk level of organ systems to calculate both how deep and for how long each vital parameter may deviate from its target. Meanwhile, the data-knowledge platform utilises alarm protocols and contextual patient information (including the main problem and additional labels) to generate personalised target ranges. Together, these algorithms produce the combined output: personalised alarm rules to eventually reduce the alarm burden in the ICU.

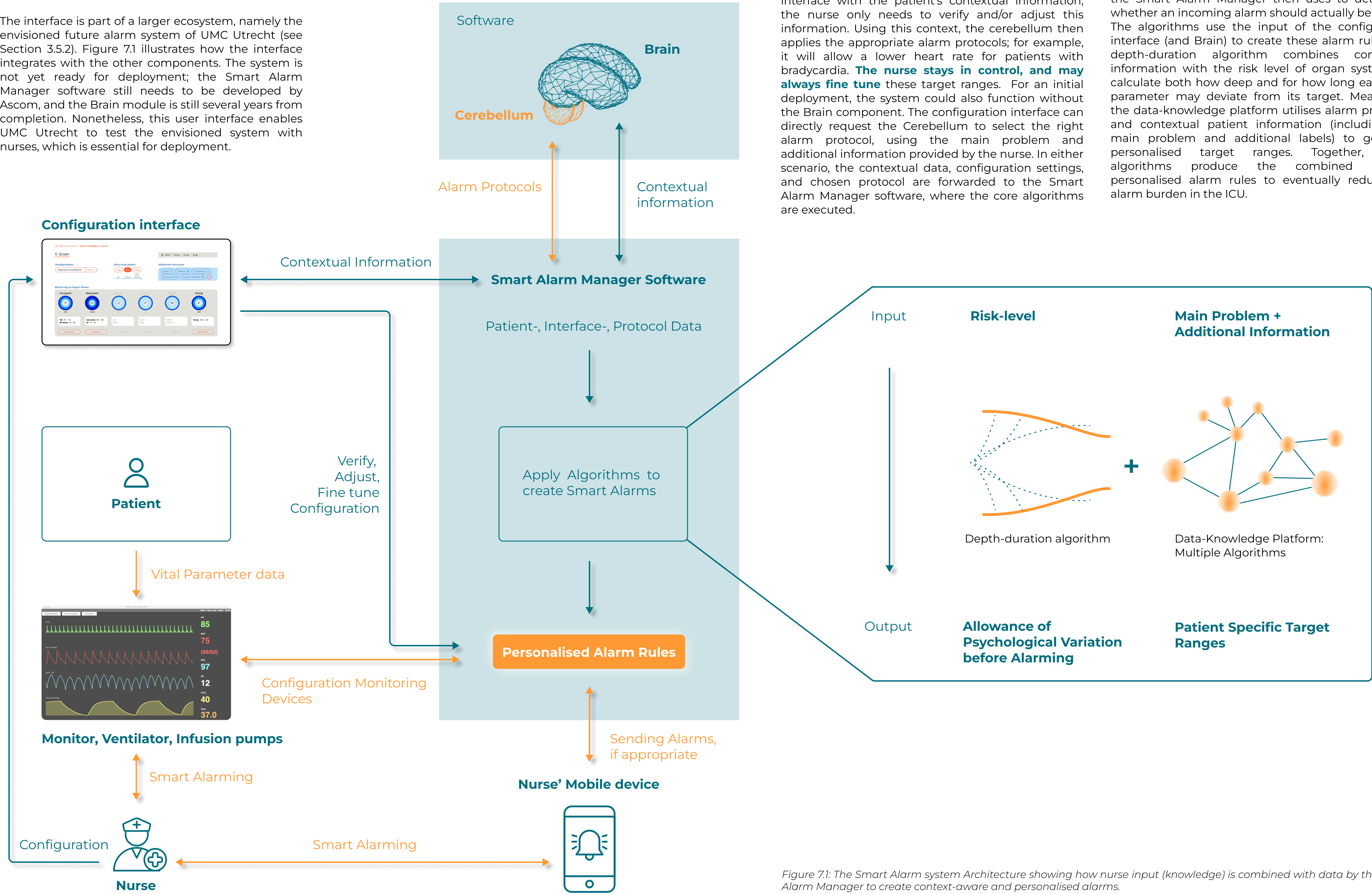
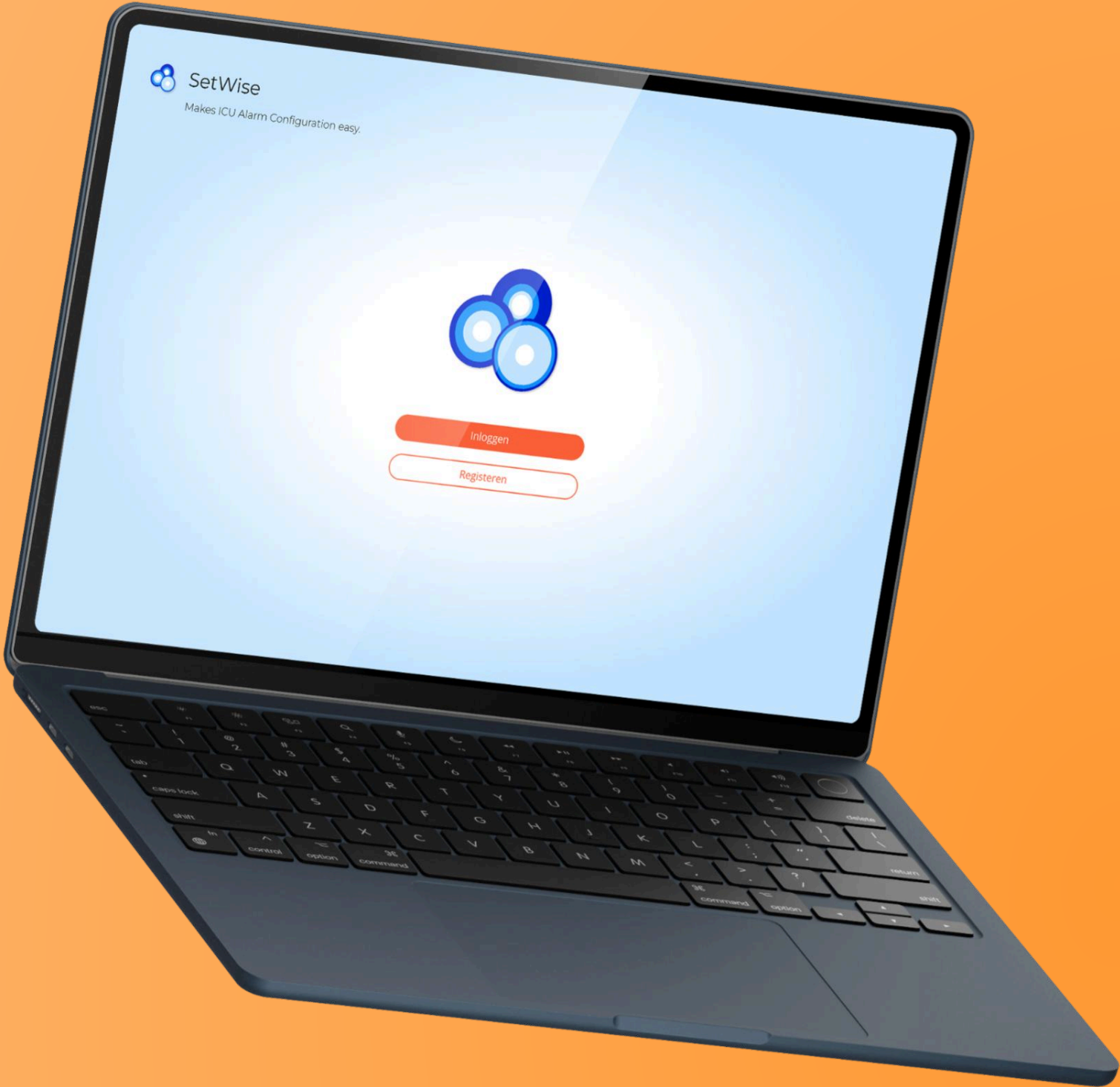


Figure 7.1: The Smart Alarm system Architecture showing how nurse input (knowledge) is combined with data by the Smart Alarm Manager to create context-aware and personalised alarms.

Accessible anywhere, from any screen



[Go to Prototype](#)

08

Evaluation

This chapter presents the evaluation of the final prototype, conducted with eight ICU nurses. The evaluation consists of four parts: a task-based interaction with the prototype, assessment of the system's outcomes, questionnaires and a small interview. The purpose of the evaluation is to assess whether the design goal has been achieved.

- 8.1 Test procedure
- 8.2 Results
- 8.3 Discussion
- 8.4 Conclusion



8.1 Test Procedure

The goal of this evaluation is to assess whether the final prototype meets the design goal of this project: *“Prototype a graphical user interface which **guides** ICU professionals to **efficiently** set up alarms for patients, which provides **confidence** that they can safely monitor patients from a distance.”*

Although actual patient safety cannot be measured within the scope of this project (and the system is not ready for clinical implementation), we can assess whether nurses feel in control of the system, which is required for trust and adoption. So, the design goal can be divided into three core evaluation criteria, which also serve as the basis for the **main research questions** of this evaluation:

- 1. Guidance** - Does the interface provide sufficient support and information while configuring alarm settings?
- 2. Efficiency** - Does the interface enable nurses to configure alarms in an intuitive and streamlined way?
- 3. Confidence** - Does the interface provide nurses with a sense of control of the system?

Additionally, this led to the following **subquestions**:

- 1. Is the interface easy to use?
- 2. Do nurses comprehend the information presented on the screen?
- 3. Does the system behave as nurses expect it to?
- 4. Do nurses comprehend the concept of target ranges and their implications?

The evaluation consists of four parts. The full evaluation plan can be found in appendix I.

Part 1: Interaction with the prototype

The participants are presented with a clinical scenario that evolves over four steps: the patient is admitted to the ICU, experiences deterioration, and eventually recovers. For each step, participants are asked to interact with the final prototype to configure appropriate alarm settings. The scenario is printed and provided beforehand. Participants are instructed to **think aloud** during the task to help identify how they navigate through the interface, how they interpret information, and what design elements support or hinder their understanding.

Part 2: Monitor simulation

To explore whether participants feel in control of the alarm system, it is essential that they can see the **output of their configuration**. Ideally, this would be tested by connecting the final prototype to the Digital Patient Twin, thereby simulating a real-time patient monitor (see Section 1.2). However, due to technical and time constraints, it was not feasible to develop a working front-end from the Figma prototype and connect it to the Python-based simulation model.

Instead, four static screenshots (A to D) derived from the simulated monitor are used to mimic this experience (see Appendix J). Additionally, participants are provided with corresponding trend data of the patient, enabling them to make well-informed estimations about the likelihood of alarms occurring. The four monitor screenshots depict a patient's deterioration based on the same clinical scenario of the first test part. Screens A and C show minor deterioration, where an alarm is unlikely to be triggered by the future alarm system, while Screens B and D illustrate more significant deterioration, where an alarm will probably occur. Participants are asked to assess whether an alarm would be **expected** based on their configurations during task completion (written down by the test executor), and whether such an alarm would be **desired, informative**, and **clinically actionable**. This test part determines whether the system behaves in line with the expectations of users.

Part 3: Questionnaires

The participants are asked to complete two questionnaires following the interaction tasks (Appendix K). First, the validated AttrakDiff questionnaire, which measures overall user satisfaction by assessing both pragmatic and hedonic quality of interactive products (Hassenzahl, 2003). It contains 28 pairs of opposite terms, in which the participant must rate which verb is more applicable to the prototype on a 7-point scale. The terms are divided into four categories: pragmatic quality (PQ), Identity (Hedonic Quality-I), Stimulation (HQ-S) and Attractiveness (ATT). The second questionnaire contains direct statements related to the design goal and ease of use. Participants have to indicate their level of agreement with each statement using a 7-point scale.

Part 4: Small interview

In the final part, several open-ended questions are asked to complement the other test parts with qualitative insights about participants' experiences with the prototype. This is to determine which specific interface elements contribute to (or do not contribute to) the validation of the design goal.

Participants

To ensure a diverse participant group, four participants of the adult ICU were recruited (by the manager), and four participants of the PICU were recruited by the Paediatric Intensivist of the SASICU project (see table 8.1). In contrast with earlier evaluations (described in Chapter 6), participants were not necessarily selected based on their openness to innovation. Additionally, none of the participants had participated in earlier tests to avoid bias and to ensure consistent testing conditions. Therefore, a short introduction to the envisioned future alarm system is provided. Due to the unpredictable and hectic ICU context, recruitment

Table 8.1: Test participants of the final evaluation test.

Department	Participant	Work Experience	Gender
PICU	1 - Senior Nurse	> 30 years	Male
	2 - Senior Nurse	> 20 years	Female
	3 - Junior Nurse	< 5 years	Female
	4 - Medior Nurse	10 years	Female
Adult ICU	5 - Junior Nurse	5 years	Male
	6 - Medior Nurse	10 years	Female
	7 - Medior Nurse	10 years	Male
	8 - Medior Nurse	5 - 10 years	Male

was based on staff availability. Despite this, efforts were made to include a diverse group of users.

Physical Test Set-Up

The evaluation took place in a mimicked clinical setting to simulate actual working conditions. PICU participants were tested in the WKZ simulation room (Figure 8.1), while adult ICU participants were tested in

an empty patient room. The interface prototype was displayed on a desktop computer positioned next to the hospital bed, and a simulated monitor screenshot was shown on a nearby second screen, mimicking a real bedside configuration.



Figure 8.1: The test setup in the simulation room at WKZ, with on the left the prototype, and on the right the simulated monitor.

8.2 Results

This section presents the key findings from each component of the evaluation. Full calculations and additional details are available in Appendix L.

Task Completion

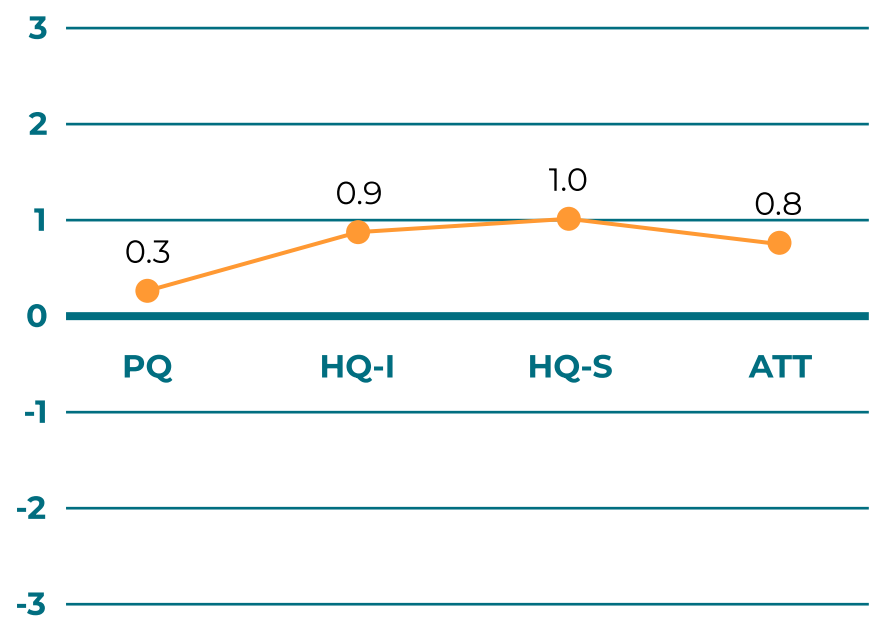
All eight participants successfully added a new patient and configured the alarm settings according to the clinical scenario. They were generally able to progress through the tasks independently. Only in one or two cases did the test facilitator need to provide a brief hint or clarification.

Monitor Simulation

During this component of the evaluation, participants assessed four screenshots (A–D) depicting simulated vital sign trends and were asked to determine whether an alarm would be expected. Participants showed a high level of agreement in their responses. For screenshots B to C, their estimations were aligned well with the expected behaviour of the future alarm system. However, for screenshot A, which presents a small deterioration in oxygen saturation, many participants expected an alarm, even though the new system would likely suppress it.

