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APPLYING DESIGN THINKING TO IDENTIFY OPPORTUNITIES TO INNOVATE IN THE MANAGEMENT OF CLINICAL DETERIORATION

Master Thesis

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DISAINMÕTLEMINE KUI INNOVATSIOONI VIIS KLIINILISE SEISUNDI HALVENEMISE PUHUL

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Author’s declaration of originality

I hereby certify that I am the sole author of this thesis. All the used materials, references to the literature and the work of others have been referred to. This thesis has not been presented for examination anywhere else.

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Abstract

Unrecognized clinical deterioration is a problem whose complexity is poorly understood. Interventions to address this issue show contradicting or insufficient evidence to prove their effectiveness in different clinical settings. The present document is a qualitative exploratory study in which the main aim was to identify the opportunities for innovation in management of clinical deterioration by employing a design thinking model known as the Double Diamond model [1] as the conceptual framework. The study used mixed methods of data collection that consisted of a scoping review of literature and purposive semi-structured interviews to collect and map out the evidence regarding the focus areas in need of improvement to recognizing and responding to clinical deterioration. The thesis is divided in two stages determined by pairs of divergent-convergent thinking. In the first stage the key areas that need to be improved were mapped: (1) user experience, (2) education, (3) escalation of care and response, (4) predictive ability and (5) technology. In the second stage opportunities in which innovative solutions could respond to the problematic areas were drafted and later those with potential applicability supported by the findings in the first stage were grouped into opportunities to (1) improve user experience, (2) educate, (3) respond and escalate in a timely manner, and (4) introduce new technology. Finally, the emergency department and the general ward were the settings in which a current scenario constructed from the customer journey maps was contrasted to a proposed scenario in which the different opportunities to innovate could converge in a multi-faceted strategy to improve the management of clinical deterioration. In conclusion the use of design thinking helped the author answer the main research questions and gain deeper understanding of why new problem-solving approaches, bottom-up strategies developed in cooperation with the different stakeholders can lead to more successful implementations and produce better results to address the issue of unrecognized patient deterioration.

This thesis is written in English and is 68 pages long, including 12 chapters, 13 figures and 5 tables.

Annotatsioon

Disainmõtlemine kui innovatsiooni viis kliinilise seisundi halvenemise puhul

Tuvastamata põhjustel kliinilise seisundi halvenemine on probleem, mille keerukust pole piisavalt mõistetud. Teemat puudutavad sekkumised annavad vasturääkivaid ning ebapiisavaid tõendeid, et tõestada enda efektiivsust erinevate kliiniliste olukordade puhul. Käesolev dokument on kvalitatiivne ettevalmistav uuring, mille peamiseks eesmärgiks oli identifitseerida innovatiivse lähenemise võimalused kliinilise seisundi halvenemise korral, rakendades kontseptuaalse raamistikuna Double Diamond nimelist disainmõtlemise mudelit. Uuringus kasutati erinevaid andmekogumise meetodeid, mis hõlmasid kirjanduse läbivaatamist ning eesmärgipäraseid poolstruktureeritud intervjuusid kogumaks ning kaardistamaks tõendeid fookuses olevate ning parendamist vajavate kliinilise seisukorra halvenemist tuvastavate ning sellele reageerivate teemade kohta. Magistriöö on jaotatud kahte ossa, mis on määratletud hargneva ja koondava mõtlemise paaridena. Esimeses osas on parendamist vajavad võtmevaldkonnad: (1) kasutajakogemus, (2) haridus, (3) hoolimise ja reageerimise kasv, (4) ennetusvõimekus ja (5) tehnoloogia. Teises osas tuuakse välja võimalused, kus innovatiivsed lahendused võiksid olla problemaatilistele valdkondadele vastusteks ning hiljem grupeeriti potentsiaalselt rakendatavaid võimalusi ka esimeses osas kajastatud leidudega toetatuna erinevateks võimalusteks, et (1) parendada kasutajakogemust, (2) harida, (3) õigeaegselt reageerida ning eskaleerida, ja (4) tutvustada uut tehnoloogiat. Lõpetuseks kasutati olemasoleva klienditeekonna olukorra kaardistamiseks erakorralise meditsiini osakonna palatit ning tavapalatit ning vastandati see ettepanekul oleva stsenaariumiga, kus erinevad innovatsioonivõimalused võiksid koonduda mitmekülgseks strateegiaks parendamaks kliinilise seisundi halvenemise haldamist. Kokkuvõtteks aitas disainmõtlemine autoril vastata peamistele uuringu küsimustele ning saavutada sügavamat arusaamist sellest, miks uudsed probleemilahenduse lähenemised ja erinevate huvigruppidega välja töötatud rohujuure tasandilt üles-suunalised strateegiad võivad viia edukama rakendamise juurde