AttrakDiff Questionnaire

Figure 8.2 displays the mean scores of the four different categories from the Attrakdiff questionnaire. All categories scored between 0.3 and 1.0, indicating neutral to positive perceptions. Figure 8.4 presents detailed results from all individual participants across the 28 opposing word pairs. The scores are notably distributed across participants. This is confirmed by the relatively high standard deviations shown in Figure 8.2. In general, participants from the adult ICU tended to be more critical about SetWise than PICU participants.



PQ = Pragmatic Quality (STD = 1.3)
HQ-I = Hedonic Quality - Identity (STD = 0.5)
HQ-S = Hedonic Quality - Stimulation (STD = 0.7)
ATT = Attractiveness (STD = 0.8)

Figure 8.2: Mean scores for the AttrakDiff categories.

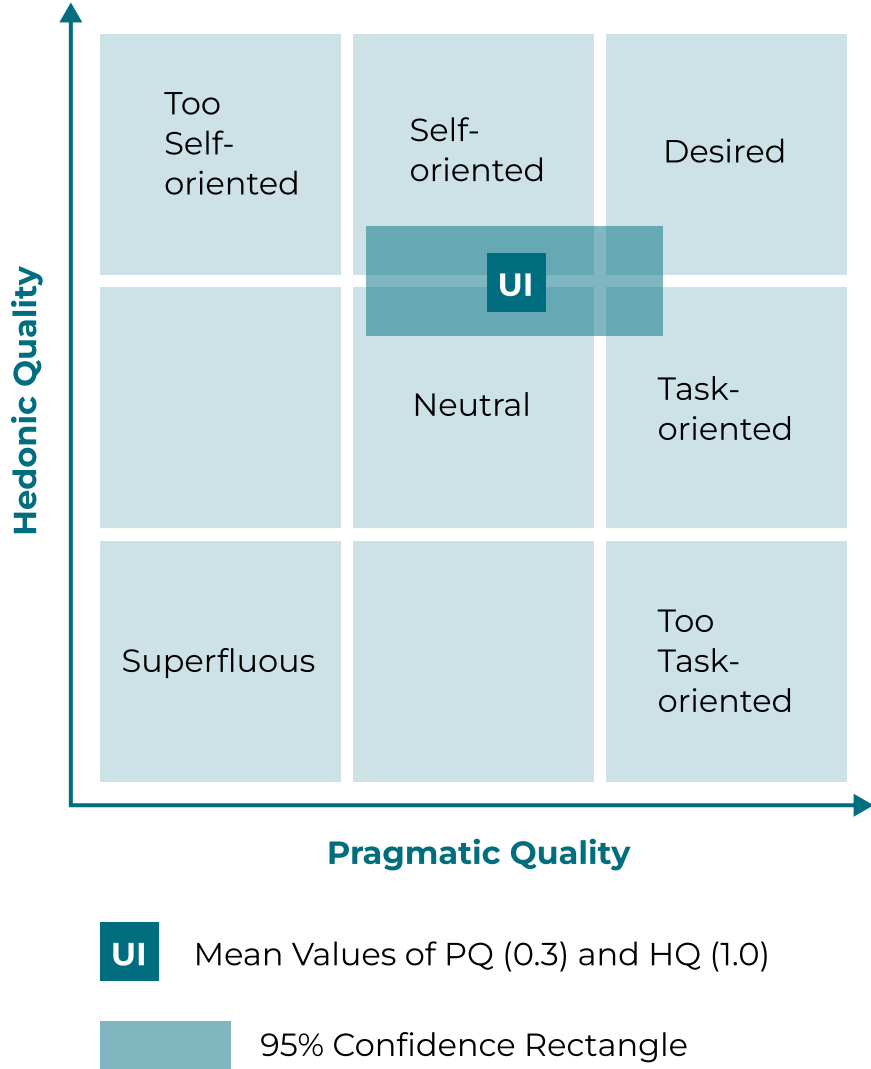


Figure 8.3: The position of SetWise within the Attrakdiff Portfolio framework, including 95% confidence interval.

Figure 8.3 illustrates the overall positioning of SetWise in the AttrakDiff portfolio framework, which is a two-dimensional diagram visualising the overall user experience. The mean values obtained from the responses are PQ = 0.3 and HQ = 1.0, indicating a slightly positive perception of usability and a moderately strong hedonic impression. A 95% confidence rectangle has been added to indicate the variation in user responses. This area extends across four zones in the diagram: Neutral, Self-oriented, Task-oriented, and Desired, reflecting a wide range of user experiences, especially on the pragmatic quality axis. However, the central tendency of the scores falls within the Self-oriented and Neutral regions, suggesting a product that is perceived as expressive and engaging, though not consistently task-focused.

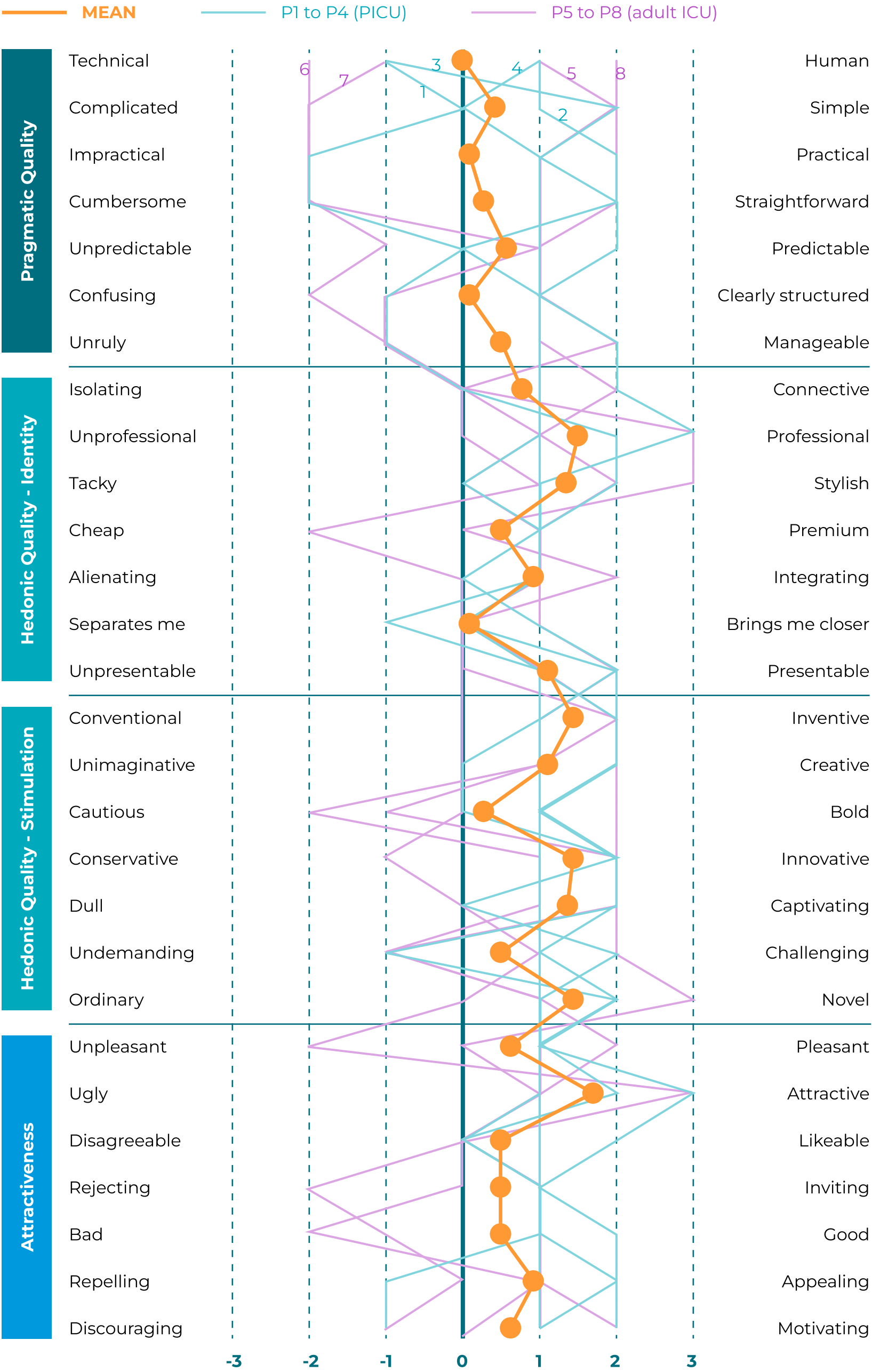


Figure 8.4: The individual participant and mean ratings on the Attrakdiff opposite terms, across four categories.

Design Goal Validation Questionnaire

Figure 8.5 presents the mean scores and standard deviations from the design goal validation questionnaire. The responses show high variability, as indicated by the standard deviations.

Scores for **usability** were the highest, particularly in terms of the interface's understandability, which scored positively (mean = 5.5). Participants reported a relatively low sense of control, however, they were quite **confident** about the system's behaviour (mean = 4.8). **Efficiency** was rated around neutral, with mean scores of 4.1 and 4.5. **Guidance** scored the lowest, with both questionnaire items falling slightly below neutral (mean = 3.8 and 3.5).

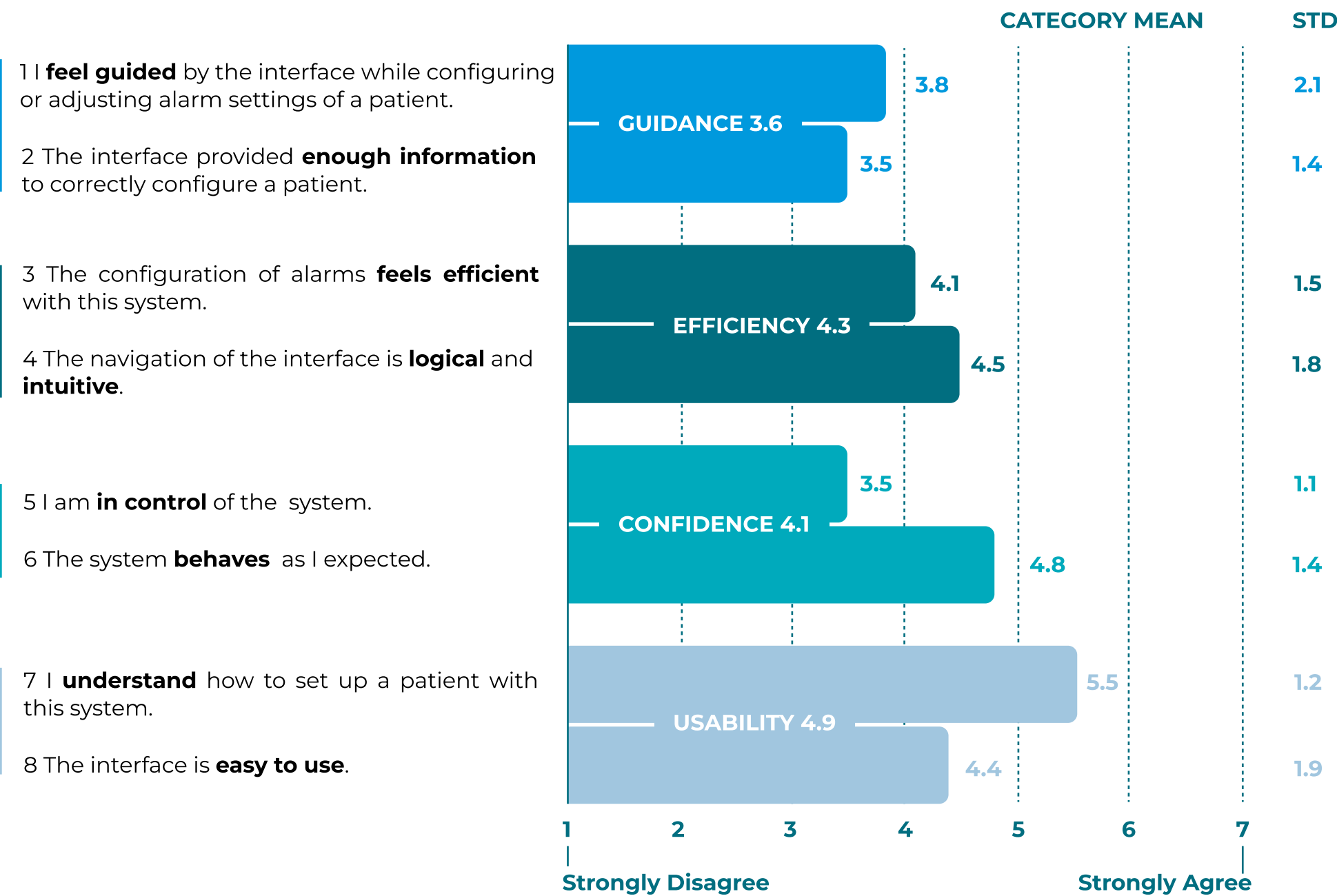


Figure 8.5: Mean scores for each questionnaire item related to the key elements of the design goal: guidance, efficiency and confidence, including Standard Deviations (STD). Usability is incorporated as the last two questionnaire items.

Open Questions

The responses to the open-ended questions were analysed to identify recurring themes across participants. This was achieved by reviewing interview transcripts and highlighting key quotes, which resulted in five main themes and several minor insights. Appendix L provides a complete overview of all user quotes that contributed to these findings. Each main theme is illustrated with a representative quote:

1. Appreciation of depth/duration algorithm

Seven out of eight participants expressed a positive attitude towards the depth- and duration-based alarm settings. This was the only feature that almost all participants agreed on.

“It is easy to work with this system, and it’s good that we are getting rid of those small alarms” - P3

2. Low Trust in Proposed Values

Several participants stated that they would always manually verify the system’s proposed target ranges.

“I will always check all the values.” - P7

3. Mixed Views of Additional Information

Participants had differing views on the usefulness of additional information shortcuts. While some identified them as helpful, others expressed concerns about forgetting to deselect them or increased system complexity.

“If you don’t realise that the target ranges changed when clicking sepsis, then this could have consequences.” - P8

4. Need for a patient’s Current Values

Several participants emphasised the importance of integrating a patient’s real-time monitor while calculating the desired target ranges for vital signs. This is crucial to ensure that the system takes into account the patient’s current condition.

“I think it’s very valuable to have templates for certain patient groups, that works very well. But normally we configure a lot based on the current values of the patient. So sometimes these templates will not fit anymore.” - P5

5. Diverse attitudes - Overall System

The attitude towards the overall system varied. Some participants recognised the long-term potential of the new system but acknowledged a need for adaptation and training. Others preferred the current system, especially those who did not perceive alarms as a significant issue, such as some PICU nurses.

“I think you need to get used to the new way of working. Initially the system can feel a bit unsafe, but eventually it will also bring things.” - P4

Minor insights

In addition to the main themes, several smaller but notable insights derived from the transcripts are:

- The overall navigation is clear for most participants, although some were uncertain about estimating the patient’s risk level.

“Why is the risk level important? This can change every half an hour.” - P7

- Participants have varying monitoring strategies; some prefer tight monitoring, while others choose looser configurations.
- Two participants expressed concerns about handing over alarm settings during shift changes.
- Several participants noted that alarms can be informative without requiring immediate therapy intervention. For example, an alarm may indicate discomfort, motivating the nurse to provide more attention to the patient.

8.3 Discussion

This section interprets the results of the final design evaluation of SetWise, while reflecting on the design goal.

Guidance

In general, the participants expressed mixed views on the extent to which the system guided them through the configuration process. The average rating of guiding was 3.6 on a 7-point scale, but the high standard deviation shows notable variation in user experience. This variety among participants is recognised during the interviews:

“It’s really nice that the system guides you step-by-step through all the things you might want to adjust.” - P5

“It feels cluttered because you have so many things to choose.” - P6

The lack of prior training and education likely contributed to these differences. The feeling of being guided comes from two sides: the interface itself can provide guidance, but training on the new concept of alarming also influences how guided the user feels. Since this User Interface is designed for an entirely novel alarm system that does not exist yet, the unfamiliarity likely contributes to the limited sense of guidance reported by participants. Iterative holistic training and continued practice with this new concept of alarming may improve the perceived guidance of the interface over time.

Efficiency and Usability

Task completion was successful for all participants, with minimal need for support. This suggests that SetWise supports intuitive navigation and task efficiency. A mean usability rating of 4.9 supports this observation. The participants explained during the interviews:

“Without having seen the system before, I can navigate through it by just reading the steps.” - P4

“This system will save us time. And besides: less alarms; what we all want.” - P3

However, the **pragmatic quality** of the interface (as assessed by the AttrakDiff questionnaire) showed considerable variation, with three participants describing the system as impractical or cumbersome. This could be because they are so familiar with the current system, which makes it difficult to unlearn their existing routines for configuring alarms. Hafner (2015) pointed out that the **unlearning process** of a computer system is often underestimated, while it requires significant emotional and cognitive effort. Especially nurses with extensive experience may be more resistant to adopting new systems:

“I am working here for 32 years, so I am not bothered by the alarms. I rather have them than not.” - P1

“I want to interpret myself if I find an alarm useful or not. That’s on me, not on the system” - P1

Confidence (Sense of Control)

The evaluation was limited in its ability to assess to confidence, because the safety of the system cannot be tested without a more realistic test setup. Therefore, the evaluation focused on the perceived sense of control, which was rated relatively low (mean = 3.5), despite a moderate agreement that the system behaves as expected (mean = 4.8).

The results of the monitor simulation part correspond with this finding. Unfortunately, the results are not very reliable because the assessments of participants were affected by misinterpretations of the trend data shown along with the static screenshots. For instance, short dips were interpreted as long-lasting, affecting their assessment of whether an alarm was appropriate. However, the discussion of the monitor simulation showed an interesting insight. Sometimes an alarm is not actionable, but still useful for required attention:

“It’s not that I’m acute going to do something with a small dip, but it is an indicator that my patient possibly deteriorates. Just a small warning: I have to be a bit more cautious.” - P8

Further, shifting from absolute thresholds to target ranges did probably not contribute to a sense of control:

“It would be nice to see the exact seconds within the tight-mid-loose graphs. Then it feels you are a bit more in control.” - P8

Additionally, the Additional Information shortcuts could have influenced the perceived control. For some participants, the real-time changes were insufficient to demonstrate the implications of their settings clearly.

“You don’t know which thresholds correspond with the information labels. That makes it really cluttered. Especially if you select multiple, you don’t know anymore which label is affecting which thresholds.” - P6

Individual Differences

The individual results of the total evaluation differ greatly. This is not unexpected, when looking back at **Sections 3.4** and **3.5**, which explain that each nurse is different and uses their own approach to alarm configuration.

Figure 3.4 shows that factors such as risk tolerance, personality and level of experience influence how nurses currently set alarm thresholds. Participants with a low risk tolerance may respond more negatively to the new system, as it allows for looser monitoring settings.

Figure 3.5 presents four identified nurse profiles, that can help explain the differences in test results. The **moderate/straightforward** and **experienced/short-tempered** nurses likely experience more difficulties while adapting to a new system. These nurses prefer a logical system which is streamlined with the current patient-monitoring system, which may have led them to find the new system confusing or insufficiently guiding. In contrast, the **sociable/flexible** nurses were probably more open to the new system and could see its potential. The **young/sensitive** profile may also be more willing to try a new system, however this group needs a simple system to get used to the fast-paced ICU environment.

The results from the AttrakDiff questionnaire presented in figure 8.4 also illustrate these differences between well. Interestingly, nurses from the adult ICU seemed to be more critical than the PICU nurses. One possible reason is that adult ICUs often use separate patient rooms, which makes it harder for nurses to keep an overview. In this context, having fewer alarms may feel more risky, since they cannot always see the patient directly.

A nurse who is not particularly bothered by frequent alarms may be working in the PICU, where the patient overview is generally better. In that setting, nurses can often visually assess the situation from a distance and silence alarms directly from the central nurse station. This makes it easier to judge whether an alarm is meaningful or not without entering the patient’s room. In contrast, nurses in the adult ICU receive alerts on a beeper without immediate insight into the

alarm’s source or urgency, requiring them to check each situation physically. So, nurses have developed different habits around alarm handling due to departmental differences, which may influence how nurses assess and experience the new system.

Limitations

This study involved only eight participants, limiting the representativeness of the findings. Although the group was diverse in terms of gender, participants were relatively similar in terms of experience level. Nonetheless, this small sample already showed considerable variation in opinions and preferences. This verifies the insight that SetWise should be adaptable to different nurse profiles.

Several participants noted that configuring the alarm settings without seeing the patient in bed was challenging. This suggests that nurses consider visual patient cues when making configuration decisions. The absence of this context may have made it more difficult to configure alarms for the test scenario and assess the new system appropriately. Moreover, the simulated monitor was not directly connected to the interface, which made it harder for participants to evaluate the expected outcome of their configuration choices.

The AttrakDiff questionnaire was translated into Dutch, which may have resulted in some variation in interpretation compared to the original, validated English version.

The goal of this test was to evaluate the graphical *user interface*, not the future alarm system. Since the future system and its underlying alarm approach do not yet exist, this may have negatively affected how participants perceived the interface. To properly evaluate the interface, the whole system should be further developed and integrated.

Finally, this evaluation was based on a first-time use of the interface. Ongoing testing is necessary to assess how perceptions change with repeated use and training.



Figure 8.6: Participants conducting tasks with the final prototype.

8.4 Conclusion

SetWise demonstrates potential: all participants successfully reached their primary goal during the task-based evaluation; configuring alarm settings for a patient based on a given clinical scenario. However, the considerable variation in participants' attitudes towards the system suggests that nurses prefer different strategies to reach this primary goal. The concept of Nurse Profiles may offer helpful insight into these differences, supporting the design of a system that accommodates diverse needs and preferences.

Overall, SetWise was perceived more positively than neutrally, particularly in terms of usability and efficiency. The depth/duration algorithm was the only feature which received unanimous appreciation, due to its ability to filter out alarms triggered by minor fluctuations in vital signs.

Participants were not entirely trusting the new system yet, but this is likely due more to the entirely novel approach to alarm configuration than to the interface itself. With appropriate and targeted training addressing this paradigm shift, SetWise has the potential to be successfully adopted by a diverse group of nurses.

Key Takeaways of Evaluation

- The variation between participants suggests that a one-size-fits-all approach may not be suitable, and that the system should allow for adjustable levels of guidance, transparency, and manual control to accommodate different user types.
- Adequate training and education on the new approach to alarm configuration should be developed. In particular, the experienced/short-tempered and the young/flexible nurse profiles may benefit from tailored support. The cognitive effort required to unlearn the current system should be acknowledged.
- Real-time monitor values and/or trend data should be considered when recalculating desired target ranges, when the patient's condition changes.
- The potential risks of additional information shortcuts should be examined. This is also relevant in relation to the handover of alarm settings between nursing shifts.

09

Future Directions

This chapter presents the overall conclusions of the graduation project, followed by recommendations and suggestions for future implementation.

9.1 Project Conclusion

9.2 Recommendations and Implementation



9.1 Project Conclusion

This thesis aimed to improve the configuration of alarm settings in the ICU by designing and evaluating SetWise, a User Interface concept that supports context-aware configuration through the use of target ranges, scenario-based presets, and a depth/duration algorithm that reduces unnecessary alarms. The primary objective was to:

Design a graphical user interface for ICU nurses to correctly set up a new central alarm system which reduces the alarm load at the ICU.

During the initial research phase, consisting of fieldwork and literature, the highly demanding ICU environment highlighted the need for **guidance** and **efficiency**. Additionally, the evaluation of the initial prototype showed the need for trust or **confidence** in a new system. During this project, it became clear that confidence consists of two components:

- The safety of the entire system: Is the patient safely monitored?
- **Being in control** of the system.

The final design, **SetWise**, was developed through a user-centred design approach, involving iterative prototyping and evaluations with ICU nurses. The iterations focused on integrating the key elements of the design goal: guidance, efficiency and a sense of control. SetWise was evaluated with eight ICU nurses. The results varied significantly between nurses, which was a recurring theme throughout the whole project.

While all nurses share the goal of providing the best patient care, they each **prefer different strategies** to achieve it. Overall, the new system was rated slightly more positive than neutral, which shows potential for the future. Although promising, the system requires further refinement, testing in live environments, and proper training before it can be deployed. These considerations are addressed in the following recommendations section.

This thesis offers a **tangible step** towards a **Smarter** and **Quieter ICU**. The functional prototype provides a foundation for creating a comprehensive test environment to support the further development of the SASICU project. Additionally, it encourages broader discussion on a potential paradigm shift in how we approach alarm configuration: moving from micromanagement with absolute thresholds towards a system that has situational awareness of the patient.

9.2 Recommendations

To support the further development of SetWise at UMC Utrecht, the following recommendations are proposed:

1. Implement Design Improvements

Improve the interface design based on insights from the evaluation tests conducted throughout this project. While not all improvements could be implemented within the scope of this project, Appendix G contains a backlog of possible valuable design considerations. For instance, introduce a confirmation mechanism to help prevent accidental changes to alarm settings.

2. Support Individual user needs

Customise SetWise to accommodate different Nurse Profiles. Offer different system presets or interaction styles based on user preferences or experience levels. For example, provide a detailed and guided version to younger or more cautious nurses while maintaining flexibility for more experienced users.

3. Refine Underlying Algorithm

While developing the algorithms, consider integrating current patient monitor values or trend data as input for calculating the desired target range. This ensures that alarm settings more accurately reflect the patient's real-time condition. Additionally, this might create an opportunity to nudge nurses to remove additional information labels when the patient recovers.

4. Develop a realistic Test Environment

Create a comprehensive test setup with real-time monitor data, to make the test setup more realistic. This enables nurses to empathise more with the clinical scenario and configure alarms in a way that closely mirrors actual practice. Additionally, nurses from the NICU should also be included in further testing.

5. Invest in Training and Education

Provide nurses with appropriate training and education to help them adapt to the new system. Clearly explain the system's functionality so that users understand what they are configuring. The training content should be adjusted for different nurse groups:

- For sociable/flexible nurses, offer more in-depth explanations of how the algorithms work to build trust in the system.
- For sensitive, short-tempered, or experienced nurses, offer more gradual and detailed training. They might need more time to adapt.

The *unlearning* process of the current system should not be underestimated. To facilitate the unlearning process, nurses should be given the freedom to explore, receive help from tools or others, and have sufficient time to adapt (Hafner, 2015).

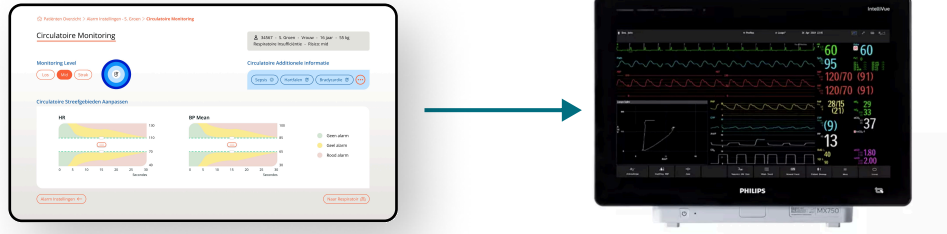
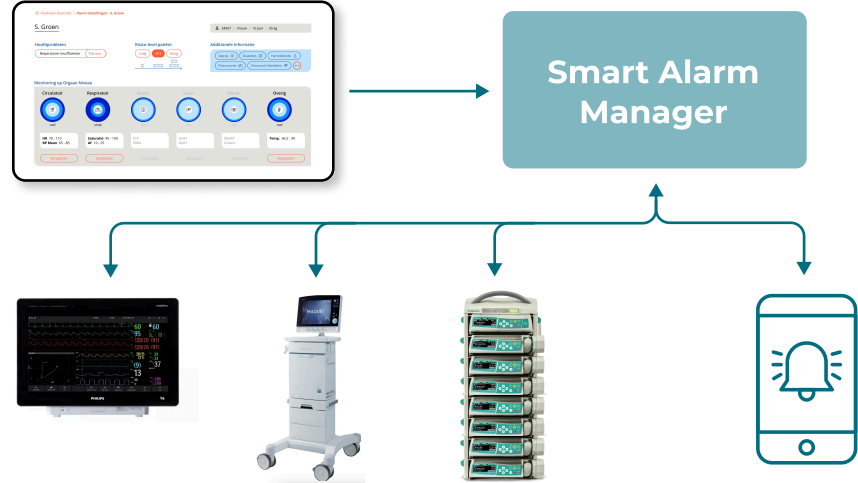
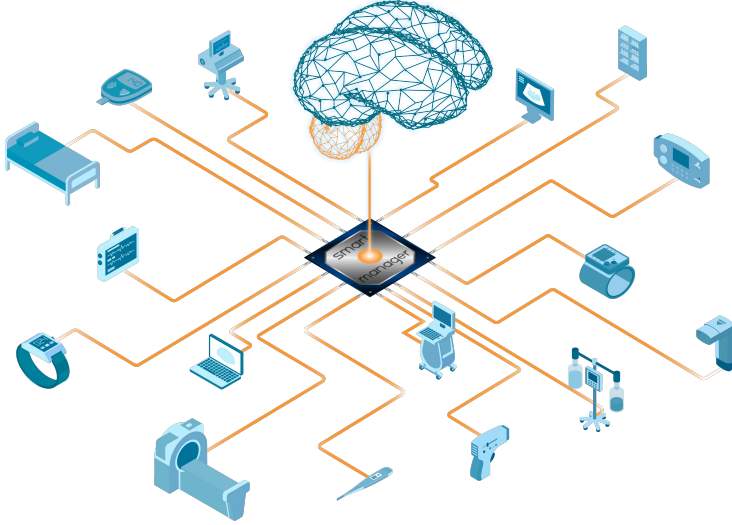
6. Plan for Step-by-Step Implementation

Introduce SetWise gradually over the next 10 years to give nurses enough time to adapt to the new system. Figure 9.1 proposes a step-by-step implementation plan. For each step, stakeholders, implementation requirements and opportunities are identified. In the first phase, only the basic functionalities of SetWise should be enabled. In this phase, nurses can use SetWise solely to configure the physiological monitor in **2027**. The depth/duration algorithm is applied to these vital signs, which makes this phase a suitable pilot for testing the algorithm. This allows nurses to become familiar with the basic interface.

By **2030**, further technological developments are expected to enable interoperability among various monitoring devices. This allows nurses to configure all alarm settings centrally in SetWise. In this step, SetWise will function as the front end of a Smart Alarm Manager, which combines several algorithms to create meaningful alarm messages and sends them to the nurse's mobile device. At this point, a mobile version of SetWise could be introduced, allowing nurses to easily adjust alarm settings within their workflow.

In a later phase, around **2035**, the system becomes even smarter. The Electronic Health Record will be fully integrated into the alarm system, allowing the system to become even more context-aware of the patient's condition. SetWise will be pre-filled with alarm configurations and contextual information, and nurses only need to verify or fine-tune the proposed settings.

The future of SetWise

YEAR	2027	2030	2035
CONCEPT	Configuration of the <i>Existing</i> Alarm System  SetWise makes the configuration of the physiological monitor easier in the PICU department of UMC Utrecht.	Centralised Configuration of <i>Future</i> Alarm System  SetWise forms the central configuration of all monitoring devices, and nurses receive meaningful alarm messages.	Advanced Integrations: Smarter and Quieter  SetWise is integrated with the Electronic Health Record, making the configuration is even more context aware.
WHAT?	• Partial functionality, configure physiological monitor • Depth/duration algorithm is reducing yellow alarms • Red alarm thresholds are still set on the monitor itself • No clinical profile and contextual shortcuts	• Full functionality of SetWise • Mobile devices with meaningful alarms messages • Interoperability: All monitoring devices are connected • Centralised configuration	• Brain and Cerebellum help nurses to configure alarms • EPD and configuration all in one • Target ranges also based on trend data of patient • Nurses only need to verify prepopulated information
OPPORTUNITIES	• Nurses can get used to the new way of alarming • Pilot run of the depth/duration algorithm Invest in Targeted Training on New approach of alarm configuration to serve different Nurse Profiles	Make the Design and Code Open Source to inspire other hospitals and research organisations to make a shift in ICU Alarm Configuration. Collaborate with a vendor who will lead the development of the Smart Alarm Manager and arrange CE certification. SetWise could be the front-end of the Smart Alarm Manager.	
REQUIRED STEPS	• Include all parameters of physiological monitor and consider design improvements • Develop Interface Design of Figma • Evaluation in complete test environment	• Adjust Interface Design to incorporate ventilator and infusion pumps. • Development of Smart Alarm Manager by vendor of monitoring devices	• Refine algorithms with real-time or trend patient data • Development of Brain and Cerebellum: Data Knowledge Platform and predefined Alarm Protocols
STAKEHOLDERS	• The Patient • The PICU department at WKZ • Philips for integration with physiological monitor	• All ICU departments • Other hospitals in the Netherlands • Vendors of monitoring devices	• Other hospitals worldwide • Research institutions



Cumulative Stakeholder Engagement

Figure 9.1: A step-by-step implementation plan for SetWise for the coming 10 years. For each concept, the opportunities, required steps and the new involved stakeholders are provided.