ning anda ka paremaid tulemusi patsiendi olukorra tuvastamata põhjustel halvenemisega tegelemiseks.

Lõputöö on kirjutatud Inglise keeles ning sisaldab teksti 68 leheküljel, 12 peatükki, 13 joonist, 5 tabelit.

List of abbreviations and terms

TUT	*Tallinn University of Technology*
PRISMA	*Preferred Reporting Items for Systematic Reviews and Meta-analyses*
	Early warning score
EWS	*Early warning score*
NEWS	*National Early Warning Scores*
RRS	*Rapid response systems*
RRT	*Rapid response teams*
TTS	*Track and trigger systems*
ICU	*Intensive care unit*
ED	*Emergency department*

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1 Introduction

Unrecognized clinical deterioration has been attributed to reduced or inappropriate monitoring of vital signs and to inadequate escalation of care for the deteriorating patient [2]; however, there are additional factors that contribute to this issue. These factors vary from organizational factors [3] (existence of appropriate protocols to respond to deterioration) to technical factors [4] (cumbersome and confusing electronic health records). Adverse events such as increased risk of mortality, prolonged length of stay and unplanned admissions into the intensive care are some of the consequences of delayed response to a patient's deteriorating condition.

To address the issue of unrecognized deterioration, interventions such as the implementation of early warning scores (EWS) [5], rapid response (RRS) [6] or track and trigger systems (TTS) [7], and systems for continuous monitoring of vital signs[8] have been implemented in many countries with the purpose of providing timely treatment to a patient before the occurrence of an adverse event. These interventions, however, still have many limitations and present high variability on how they are implemented and adhered to and thus fail to deliver improved outcomes or show little to no impact.[9]

There is significant room to improve in this field and create user-driven solutions that are designed with the complexity of the system in mind. For solutions to be sustainable and capable of delivering value, new problem-solving approaches that consider the needs of its users need to be embedded into every phase of the product development cycle. It is important that these approaches help developers confirm or discard initial assumptions of what is needed before major investments are made to develop or implement interventions. In this thesis, a design thinking approach will be used to explore the current practice in the management of clinical deterioration, define focus areas, identify domains where innovation can occur in each focus area, and deliver potential scenarios in which solutions could be developed.

This master thesis was elaborated in two stages based on a design thinking framework that provided the roadmap to achieving the main aim. The first stage consists of a of a scoping review of literature and semi-structured interviews with nurses. The results from

the scoping review as well as semi-structured interviews from which the customer journey maps were obtained, help to expand the knowledge regarding current practice in the management of clinical deterioration and define the focus areas that need improvement. The second stage identifies the opportunities for innovation and finally converges into potential scenarios in which innovative solutions could be developed to improve the management of clinical deterioration compared to current practice.

1.1 Aims of the thesis

The overall aim of the thesis is to identify the opportunities for innovation and present potential scenarios in which innovative solutions could improve the management of clinical deterioration compared to current practice. To achieve this goal, the author posed three main research questions:

- Which are the interventions currently used to manage clinical deterioration?
- What are the key areas that need improvement in the management of clinical deterioration?
- In which scenarios could innovative solutions improve current practice?