References

- **Bach**, T. A., Berglund, L.-M., & Turk, E. (2018). Managing alarm systems for quality and safety in the hospital setting. *BMJ Open Quality*, 7(3), e000202. <https://doi.org/10.1136/bmjopen-2017-000202>
- **Bannert**, M. (2002). Managing cognitive load—Recent trends in cognitive load theory. *Learning and Instruction*, 12(1), 139–146. [https://doi.org/10.1016/S0959-4752\(01\)00021-4](https://doi.org/10.1016/S0959-4752(01)00021-4)
- **Bostan**, I., Özcan, E., Gommers, D., & van Egmond, R. (2022). Annoyance by Alarms in the ICU: A Cognitive Approach to the Role of Interruptions by Patient Monitoring Alarms.
- **Bostan**, I., van Egmond, R., Gommers, D., & Özcan, E. (2024). Customizing ICU patient monitoring: A user-centered approach informed by nurse profiles. *Cognition, Technology & Work*, 26(3), 507–522. <https://doi.org/10.1007/s10111-024-00763-9>
- **Brooke**, J. (2013). SUS: a retrospective. *Journal of usability studies*, 8(2).
- **Brostowicz**, H. M., & Rais-Bahrami, K. (2010). Oxygen saturation monitoring in the Neonatal Intensive Care Unit (NICU): Evaluation of a new alarm management. *Journal of Neonatal-Perinatal Medicine*, 3(2), 135–139. <https://doi.org/10.3233/NPM-2010-0105>
- **Chambrin**, M.-C. (2001). Alarms in the intensive care unit: How can the number of false alarms be reduced? *Critical Care*, 5(4), 184–188. <https://doi.org/10.1186/cc1021>
- **Cho**, O. M., Kim, H., Lee, Y. W., & Cho, I. (2016). Clinical Alarms in Intensive Care Units: Perceived Obstacles of Alarm Management and Alarm Fatigue in Nurses. *Healthcare Informatics Research*, 22(1), 46–53. <https://doi.org/10.4258/hir.2016.22.1.46>
- **Cvach**, M. (2012). Monitor Alarm Fatigue: An Integrative Review. *Biomedical Instrumentation & Technology*, 46(4), 268–277. <https://doi.org/10.2345/0899-8205-46.4.268>
- **Fernandes**, C. O., Miles, S., Lucena, C. J. P. D., & Cowan, D. (2019). Artificial Intelligence Technologies for Coping with Alarm Fatigue in Hospital Environments Because of Sensory Overload: Algorithm Development and Validation. *Journal of Medical Internet Research*, 21(11), e15406. <https://doi.org/10.2196/15406>
- **Hafner**, J. H. (2015). Computer System Unlearning in Individuals. 2015 48th Hawaii International Conference on System Sciences, 3860–3869. <https://doi.org/10.1109/HICSS.2015.463>
- **Hassenzahl**, M., Burmester, M., Koller, F. (2003). AttrakDiff: Ein Fragebogen zur Messung wahrgenommener hedonischer und pragmatischer Qualität. In: Szwillus, G., Ziegler, J. (eds) *Mensch & Computer 2003. Berichte des German Chapter of the ACM*, vol 57. Vieweg+Teubner Verlag. https://doi.org/10.1007/978-3-322-80058-9_19
- **Jansen**, R. J., van Egmond, R., de Ridder, H., & Silvester, S. (2013). Transitional Journey Maps: Capturing the dynamics of operational policing.
- **Jee**, R. A., Shepherd, J. R., Boyles, C. E., Marsh, M. J., Thomas, P. W., & Ross, O. C. (2012). Evaluation and comparison of parental needs, stressors, and coping strategies in a pediatric intensive care unit. *Pediatric Critical Care Medicine*, 13(3), e166. <https://doi.org/10.1097/PCC.0b013e31823893ad>
- **Kasparick**, M., Klotz, T., Thürk, G., Andersen, B., Rother, B., Golatowski, F., Neumuth, T., & Rockstroh, M. (2023). Silent ICU based on IEEE 11073 SDC. *Current Directions in Biomedical Engineering*, 9(1), 303–306. <https://doi.org/10.1515/cdbme-2023-1076>
- **Konkani**, A., Oakley, B., & Bauld, T. J. (2012). Reducing Hospital Noise: A Review of Medical Device Alarm Management. *Biomedical Instrumentation & Technology*, 46(6), 478–487. <https://doi.org/10.2345/0899-8205-46.6.478>

- **Koomen**, E., Webster, C. S., Konrad, D., van der Hoeven, J. G., Best, T., Kesecioglu, J., Gommers, D. A., de Vries, W. B., & Kappen, T. H. (2021). Reducing medical device alarms by an order of magnitude: A human factors approach. *Anaesthesia and Intensive Care*, 49(1), 52–61. <https://doi.org/10.1177/0310057X20968840>
- **Lawless**, S. T. (1994). Crying wolf: False alarms in a pediatric intensive care unit. *Critical Care Medicine*, 22(6), 981.
- **Lewandowska**, K., Weisbrot, M., Cieloszyk, A., Mędrzycka-Dąbrowska, W., Krupa, S., & Ozga, D. (2020). Impact of Alarm Fatigue on the Work of Nurses in an Intensive Care Environment—A Systematic Review. *International Journal of Environmental Research and Public Health*, 17(22), Article 22. <https://doi.org/10.3390/ijerph17228409>
- **Lu**, S.-F., Kuo, Y.-W., Hung, S.-H., Wu, C.-H., Wang, C.-Y., Chou, S.-S., & Huang, S.-H. (2024). Coping strategies of intensive care units nurses in alarm management: A qualitative research study. *BMC Nursing*, 23(1), 713. <https://doi.org/10.1186/s12912-024-02374-1>
- **Muller**, M. J., & Kuhn, S. (1993). Participatory design. *Communications of the ACM*, 36(6), 24–28. <https://doi.org/10.1145/153571.255960>
- **Özcan**, E., Bogers, K., Gommers, D., & Spagnol, S. (2025). NURSES' INTERPRETATION OF ICU SOUNDSCAPE: AN ANNOTATED SOUND LEVEL MEASUREMENT AT ERASMUS MEDICAL CENTER.
- **Özcan**, E., Spagnol, S., & Gommers, D. (2024). Quieter and calmer than before: Sound level measurement and experience in the intensive care unit at Erasmus Medical Center. *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*, 270(5), 6037–6048. https://doi.org/10.3397/IN_2024_3676
- **Patel**, V. L., & Kushniruk, A. W. (1998). Interface design for health care environments: The role of cognitive science. *Proceedings of the AMIA Symposium*, 29–37.
- **Sanz-Segura**, R., Pérez, E. M., & Özcan, E. (2019). Alarm Compliance in Healthcare: Design Considerations for Actionable Alarms (In Intensive Care Units). *Proceedings of the Design Society: International Conference on Engineering Design*, 1(1), 839–846. <https://doi.org/10.1017/dsi.2019.88>
- **SASICU** | IHI Innovative Health Initiative. (2023, October 1). <http://www.ihieuropa.eu/projects-results/project-factsheets/sasicu>
- **Shneiderman**, B., Plaisant, C., Cohen, M., Jacobs, S., and Elmqvist, N., *Designing the User Interface: Strategies for Effective Human-Computer Interaction: Sixth Edition*, Pearson (May 2016) <http://www.cs.umd.edu/hcil/DTUI6>
- **Sun**, L., Joshi, M., Khan, S. N., Ashrafian, H., & Darzi, A. (2020). Clinical impact of multi-parameter continuous non-invasive monitoring in hospital wards: A systematic review and meta-analysis. *Journal of the Royal Society of Medicine*, 113(6), 217–224. <https://doi.org/10.1177/0141076820925436>
- **The Silent ICU**: Revolutionizing healthcare through innovation and interoperability |Ascom. (2024, June 11). Ascom Global Website. <https://www.ascom.com/news/blogs/global-blogs/silent-icu/>
- **Varisco**, G. (2023). Monitoring the critical newborn.
- **Wilken** Marc, Hüske-Kraus Dirk, Klausen Andreas, Koch Christian, Schlauch Wolfgang, & Röhrig Rainer. (2017). Alarm Fatigue: Causes and Effects. In *Studies in Health Technology and Informatics*. IOS Press. <https://doi.org/10.3233/978-1-61499-808-2-107>
- **Williams**, C. M. (2005). The identification of family members' contribution to patients' care in the intensive care unit: A naturalistic inquiry. *Nursing in Critical Care*, 10(1), 6–14. <https://doi.org/10.1111/j.1362-1017.2005.00092.x>

Appendices

- A Project brief
- B The first prototype
- C Informed Consent Form
- D Test Procedure of First Evaluation
- E Participant Quotes of First evaluation test
- F First Low-Fidelity prototype of iteration 1
- G Backlog of feedback during iterations
- H Interview Questions Usability Experts
- I Test Procedure Final Evaluation
- J Simulated Monitors of patient deterioration for evaluation
- K Questionnaires Final evaluation
- L Calculations and detailed results of Final Evaluation



A: Project Brief

FOR our future

IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

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

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME

Complete all fields and indicate which master(s) you are in

Family name

Boelhouwer

Initials

I.

Given name

Ileen

Student number

4839838

IDE master(s)

IPD

Dfi

SPD

2nd non-IDE master

Individual programme (date of approval)

Medisign

HPM

SUPERVISORY TEAM

Fill in the required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair

Dr. Elif Ozcan Vieira

dept./section

Perceptual Intelligence

mentor

Dr.Ir. Lyè Goto

dept./section

Human Factors

2nd mentor

Erik Koomen

client:

Wilhelmina Kinderziekenhuis (UMC)

city:

Utrecht

country:

The Netherlands

optional comments

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

Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in by the Chair of the supervisory team

Sign for approval (Chair)

Name

Elif Ozcan Vieira

Date

14 February 2025

Signature

Elif Ozcan Vieira

CHECK ON STUDY PROGRESS

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

Master electives no. of EC accumulated in total

EC

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

EC

★

YES

all 1st year master courses passed

NO

missing 1st year courses

Comments:

Sign for approval (SSC E&SA)

Name

Lisette Boot

Date

19-02-2025

Signature

L. Boot

Digitaal ondertekend door L. Boot Datum: 2025.02.19 14:27:42 +01'00'

APPROVAL OF BOARD OF EXAMINERS IDE on SUPERVISORY TEAM -> to be checked and filled in by IDE's Board of Examiners

Does the composition of the Supervisory Team comply with regulations?

YES

★

Supervisory Team approved

NO

Supervisory Team not approved

Comments:

Based on study progress, students is ...

★

ALLOWED to start the graduation project

NOT allowed to start the graduation project

Comments:

Sign for approval (BoEx)

Name

Monique von Morgen

Date

20/2/2025

Signature

Monique von Morgen

Digitally signed by Monique von Morgen Date: 2025.02.20 10:32:12 +01'00'

130

131



Personal Project Brief – IDE Master Graduation Project

Name student

Ileen Boelhauer

Student number

4839838

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

Project title

Interface Design for a silent ICU

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 paediatric Intensive Care in the Wilhelmina child hospital (WKZ) in Utrecht is a department with a high sound level due to alarms. These alarms are necessary to enable the nurses and physicians to provide the right care for the patients. The alarms are generated by the medical devices, which are measuring and supporting vital systems of the patient. Not only the patients and the medical staff are being exposed to these alarms, but also the parents/family of the patients need to deal with the alarms. Alarm fatigue is a global problem, meaning that medical staff does not notice an alarm anymore because of sound overload [1]. Next to that, alarms are causing stress and anxiety for both patients and family. So, a European project named SASICU (Smart and Silent ICU) was initiated to address this global issue, among others [2]. UMC Utrecht collaborates in this project with Ascom, the company that will deliver the final interface in a few years. Read more about the project on sasicu.eu. Currently, a new ICU is being built with separate rooms for all patients at WKZ, to increase privacy and reduce noise for the patients and medical staff. Next to this, an algorithm is being developed to reduce the number of alarms which requires a new approach to manage the alarms in the clinic.

The opportunities per stakeholder are:
Nurses (main stakeholder): improvement of working environment by reducing alarm overload.
Patients: increased quality of ICU care by being exposed to less noise.
Family: reducing stress and worries about the patient by reducing the number of alarms.

References:
[1] Lewis, C.L.; Oster, C.A. Research Outcomes of Implementing CEASE: An Innovative, Nurse-Driven, Evidence-Based, Patient-Customized Monitoring Bundle to Decrease Alarm Fatigue in the Intensive Care Unit/Step-down Unit. Dimens. Crit. Care Nurs. 2019, 38, 160–173. [Google Scholar] [CrossRef]
[2] About SASICU — sasicu.eu. (n.d.). sasicu.eu. https://www.sasicu.eu/about-sasicu

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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)

Mostly, the nurses are responsible for two patients during a work shift. They must keep track of the vital parameters of those patients, by keeping an eye on the medical data. The nurses need to respond to the alarms, this occurs almost every two minutes. Currently, an alarm already goes off if the heart rate is slightly too high, while this has no serious consequences for the patient: a non-actionable alarm. The new algorithm can recognise a non-actionable alarm and "suppress" the alarm sound. Multiple non-actionable alarms can result in ONE actionable alarm over time because the overall risk situation of the patient has changed.

However, the algorithm needs input from the nurses, so a clear graphical user interface is needed for this interaction. Besides, the nurses must trust and understand this algorithm and learn how to correctly set up the central alarm system of a specific patient. For example, they must indicate the risk category and how strictly they want to monitor the patient. But less alarms could cause uncertainty about the health of the patient; the nurses should understand what the algorithm is doing to understand that their patients are still safe. The nurses need to get used to a new approach of interpreting, managing and interacting with alarms. A low-fidelity Figma prototype (see figure 1) was developed by a doctor in training to create a first approach for the nurses to set up the alarms, but it still raises a lot of questions. Therefore, this project will start with a small evaluation of this first prototype.

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:

Prototype a graphical user interface for ICU nurses to set up a new central alarm system which manages the alarm load at UMC Utrecht.

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)

This project will follow an iterative design process, where the following 4 phases will be repeated in each cycle: research, design conceptualisation, prototyping, evaluation. I want to involve the users in each cycle. A global overview of the total project approach:

Research and analysis: I want to perform a small literature study in combination with a deep dive in the context by shadowing the nurses at different ICU departments for a few days, doing observations and interviewing. I want to discover their current strategies for setting alarms. Besides, I will evaluate the first low-fi prototype (already developed by trainee doctor) with some nurses. At the end of this phase, I will connect all the information gathered into a journey map and design goal.
Design Conceptualisation: I want to develop different solutions for the interface by co-designing with nurses and a UI workshop-day with Ascom. I also want to ask some advice to UI design experts.
Prototyping: This phase will run (partly) in parallel with the design phase. First, I will create lo-fi prototypes and ask the nurses for feedback. Finally, this will result in one high-fidelity prototype in Figma.
Evaluation: I want to evaluate this final design with different experts; technical staff of the hospital, employees

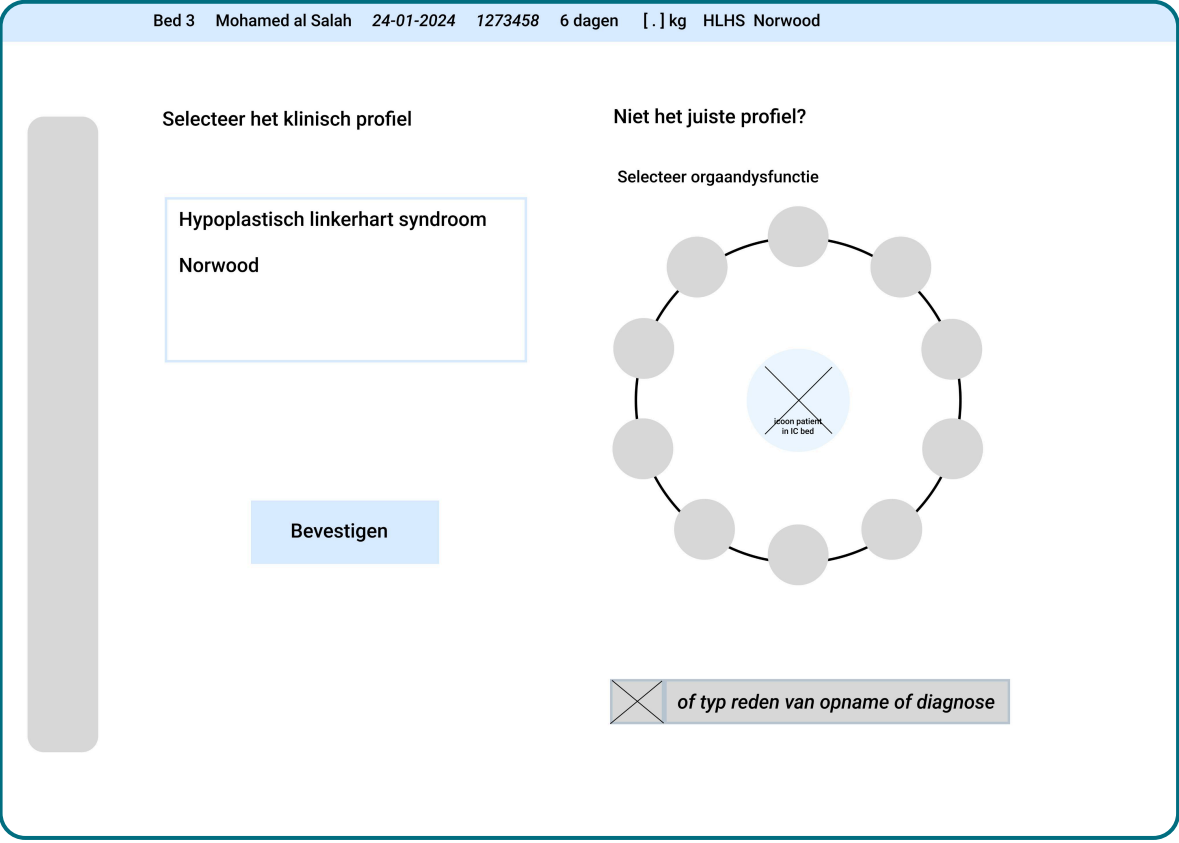
133

B: The first prototype

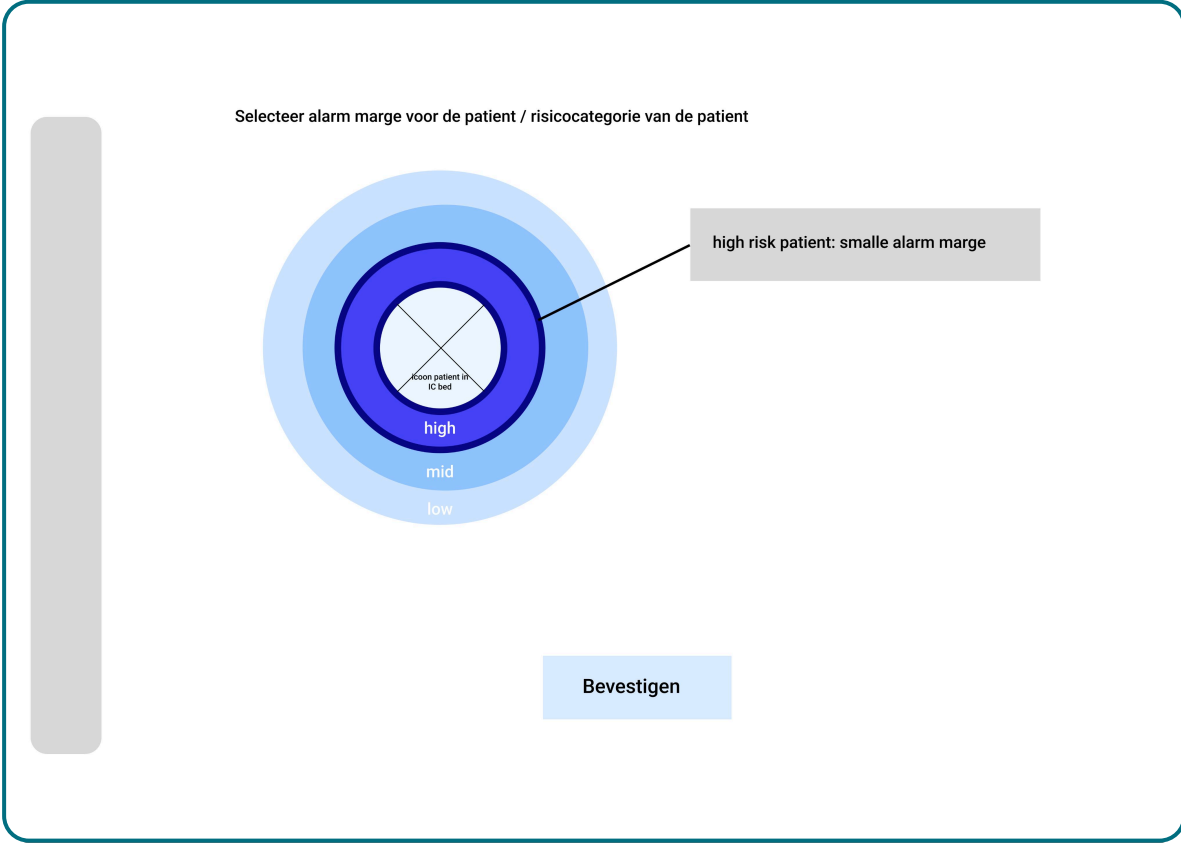
Home - Bed Overview



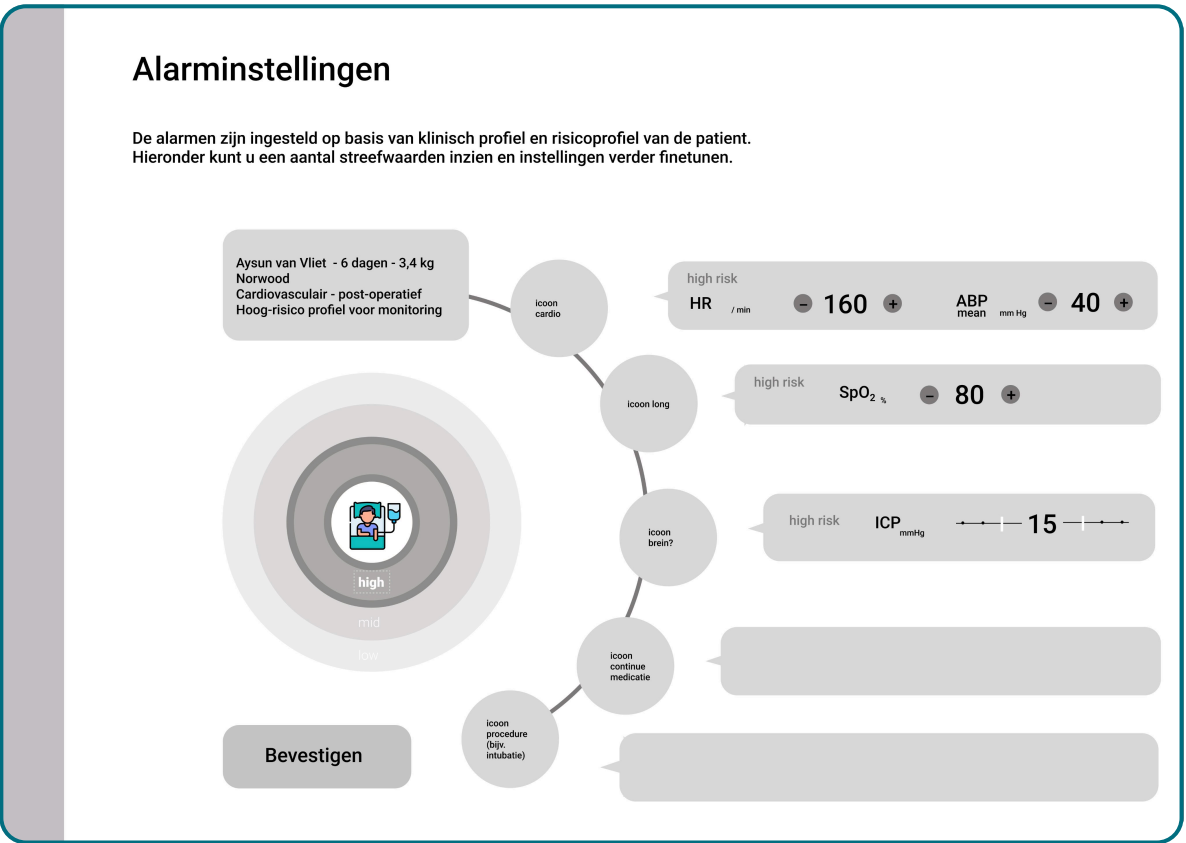
Select Clinical Profile & Organ disfunction



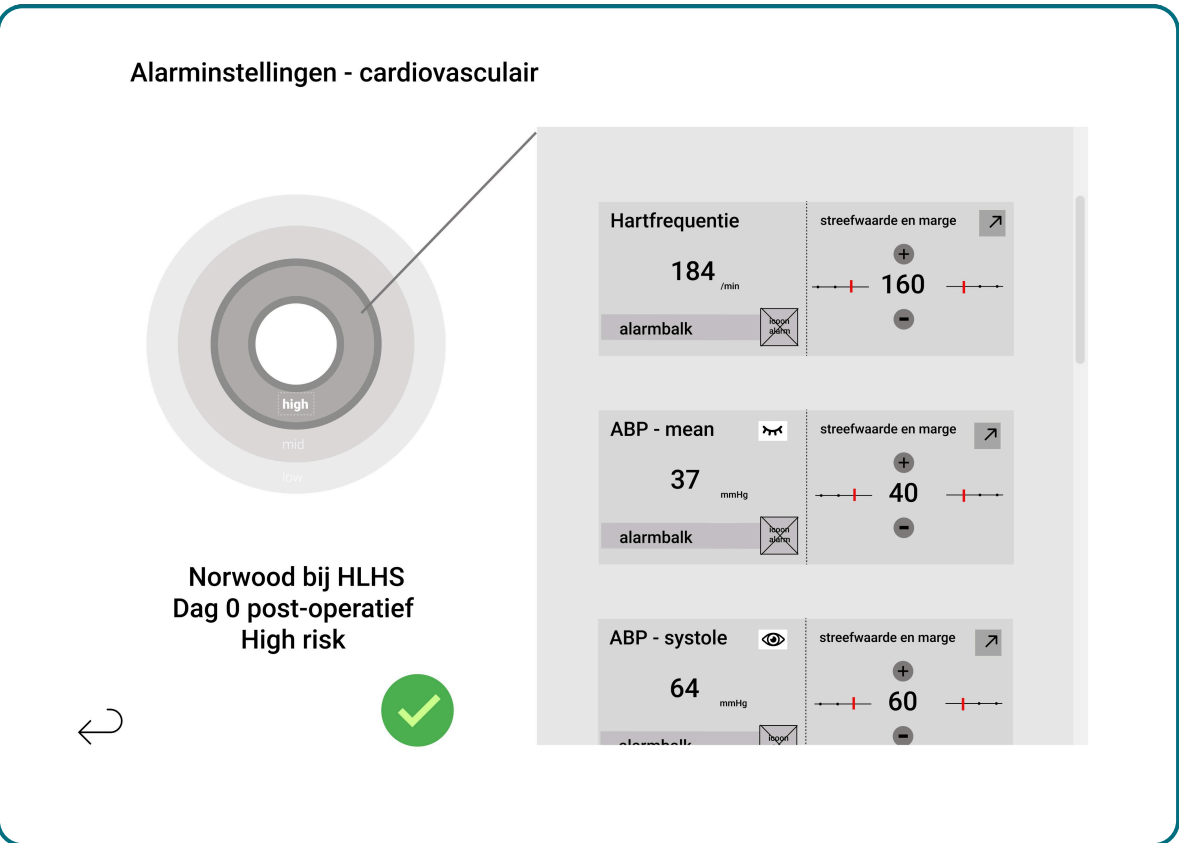
Select Risk level



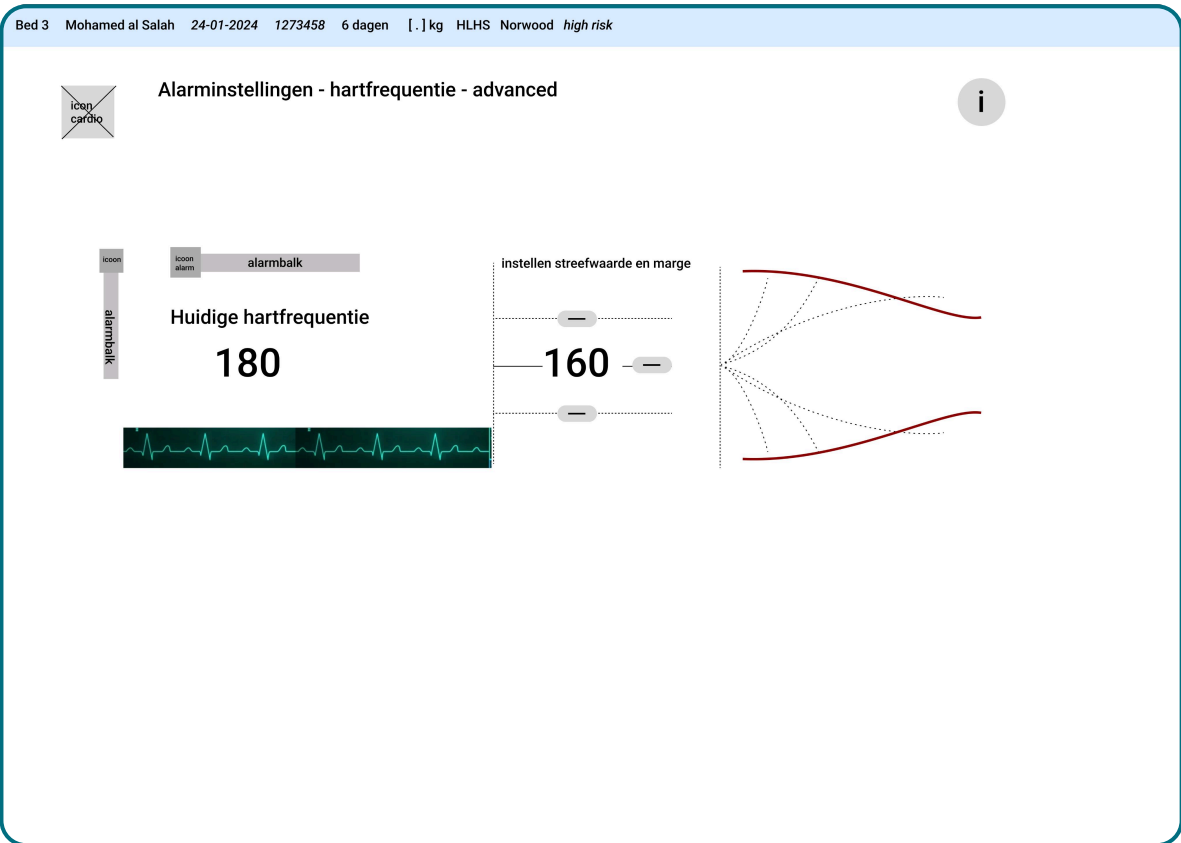
Overall Alarm Settings



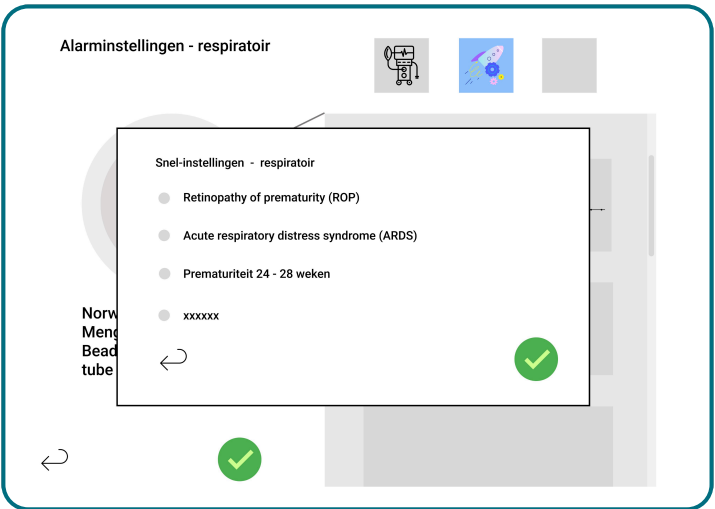
Alarm Settings Heart



Advanced Settings



Fast Pre-sets



C: Informed Consent Form for all evaluation tests of this project

Informed Consent form -
User Interface Design of new Alarm System for Intensive Care Units

You are being invited to participate in a research study titled ‘Design of a User Interface System for a new alarm system. This study is being done by Ileen Boelhouwer from the TU Delft in collaboration with an internship at UMC Utrecht.