2 Background

A deteriorating patient, as defined by Jones et al, "is one that moves from one clinical state to a worse clinical state which increases the risk of morbidity including organ dysfunction, protracted hospital stay, disability or death." [10]. Defining clinical deterioration is key to understanding the pathway of a deteriorating patient as well as the outcomes of deterioration. This definition provides an understanding of three elements of clinical deterioration: (1) transition of the patient along different levels of care and health states, (2) risk stratification of deteriorating patients moving along different health states and (3) the negative outcomes associated with clinical deterioration once the patient transitions from one health state to a worse clinical state. Each of these dimensions

presents its own level of complexity which makes unrecognized deterioration difficult to solve.

To monitor and detect deterioration before the occurrence of an adverse event, solutions such as implementation of early warning scores (EWS) have been developed and implemented in several countries. EWS are aggregate-weighted scores calculated by assigning a weight to a measured or observed parameter and later adding scores from each parameter to obtain a single score[11]. Depending on the obtained score, the decision to escalate care should be taken. In countries like the UK, the use of EWS has been adopted and implemented on a national level and has been standardized in the form of a National Early Warning Score (NEWS). [12] These scores have often defined thresholds to determine when to escalate care for the deteriorating patient. EWS consist of the addition of the weights assigned to a defined set of physiological parameters or vital signs based on the measurement obtained and often include a measure for level of consciousness like the Alert Voice Pain Unresponsive (AVPU) scale which is the most widely used scale to assess the mentation state used in EWS [13]. Track and trigger (TTS) or Rapid response systems (RRS) are activated or triggered by a score that exceeds the normal threshold or by an extreme variation in one of the parameters. There is evidence of the effectiveness of these EWS and RRS for predicting adverse events such as ICU admission, hospital admission and mortality; however, there is little evidence that these systems have a significant impact on patient outcomes[7], [14]. Other studies have identified system-related factors such as lack of adherence to protocols, incomplete records of vital signs in the electronic health records and patient-provider ratios and patient related factors such as co-morbidities, severity of illness and type of criteria used to define deterioration as factors that contribute to delayed escalation of care for deteriorating patient [15] and thus lead to the transition from one health state to a worse health state.

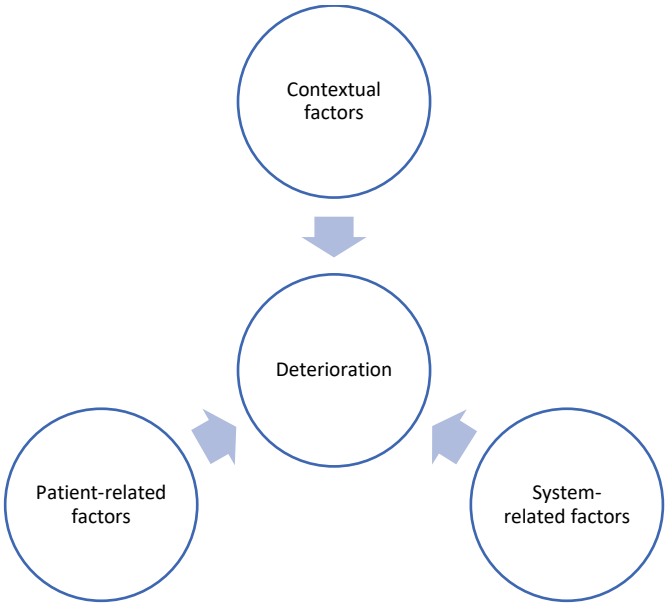

Figure 1 - Factors contributing to clinical deterioration (Source: author)

The early detection of clinical deterioration requires complex interventions that are able address the underlying factors that contribute to this problem on all its dimensions. New approaches and tools to develop innovative, user-driven solutions are therefore necessary.