The purpose of this research study is to find out about the needs and wishes of caregivers (nurses, doctors at the Intensive Care Unit) regarding the set-up of the new alarm system and to evaluate first prototypes. You will be asked several open questions, and you will be asked to interact with a digital prototype and give your opinion on it. It will take you approximately 30 minutes to complete. The results of the qualitative interviews will be used as input for the design of the user interface and will be used in the thesis publication.

As with any online activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks; the interviews are anonymous, and we will only collect your age, gender and profession. If you agree, we will take some photos for the report, these photos will be anonymised by blurring faces, if you prefer. We would like to record the interview audio to transcribe the interviews, if you give consent.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions. Audio recordings will be deleted within one month, after the transcription. The necessary photos will be blurred immediately, and the photos which are not used in the thesis will be deleted within 6 months. The master thesis, including some (blurred) pictures and the transcriptions will be published in the TU Delft Repository, which is open for everyone.

Do you have any questions about this research?

Thank you for your participation!

Responsible researcher:
Ileen Boelhouwer
E-mail: i.boelhouwer@student.tudelft.nl

The following list asks for your consent on some specific topics. Please tick the appropriate boxes.

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
1. I have read and understood the study information, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions, and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves: interacting with a digital prototype, answering open interview questions and giving information about age, gender and profession.	☐	☐
4. I give consent to make pictures of me while executing the study, in which I AM recognisable, used for visualisation in the master thesis.	☐	☐
5. I give consent to make pictures of me while executing the study, in which I am NOT recognisable, used for visualisation in the master thesis.	☐	☐
6. I give consent to record audio during the study.	☐	☐
7. I understand that personal information collected about me that can identify me, such as my name will not be shared beyond the study team.	☐	☐
8. I agree that my responses, views or other input can be quoted anonymously in the master thesis and/or oral presentation.	☐	☐
9. I give permission to include anonymous transcriptions (including age, gender and profession) and (unrecognisable) photos in the master thesis, which will be archived in the TU Delft repository which is publicly available. The repository is used for future research and learning.	☐	☐

Signatures

Name of participant [printed]

Signature

Date

D: Test Procedure of first evaluation

Evaluatie 1^e Prototype (Ontworpen door Marijn Soeteman) – 6 Maart 2025

Script:

Heel erg bedankt dat je tijd vrij wilt maken hiervoor!

Vind je het oké als ik de audio van deze test opneem zodat ik niet mee hoeft te typen met je antwoorden?

Vragen vooraf:

- Wat vind je van het huidige alarmsysteem?
- Waar hou je rekening mee als je de alarmen van een patiënt instelt? Hoe pak je dit aan?
- [Hoe ziet je dagdienst eruit m.b.t. alarmen?]
- [Wat doe je als je binnenkomt en/of overdraagt aan andere collega's, vertel je iets over de alarmgrenzen?]
- [Heb je wel eens irritaties rondom hoe collega's de alarmen instellen?]
- Hoeveel weet je al van het slimme en stille alarm project af?

Dit project heeft als doel om uiteindelijk stillere IC-units te verwezenlijken met een slim alarmsysteem. Dit slimme alarmsysteem zorgt ervoor dat er (bijna) alleen maar klinisch relevante alarmen zullen afgaan, dus alleen alarmen waar jij als zorgverlener ook echt iets mee moet doen. Hiermee zal het aantal alarmen op de IC hopelijk drastisch omlaaggaan. Om dit werkzaam te krijgen, zijn er twee grote verschillen ten opzichte van het huidige alarmsysteem.

1. Tijdens het instellen van de alarmgrenzen zal er gewerkt worden met een klinisch risicoprofiel in plaats van alleen onder- en bovengrenzen van één parameter. Dus je stelt op het begin in hoe strak je een patiënt in het algemeen wil monitoren, en daarna kan je het nog finetunen. Doordat je een klinisch profiel hebt gekozen, zorgt het systeem er al voor dat de belangrijke parameters voor dit ziektebeeld, strakker gemonitord worden. Is dit een beetje duidelijk?
2. Daarnaast kijkt dit nieuwe systeem niet alleen naar hoe hoog een hartslag is, maar ook hoelang de hartslag zo hoog is. Bijvoorbeeld, als de hartslag heel eventjes boven de bovengrens schiet, dan zou met het oude systeem al een alarm afgaan. Maar dit nieuwe systeem, laat het alarm (bijvoorbeeld) alleen afgaan als de hartslag voor een uur lang veel te hoog is. Dit is nog steeds veilig voor de patiënt, alleen zijn er minder alarmen. Is dit een beetje duidelijk?

Marijn Soeteman heeft hiervoor een eerste ontwerp gemaakt, en dit digitale prototype zou ik graag met je willen testen. Het is een interface waarmee je de alarmen van de patiënten kan instellen, dus wat je normaal op de monitor aan de bedzijde zou doen met de boven en ondergrenzen. Ik ga je zometeen wat taken geven, en je kan niks verkeerd doen! Probeer je voor te stellen alsof je in de toekomst op de nieuwe PICU staat en een nieuwe patiënt krijgt, en stel daarvoor de alarmen in.

Is alles een beetje duidelijk? Heb je nog vragen? Is het goed als ik de audio opneem? Is het oké als ik wat foto's neem tijdens het testen van het prototype?

Taken:

1. Stel je voor: er wordt een nieuwe patiënt opgenomen met Hypoplastisch linkerhart syndroom én zwakke longen. Koppel de patiënt aan een bed en stel het klinisch profiel in, en geef aan dat je deze patiënt zo strak mogelijk wilt monitoren, want het is een hoge risico patiënt (alarmmarge).
2. Ga nu naar de alarm instellingen en zet de streef hartslag op 170.
3. Stel je voor dat je gaat intuberen, en zet de alarminstellingen voor intubatie aan.
4. De patiënt is te vroeg geboren (26w + 5d), geef dit aan bij de respitoire alarminstellingen, zodat de alarmen meteen goed staan.

Observeren:

- Klikkt wel of niet longen aan bij risicoprofiel
- Verandert mid -> naar high risk
- Kan intubatie vinden
- Kan de snel instellingen vinden

Vragen achteraf:

- Wat is je eerste indruk van deze manier van het instellen van alarmen?
- Wat vond je wel en niet fijn? Welke elementen van de interface?
- Zou je hier in de toekomst mee willen werken? Werkt dit ontwerp wel of niet voor jou?
- Past het in je workflow?
- Hoe voel je je bij deze methode? (veiligheid/vertrouwen)
- Wat vind je ervan dat de boven en ondergrens geen absolute waarden meer zijn?
- Wat vind je van de snel instellingen en procedures? Zou je deze gebruiken in de toekomst?
- Snap je het diepte en duur verhaal? -> advanced schermje hierbij laten zien !!!

[Eventueel specifieke vragen over de UI:]

- Hoe zou je het liefst patiënten aan een bed willen koppelen? Slepen? Of erop klikken en dan uit patiëntenlijst kiezen? Of vind je het handig dat het al gekoppeld is aan hij?
- Wat vind je van de alarmbalk? Dat je kan zien of een alarm bijna afgaat?
- Wat vind je ervan dat je na het instellen van de risico marge al klaar bent? Waar zou je nog meer inzicht in willen hebben als dit te weinig is?

E: Participant Quotes of First Evaluation Test

Alarm fatigue

Soms plakken de ECG stickers niet goed op de huid en dan druk je dus heel vaak het alarm weg. (3)

Been

We willen geen overbodige alarmen maar we willen ook niks missen. (1)

Been

Ik heb er altijd een ontzettende hekel aan als er permanent heel veel alarmen gaan en er niks mee gedaan wordt (1)

Been

Ik hoef niks te doen met 9 van de 10 alarmen, er is ook best veel storing. Of meetfouten, soms telt de monitor dubbel. Hartslag van 200 is dan eigenlijk gewoon 100. (3)

Been

Ik zou het heel tof vinden als de alarmen straks niet te horen zijn als er geen zorgprofessional in de kamer is. (2)

Been

Procedures

Ik denk dat procedures wel handig kunnen zijn. Kijk, bij intubatie ga ik niet instellen dat de saturatie onder de 75 mag zijn, **want de kans dat vergeet om deze grens weer terug te zetten is te groot.** (3)

Been

Misschien wil ik bij een intubatie juist eerder gealarmeerd worden. Voor procedures zou een lijnplaatsing of transport interessanter zijn. Maar procedures kunnen het ook weer complexer maken, je wilt ook niet overal uitzonderingen voor creëren. (2)

Been

Bij een procedure wil je eigenlijk alles wat geen rood alarm is, onderdrukken. Bij het wassen van een patiënt bijvoorbeeld. (3)

Been

Procedures lijken me handig, ik zou hier nog meer dingen aan toevoegen zoals verzorging. Maar bij intubatie wil ik nooit de alarmen helemaal uitschakelen, maar wel de grenzen wat ruimer maken. (1)

Been

Alarm boundaries

Wij moeten scherp zijn op hoe we onze grenzen instellen. Als je gewoon netjes je grenzen invult, dan gaan er ook niet zo heel veel alarmen af. (3)

Been

Het maakt mij niet uit of ik nou bij 120 of 130 gealarmeerd wordt. Mijn collega kiest misschien ook wel voor een ander getal. Het gaat er meer om de verhoging van de hartslag. (3)

Been

Als het goed is, houdt het systeem nu rekening met de juiste onder- en bovengrenzen. Normaal stel ik dit voor mezelf in, zodat ik weet wanneer een kind wakker is of pijn heeft. Maar nu zou ik er wel enigszins op durven vertrouwen, dat het systeem werkt. (3)

Been

Stel het blijkt dat er nog steeds heel veel alarmen afgaan na het instellen van dit systeem, dan zou het wel fijn zijn als je de boven en ondergrens nog kan finetunen naar ruimere alarmgrenzen. Dan moet je op die manier gaan denken. (3)

Been

UI elements

De alarmbalk geeft wel een goed beeld van hoe zit je in je streefwaarde. Maar hier wordt je wel door gealarmeerd, zonder dat er een alarm afgaat. Dus we zouden in de praktijk moeten kijken hoe dit werkt. (3)

Been

Wil je de alarmbalk wel zien, als je de alarmen juist weg filtert? Aan de andere kant, zie je dat het systeem het in de gaten houdt. De alarmbalk moet wel sneller vollopen naarmate de waarde extremer wordt, dan zou ik dat wel willen zien. (2)

Been

Ik zou zelf eerder voor een standaard, midden en hoog risico gaan. Bestaat laag-risico op een IC? (2)

Been

Ik zou het fijn vinden om te kunnen sliden bij het aanpassen van de streefwaarde. (2)

Been

De alarmbalk lijkt me goed, zolang ik maar weet wat het betekent. (1)

Been

Workflow

De snelinstellingen lijken me handig, we hoeven dan niet meer zoveel na te denken. Ik denk dat je er minder alarmen van kan krijgen, omdat de grenzen beter worden ingesteld. (3)

Been

Ik ben eigenlijk wel blij verrast :) (3)

Been

Het gaat me wel veel werk kosten als ik bij een kind bij alle organen moet aangeven wat er niet goed werkt. (1)

Been

Over het diepte/duur verhaal: Als dit werkt, dan is het natuurlijk wel super mooi. (1)

Been

Je moet dus een beetje vertrouwen gaan krijgen in alarmen. Dat als ze gaan, dat er ook echt wat is. (2)

Been

Over het algemene concept: Ik denk dat dit wel fijn kan werken, omdat je dus veel nutteloze alarmen eruit kan filteren. Nu moet je handmatig ALLE grenzen invullen (je kan alleen baby, kind of volwassene aangeven). En deze grenzen zijn denk ik wel ruimer dan met een klinisch profiel. (3)

Been

Ik zou wel vertrouwen op het systeem. Het wordt natuurlijk niet in gebruik genomen als het niet betrouwbaar is. (1)

Been

F: Low-fidelity prototype - iteration 1

With comments from the client: the SASICU team from UMC Utrecht

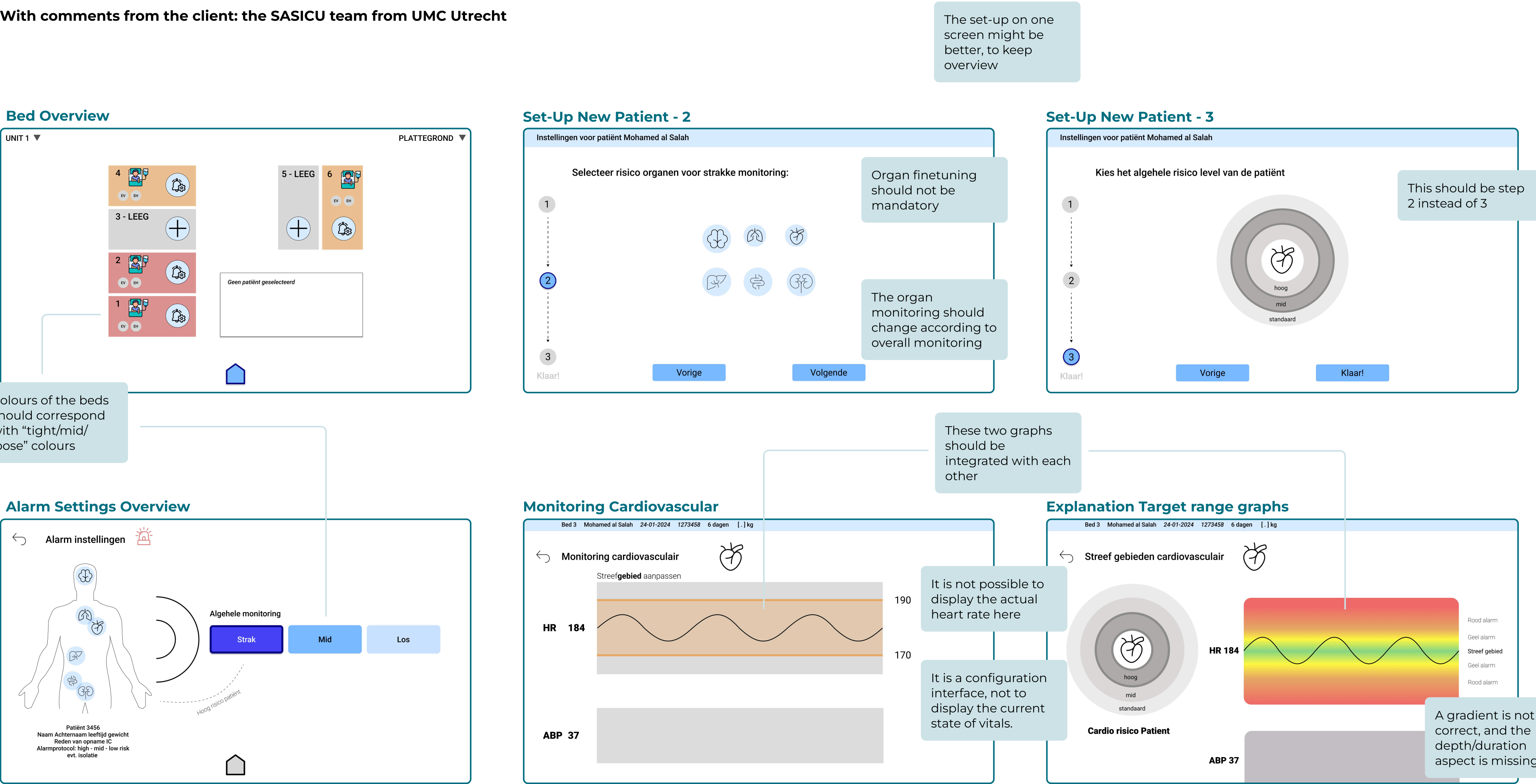


Figure 2.1: simplified floor plan of the PICU at WKZ.

Figure 2.1: the central nurse station at the PICU at WKZ, a social place for nurses where they can keep overview of the patients and do necessary administration..

G: Backlog of Feedback during Iterations

Feedback which fell outside of scope of this project, but should be considered for further development of this interface.

Feedback - iteration 2

- The user should have the option to choose how the blood pressure should be monitored. Only BP Mean, dia & sys, or all.
- The user should be able to not monitor a certain parameter. (this is not the same as silencing)
- It could be an idea to organise the parameters based on device instead of organ-system. Or at least show on which device a parameter is monitored, for example saturation, on monitor or ventilator?

User Expert interviews with Ascom

- Additional problems → show only the ones which are selected in the overview, else it could be confusing.
- Re-order the hierarchy of the overview; the main problem is something that you don't adjust that often, but its now on top and quite prominent in the screen. Just as the overall risk level of the patient.
- There should be looked into a "set default" button, where you can adjust the detailed monitoring settings automatically to its default state, determined by the main problem & overall risk level. This could be useful when taking over a shift from a colleague, or when you played around so much that you don't know the defaults anymore.
- Save/confirm buttons could be important for the detailed organ-system monitoring as well as the overview, to ensure that the nurse actually wanted to change something, instead of only playing around / finding out what the settings mean. Or a notification when navigating back: "you have unsaved changes, do you want to save?"
- A patient list instead of the floor plan of the unit could be more future proof or better for larger units.
- A way to compare new settings with old settings in ONE screen could help the user to determine which settings he or she prefers. Currently, the user has to toggle back and forth between settings to see these changes.
- The consistency of certain UI buttons could be improved. All navigation related buttons should look the same, but currently they also look the same as the risk-level and monitoring level buttons. This could be changed for a more intuitive and consistent interface.

Final Evaluation

- Feedback from the adult ICU, it could be nice if you can also configure where and what kind of alarm (visual, acoustic or both) takes place. For example, that the alarms are only acoustic outside the room.
- For the far future: don't enable nurses to change the target ranges proposed by the system. Only let them influence the tightness of monitoring: make the slider horizontal instead of vertical. And make the target range areas also green, to emphasise the new way of working. Currently, the target ranges are too similar to the current used absolute thresholds. And the terminology for tight, mid loose might need change, because these terms are currently used within nurse communication when they talk about wide (loose) or small (tight) thresholds. → This does not help to understand the new way of working. (based on feedback of PA - Adult ICU).
- Something to confirm the settings will be essential for deployment of this system. So that people play around and can confirm after, instead accidentally leaving a setting.
- There should be looked into how you handover certain settings to the colleague of the next shift. Or should it be possible to go back to default settings?
- A few participants (2/3) indicated that the blue colours of the monitoring levels might work better in the green yellow and red lay-out. Then it is easier to see if it is loose, mid or tight.

H: Interview questions for usability expert interviews

- 1. What is your first impression of this interface prototype?
- 2. Do you think this interface is helping to find the right elements to set-up alarms of a patient? Why yes or no?
- 3. Were the steps to set-up a patient easy to follow?
- 4. What do you think of the navigation structure and build-up of the interface?
- 5. What do you think of the positioning of UI elements? Would you position things differently?
- 6. Do you foresee any challenges while interacting with the prototype? If yes, which ones?
- 7. What would you improve? Do you have any suggestions or tips to improve the UI/UX?

I: Test Procedure Final evaluation

TEST PROCEDURE – FINAL EVALUATION

Evaluation Goal: To validate the final prototype on guidance, efficiency & confidence based on the following design goal:

“Prototype a graphical user interface which guides ICU professionals to efficiently set up alarms for patients, which provides confidence that they can safely monitor patients from a distance.”

Introduction & Consent

The test will be conducted in dutch, as the prototype is in dutch and the participants feel most comfortable in this language. Firstly, the participants will get a short explanation about the test and new alarm system and will be asked to sign the informed consent form:

“Welkom bij deze test, bedankt voor je deelname. Zou je eerst dit **CONSENT FORM** willen tekenen?
Dankjewel, dan start ik nu de AUDIO opname. !!!!!
Het doel van deze test is om een prototype voor het **INSTELLEN** van het nieuwe alarmsysteem te evalueren. Ik zal eerst een korte omschrijving geven van het nieuwe alarmsysteem (dit zal pas in de toekomst geïmplementeerd worden):

Het nieuwe alarmsysteem focust op het overzicht houden over de algehele situatie van de patiënt. **Door de reden van opname + het risico level in te vullen, helpt het systeem je om streefgebieden voor deze specifieke patiënt in te vullen.** Je hoeft dit dus niet meer allemaal zelf per vitale parameter op de monitor te doen. Doordat de alarmen specifiek voor een patient zijn ingesteld, hopen we het aantal alarmen te verminderen.

De test bestaat uit 4 onderdelen, eerst gaan we het prototype uit proberen, dan stel ik je wat vragen over de uitkomsten van het systeem van de monitor, daarna volgt het invullen van 2 questionnaires en wat open vragen.”

Part 1: Interaction with prototype

The users will get a printed clinical scenario, with 4 steps, in which the patient deteriorates but also recovers. Each time, they will be asked to adjust the alarm settings accordingly.

“Ik geef je nu het klinisch scenario, bestaande uit 4 stappen. Zou je deze 4 stappen willen uitvoeren met het prototype? Ik zal ze opnoemen, en dan kan je mee lezen. Zou je **HARDOP** kunnen denken tijdens het uitvoeren van de taken?”

Part 2: Monitor simulation

“Oké, nu gaan we kijken of het systeem ook doet wat je verwacht. Ik laat je hier een trend zien van de patiënt waardes, met een interval van **5 minuten**. Er zijn 4 fases waar ik je graag wat vragen over zou willen stellen, je ziet hier ook de bijbehorende snapshots van de monitor.

Voor fase 1 t/m 4:

- Wanneer je deze trend van fase X van de patiënt ziet, zou je dan een alarm verwachten met wat je net hebt ingesteld?
- Vind je dit alarm nuttig? Waarom wel of niet?
- Zou je nu iets veranderen aan je zorg voor de patiënt? Of is dit alleen een informatief alarm? “

Part 3: Questionnaires

See appendix J for Questionnaires.

“Zou je nu deze twee enquetes over het prototype willen invullen? Vul ze vooral **intuïtief** en **snel** in, en ben vooral helemaal eerlijk, daar hebben we het meeste aan.”

Part 4: Open Questions

“Als laatste hebben we nog paar open vragen:”

1. Welke onderdelen van de interface vond je fijn en welke niet?
2. Was alles duidelijk? Wat wel en wat niet?
3. Snap je het concept van streef gebieden in plaats van grenzen? Snap je waarom dit wordt gebruikt in het nieuwe systeem?
4. Begrijp je wat de grafiek rondom de streefgebieden betekent?
5. Heb je suggesties om de interface te verbeteren?

Klinisch Scenario

Patientgegevens:

Simone Maria Groen
34567
Vrouw
18-06-2009, 16 jaar
55 kg

1

Patiënt heeft Acute Lymfatische Leukemie, krijgt vanuit thuis chemokuur. Wordt nu **via de spoed laagdrempelig** op de PICU **opgenomen**, door **versnelde ademhaling en verhoogd zuurstof behoefte:** bedreigende Respiratoire Insufficiëntie. De **ALL** is op dit moment **onder controle, niet neutropeen**.

Meetwaardes:
Sat 90% met 15L Optiflow
HR 95
ABP 100/60

STAP 1: Neem deze nieuwe patiënt op, op bed 4, en stel de alarmstellingen in op basis van dit scenario.

2

Het is een dag later, patiënt oogt **minder benauwd** met optiflow, de waarden lijken zich te stabiliseren. Patiënt heeft minder zuurstof behoefte.

STAP 2: Wat zou je nu aanpassen aan de alarminstellingen op basis van dit scenario?

3

Over de nacht is de patiënt toch meer **toenemend benauwd, hoge koorts, bloeddruk** zakt ver **omlaag** en **hartslag** gaat **omhoog**. Longen klinken aan beide kanten niet schoon, verdenking op bacterieel super-infect. Patiënt krijgt NIV en antibiotica wordt gestart.

Meetwaardes:
CRP 150
HR 120
BP Mean 50
Sat 90%
NIV 8 PEEP PC +15
FIO2 70%

STAP 3: Wat zou je nu aanpassen aan de alarminstellingen op basis van deze verslechtering?

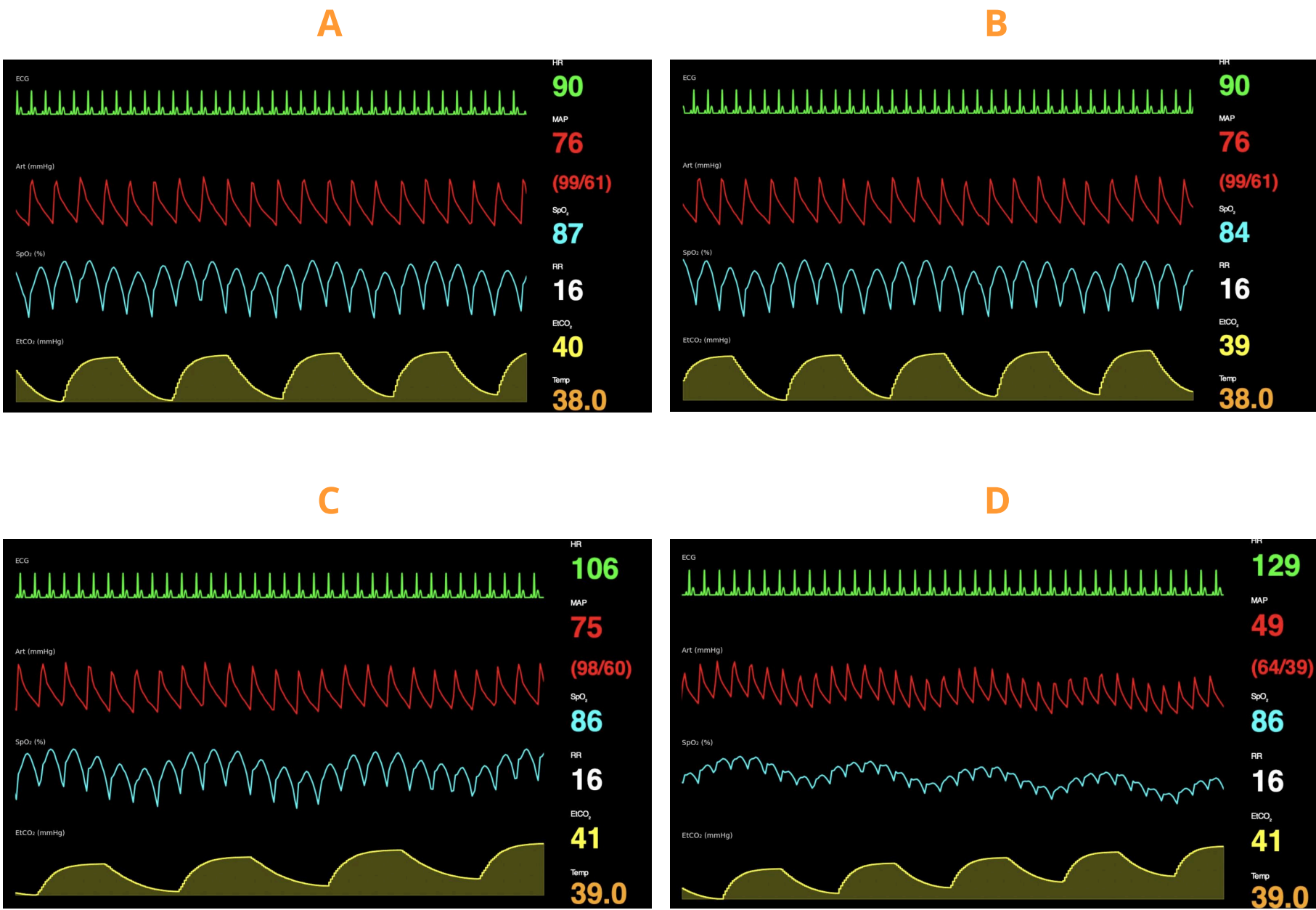
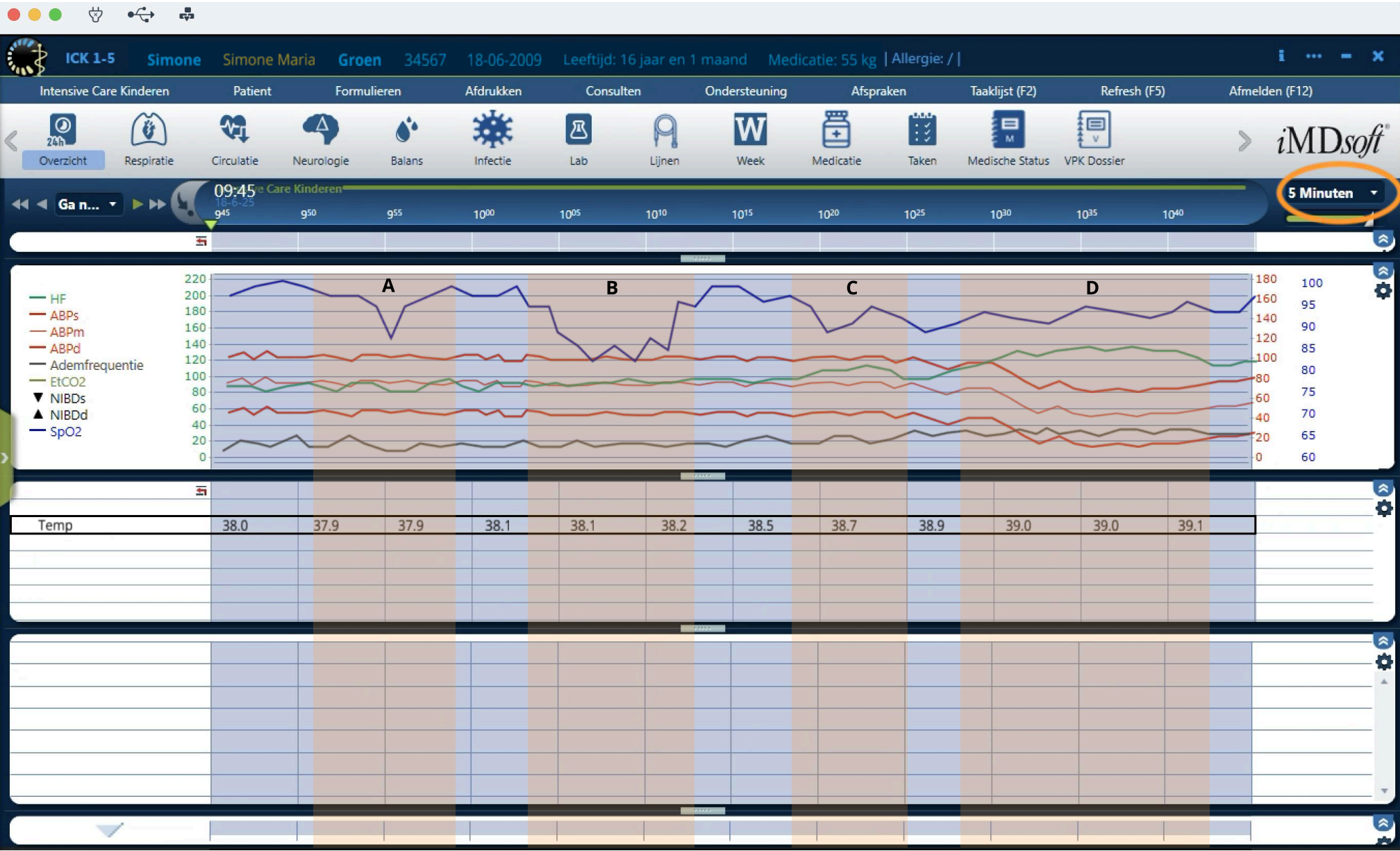
4

Het is 5 dagen later. Het **antibiotisch beleid** is **aangeslagen, zuurstof** is **afgebouwd**, en de verwachting is dat de patiënt met **2 dagen herstel** terug naar de afdeling kan.

STAP 4: Wat zou je nu aanpassen aan de alarminstellingen op basis van deze verbetering?

J: Simulated Monitors of patient deterioration for evaluation

Photoshopped Trend Data of deteriorating patient, corresponding to clinical scenario



K: Questionnaires Final evaluation

Attrakdiff

Vink aan hoe je deze begrippen bij het prototype vindt passen:

		1	2	3	4	5	6	7	
PK	Technisch	☐	☐	☐	☐	☐	☐	☐	Menselijk
	Ingewikkeld	☐	☐	☐	☐	☐	☐	☐	Eenvoudig
	Onpraktisch	☐	☐	☐	☐	☐	☐	☐	Praktisch
	Omslachtig	☐	☐	☐	☐	☐	☐	☐	Duidelijk
	Onvoorspelbaar	☐	☐	☐	☐	☐	☐	☐	Voorspelbaar
	Verwarrend	☐	☐	☐	☐	☐	☐	☐	Overzichtelijk
	Onhandelbaar	☐	☐	☐	☐	☐	☐	☐	Handelbaar
HKI	Isolerend	☐	☐	☐	☐	☐	☐	☐	Verbonden
	Amateuristisch	☐	☐	☐	☐	☐	☐	☐	Professioneel
	Stijlloos	☐	☐	☐	☐	☐	☐	☐	Stijlvol
	Minderwaardig	☐	☐	☐	☐	☐	☐	☐	Waardevol
	Afgezonderd	☐	☐	☐	☐	☐	☐	☐	Betrokken
	Scheidt mij van mensen	☐	☐	☐	☐	☐	☐	☐	Brengt mij dichter bij mensen
	Niet toonbaar	☐	☐	☐	☐	☐	☐	☐	Toonbaar
HKS	Conventioneel	☐	☐	☐	☐	☐	☐	☐	Origineel
	Fantasieloos	☐	☐	☐	☐	☐	☐	☐	Creatief
	Voorzichtig	☐	☐	☐	☐	☐	☐	☐	Gedurfd
	Conservatief	☐	☐	☐	☐	☐	☐	☐	Innovatief
	Saai	☐	☐	☐	☐	☐	☐	☐	Fascinerend
	Eenvoudig	☐	☐	☐	☐	☐	☐	☐	Uitdagend
	Gebruikelijk	☐	☐	☐	☐	☐	☐	☐	Nieuw
AT	Mooi	☐	☐	☐	☐	☐	☐	☐	Lelijk
	Goed	☐	☐	☐	☐	☐	☐	☐	Slecht
	Aangenaam	☐	☐	☐	☐	☐	☐	☐	Onaangenaam
	Sympathiek	☐	☐	☐	☐	☐	☐	☐	Onsympathiek
	Uitnodigend	☐	☐	☐	☐	☐	☐	☐	Afkeurend
	Aantrekkelijk	☐	☐	☐	☐	☐	☐	☐	Afstotelijk
	Motiverend	☐	☐	☐	☐	☐	☐	☐	Ontmoedigend

Design Goal Validation

Vink aan of je het eens of oneens bent met deze stellingen:
1 = Zeer Oneens, 7 = helemaal mee eens

	Zeer Oneens			Neutraal			Helemaal Mee Eens
	1	2	3	4	5	6	7
1. Ik voel me geleid door de interface tijdens het instellen of aanpassen van de alarmen van een patiënt.	☐	☐	☐	☐	☐	☐	☐
1. De interface voorzag me van genoeg informatie om de patiënt goed in te stellen.	☐	☐	☐	☐	☐	☐	☐
1. Het instellen van alarmen voelt efficiënt met dit systeem.	☐	☐	☐	☐	☐	☐	☐
1. De navigatie van de interface was logisch en intuïtief.	☐	☐	☐	☐	☐	☐	☐
1. Ik heb controle over het nieuwe systeem.	☐	☐	☐	☐	☐	☐	☐
1. Het systeem gedraagt zich zoals ik had verwacht. (confidence)	☐	☐	☐	☐	☐	☐	☐
1. Ik begrijp hoe ik een patiënt met dit nieuwe systeem moet instellen.	☐	☐	☐	☐	☐	☐	☐
1. Ik vind deze interface gemakkelijk te gebruiken.	☐	☐	☐	☐	☐	☐	☐

L: Detailed results of final evaluation test

AttrakDiff

Number		Begrippen	P1 (1-7)	P1	P2 (1-7)	P2	P3 (1-7)	P3	P4 (1-7)	P4	P5 (1-7)	P5	P6 (1-7)	P6	P7 (1-7)	P7	P8 (1-7)	P8	SCORES (1-7)	SCORES (-3 - 3)	MEANS			1--7
1	PK	Technisch - Menselijk	3	-1	5	1	3	-1	5	1	5	1	2	-2	3	-1	6	2	4,0	0,0	PQ	0,3	PQ	
2		Ingewikkeld - eenvoudig	4	0	5	1	6	2	4	0	6	2	2	-2	2	-2	6	2	4,4	0,4	HKI	0,9	HKI	
3		Onpraktisch - praktisch	2	-2	6	2	5	1	5	1	6	2	2	-2	2	-2	5	1	4,1	0,1	HKS	1,0	HKS	
4		Omslachtig - Duidelijk	2	-2	6	2	6	2	5	1	6	2	2	-2	2	-2	5	1	4,3	0,3	ATT	0,8	ATT	
5		Onvoorspelbaar - Voorspelbaar	4	0	4	0	6	2	5	1	5	1	3	-1	5	1	5	1	4,6	0,6				
6		Verwarrend - Overzichtelijk	3	-1	5	1	5	1	5	1	5	1	2	-2	3	-1	5	1	4,1	0,1	HK totaal	1,0		
7		Onhandelbaar -handelbaar	3	-1	5	1	6	2	5	1	5	1	3	-1	3	-1	6	2	4,5	0,5				
8	HKI	Isolerend - verbonden	4	0	5	1	6	2	5	1	6	2	4	0	4	0	4	0	4,8	0,8				
9		Amateuristisch - Professioneel	6	2	5	1	7	3	5	1	5	1	7	3	4	0	5	1	5,5	1,5				
10		Stijlloos - Stijlvol	6	2	5	1	5	1	4	0	4	0	7	3	5	1	6	2	5,3	1,3				
11		Minderwaardig - Waardevol	5	1	5	1	5	1	5	1	5	1	4	0	2	-2	5	1	4,5	0,5				
12		Afgezonderd - Betrokken	5	1	5	1	4	0	5	1	5	1	6	2	4	0	5	1	4,9	0,9				
13		Scheidt mensen - Dichterbij	4	0	4	0	5	1	3	-1	5	1	4	0	4	0	4	0	4,1	0,1				
14		Niet toonbaar - Toonbaar	6	2	5	1	6	2	5	1	6	2	4	0	4	0	5	1	5,1	1,1				
15	HKS	Conventioneel - Origineel	6	2	5	1	5	1	6	2	5	1	6	2	4	0	6	2	5,4	1,4				
16		Fantasieloos - Creatief	6	2	5	1	4	0	6	2	5	1	6	2	4	0	5	1	5,1	1,1				
17		Voorzichtig - Gedurfd	5	1	5	1	4	0	5	1	2	-2	6	2	4	0	3	-1	4,3	0,3				
18		conservatief - innovatief	6	2	5	1	6	2	6	2	5	1	6	2	3	-1	6	2	5,4	1,4				
19		Saai - Fascinerend	6	2	5	1	4	0	6	2	5	1	6	2	4	0	6	2	5,3	1,3				
20		Eenvoudig - Uitdagend	3	-1	5	1	6	2	5	1	3	-1	6	2	5	1	3	-1	4,5	0,5				
21		Gebruikelijk - Nieuw	6	2	5	1	5	1	6	2	5	1	7	3	4	0	5	1	5,4	1,4				
22	ATT	Lelijk - Mooi	7	3	5	1	6	2	5	1	5	1	7	3	5	1	5	1	5,6	1,6				
23		Slecht - Goed	6	2	5	1	5	1	5	1	5	1	2	-2	3	-1	5	1	4,5	0,5				
24		Onaangenaam - Aangenaam	5	1	5	1	5	1	5	1	6	2	4	0	2	-2	5	1	4,6	0,6				
25		Onsympathiek - Sympathiek	6	2	5	1	4	0	4	0	5	1	4	0	4	0	4	0	4,5	0,5				
26		Afkeurend - Uitnodigend	5	1	5	1	5	1	5	1	5	1	4	0	2	-2	5	1	4,5	0,5				
27		Afstotelijk - Aantrekkelijk	6	2	6	2	3	-1	5	1	5	1	5	1	4	0	5	1	4,9	0,9				
28		Ontmoedigend - Motiverend	5	1	6	2	3	-1	5	1	6	2	4	0	3	-1	5	1	4,6	0,6				

	P1	P2	P3	P4	P5	P6	P7	P8	MIN	MAX
PQ per participant	-1,0	1,1	1,3	0,9	1,4	-1,7	-1,1	1,4	-1,7	1,4
HQ-I per participant	1,1	0,9	1,4	0,6	1,1	1,1	-0,1	0,9	-0,1	1,4
HQ-S per participant	1,4	1,0	0,9	1,7	0,3	2,1	0,0	0,9	0,0	2,1
HQ totaal per participant	1,3	0,9	1,1	1,1	0,7	1,6	-0,1	0,9	-0,1	1,6
ATT	1,7	1,3	0,4	0,9	1,3	0,3	-0,7	0,9	-0,7	1,7
Standaarddeviatie PQ	1,33									
Standaarddeviatie HQ-I	0,49									
Standaarddeviatie HQ-S	0,71									
Standaarddeviatie HQ - TOTAAL	0,50									
Standaarddeviatie ATT	0,75									
n (aantal participanten	8									
df (vrijheidsgraden)	7									
t-waarde	2,365									
Betrouwbaarheidsinterval PQ	1,1	Bron voor berekenen confidence rectangle								
Betrouwbaarheidsinterval HQ	0,42	https://www.scribbr.nl/statistiek/betrouwbaarheidsinterval/								
Breedte rechthoek (PQ)	2,2									
Hoogte rechthoek (HQ)	0,8									

USER QUOTES CLUSTERED IN 5 IDENTIFIED THEMES DURING OPEN QUESTIONS

Two-sided Additional information shortcuts:
Riskful or helpful?

Positive

“The additional information can be helpful when the patient deteriorates or recovers.” - P2

“It could be nice to add “intubated” to the additional information.” - P5

“I would definitely use the circulatory, respiratory and infection additional information labels.” - P7

Negative

“You are less conscious of the settings when you use additional information.” - P4

“You don’t know which thresholds correspond with the information labels. That makes it really cluttered. Especially if you select multiple, you don’t know anymore which label is affecting which thresholds.” - P6

“The one patient with sepsis is not the other one. So I find it hard to imagine that I would use these labels. I think its faster to just change the target ranges yourself. Because now you have to go look every parameter like: what has changed with sepsis?” - P6

“If you don’t realise that the target ranges changed when clicking sepsis, then this could have consequences.” - P8

“The additional information is steering my focus, so maybe I will overlook other important things.” - P1

Incorporating the patient’s current values

“Does this system take the current values of the patient into account as well? That if the patient recovers, the target ranges are automatically adjusted?” - P8

“A blood pressure of 45 is way too low, so if the patient is not septic anymore you do not get an alarm in time.” - P4

“The target range depends on the current values of the patient. Often, I add or subtract 10 or 20 to determine the thresholds.” - P3

“I think it’s very valuable to have templates for certain patient groups, that works very well. But normally we configure a lot based on the current values of the patient. So sometimes these templates will not fit anymore.” - P5

“I do not set the thresholds the system suggests, but I look at the current values of the patient.” - P7

Positive depth duration algorithm

“This system will save us time. And besides: less alarms; what we all want.” - P3

“It is easy to work with this system, and it’s good that we are getting rid of those small alarms” - P4

“I would like to change this per separate parameter.” - P2

“It is a great addition to have these monitoring levels on how fast you alarm.” - P5

“I think it is not neccessary that you can change from low-mid-tight. Just a standard “delay” is enough. I only want to adjust the threshold.” - P7

“I want to be alarmed when the vital sign reaches the threshold. I don’t want a delay. If i need a delay, my thresholds are not set correctly.” - P1

Low trust in the system’s proposed values

“You don’t know which thresholds correspond with the information labels. That makes it really cluttered. Especially if you select multiple, you don’t know anymore which label is affecting which thresholds.” - P6

“I will always check all the values.” - P7

“I find it a risk to change the target range, so I would suppress the blood pressure alarm for 3 minutes. Because else you would not get a warning in time.” - P7

“I do not set the thresholds the system suggests, but I look at the current values of the patient.” - P7

“It would be nice to see the exact seconds within the tight-mid-loose graphs. Then it feels you are a bit more in control.” - P8

“I want to interpret myself if I find an alarm useful or not. That’s on me, not on the system” - P1

“It’s really nice that the system guides you step-by-step through all the things you might want to adjust. And its good that you already have a proposed value by the system. But I think people will always adjust.” - P5

Divided general attitude

Positive

“This system will save us time. And besides: less alarms; what we all want.” - P3

“It’s really nice that the system guides you step-by-step through all the things you might want to adjust. And its good that you already have a proposed value by the system. But I think people will always adjust.” - P5

“I think it works well to have a combination of the main problem and several additional information blocks, that’s handy.” - P4

“It was clear and insightful what influences something else.” - P7

“The interface could help me to make the configuration more quick.” - P2

“It would be really helpful to create certain stereotypes like “neurological surgery”” - P2

“I think this system can contributes to work comfort, especially if all devices are centralised on 1 system.” - P8

Negative

“It is not making it more clear for me.” - P1

“I am working here for 32 years, so I am not bothered by the alarms. I rather have them than not.” - P1

“It feels cluttered because you have so many things to choose.” - P6

“Currently, the alarms only sound when I want them to happen.” - P7

Needing time to get used to a new system

“You just need to get used to low-mid-high, and then you have way less things to change manually.” - P3

“That is really a new way of thinking.” - P4

“I should learn to switch between low-mid-high.” - P2

“I am not sure if this system is more easy, it is just very different.” - P4

“I think you need to get used to the new way of working. Initially the system can feel a bit unsafe, but eventually it will also bring things.” - P4

MINOR THEMES / INSIGHTS

Easy navigation

“Without having seen the system before, I can navigate through it by just reading the steps.” - P4

“I like that you can easily click through the different organ systems to configure the values of the parameters.” - P5

Handover issues

“You hand it over to a colleague, which expects to be in a certain profile. But if I fine tune a lot of values, than this expectation is not right anymore” - P4

“If I adjust something, my next colleague should know that it is adjusted.” - P3

Difficult risk estimation

“Basically, the risk is high for every patient. Because you start with tight thresholds, and then you see how the settings should develop.” - P6

“So I have to estimate the risk of a patient who just arrived? That is hard to say already at this moment.” - P6

“Why is the risk level important? This can change every half an hour.” - P7

Varying monitoring strategies

Mid way

“I will choose mid, because I think there is quite some margin before this patient completely deteriorates.” - P8

“If I’m in the room, and being busy with the patient, I will set my thresholds wider.” - P8

Tight monitoring

“I would never go for loose monitoring, because the patient is for a reason in the ICU.” - P4

“I want to get to know my patient. So I start tight, and later I will make them more wide. I prefer to be warned on time.” - P4

Not clinical but informative Alarms

“Alarms are also there to just do a fast check on the patient. Coughing is not dangerous, but the patient can be uncomfortable. So then we can just care for them by talking a bit or giving some water. So a short dip in saturation could be important to know that the patient feels not well. You are not giving any treatment, but just a bit of attention” - P3

“It’s not that I’m acute going to do something with a small dip, but it is an indicator that my patient possibly deteriorates. Just a small warning: I have to be a bit more cautious.” - P8

Other

“In this test set-up, it is hard that you don’t have a real patient in front of you. Normally with configuration, I feel guided by how the patient is looking.” - P3

“Maybe the alarms are most annoying for the parents, that we have to explain them every time, there is really nothing going on. It is very stressful for them” - P3

“Do I still need to confirm the monitoring level?” - P5