Emerging methods for innovation in the field of digital health are gaining popularity due to their ability to capture user and patient needs and involve them in every phase of the product development cycle from understanding of the problem, conception of the solution, design, prototyping and assessment of the solutions in an iterative and collaborative way. Methods for co-creating solutions in the field of healthcare aim to deliver value to patients and develop solutions that are sustainable and effective. Two examples of these new approaches are (1) the living lab methodology, which fosters an environment for co-creation to develop user-driven ICT systems to solve complex issues in different fields[16] and (2) design thinking as a way to innovate and provide new approaches to how we understand and aim to solve persistent healthcare issues[17]. In this thesis, design thinking will be the conceptual framework used to guide the author in the process of identifying the potential domains of innovation for the management of clinical deterioration.

The decision to employ a design thinking framework in this thesis, originated from an attempt to understand the what is clinical deterioration. The definition presented earlier

in this chapter brought to light the complexity of the issue itself and gave an initial glimpse of why the issue is so difficult to solve. This in turn lead to the concept of "wicked problems". [18] The term "wicked" was adopted to differentiate a special group of problems for which traditional processes fail to provide a solution. Several authors have defined wicked problems; among those, we find Edward P. Weber and Anne M. Khademian, who define these problems as being unstructured, cross-cutting, and relentless. [19]

- They are unstructured, meaning they have different causes and effects that are difficult to define and are therefore likely to have unintended consequences. Moreover, the introduction of new policies or interventions are likely to be influence and be influenced by the problem itself.
- They are cross-cutting because they do not have clear boundaries that define the role of each actor and actors in the system though acting independently have a high degree of interdependency with each other and the system. They have multiple stakeholder each with their own set of perspectives and often conflicting interests.
- Relentless meaning the problems cannot be solved because they are not one-dimensional and require the systems to evolve as the system's behaviour iteratively and continuously adapts and changes. These problems require sustainable long-term solutions that can be continuously improved and account for emergent patterns in the system.

The above are inherent characteristics of complex healthcare issues, one of which is unrecognized clinical deterioration which can therefore be characterized as a "wicked problem" and as such, requiring new problem-solving approaches to tackle it. The term Design Thinking, emerged in the late 1970s and 1980's and has since been broadened to refer not only to a creative process used by designers, but also as a problem- solving approach. Melles et al. define it as a "human-centred problem-solving process decision makers use to solve real world "wicked" problems." [20]

In 1969, although not explicitly defined as Design Thinking, Herbert Simone presented one of the first formal models of Design Thinking[21]. Different frameworks have since been developed such as the Five Modes of Design Thinking proposed by the Hasso-Plattner Institute of Design at Stanford [22] and the Double Diamond model proposed by

the Design Council UK [1]. Both models offer a visual representation of the Design Thinking process in different stages that, although presented differently, illustrate the same problem-solving process leading to solutions in a creative and systematic way. In this thesis, the Double Diamond model will serve as the conceptual framework.

3 Conceptual framework

The Double diamond model, (shown in Figure 2) offers a graphical representation of the design thinking process. It was developed by the Design Council UK [1]. The model illustrates a problem-solving process by dividing it in two sets of divergent-convergent thinking. The first set leads to a definition of the problem and the second set leads to a solution. The usefulness of this model as a conceptual framework lies on different factors:

- Simplicity: it presented a very complex process in a simplified manner.
- Direction: it provided a clear roadmap to guide the problem-solving process
- Flexibility: it allowed selection of different complimentary methods of data collection
- Divergent-convergent thinking: leads first to the divergence needed to understand the problem on a wider more comprehensive manner, the convergence into defining the focus areas, the divergent thought to identify different opportunities for innovation and ultimately the convergence into potential scenarios.

Stage I covers the first set of divergent-convergent thinking which will make use of a scoping review of literature and semi-structured interviews with nurses using purposive sampling. The selection of a scoping review was based on the richness of information required to answer the first research question: Which are the interventions currently used to manage clinical deterioration? A scoping review provided the author with a way to collect research articles systematically, summarize the findings and map the key concepts regarding the interventions and current practice. Additionally, Arskey and O'Malley [23] propose a final optional step when conducting scoping reviews which consists of

consulting with relevant stakeholders to gain user insight into the problem and provide insight into aspects that literature may fail to cover. For this reason, the author selected semi-structured interviews to add more depth to the understanding of the issue as well as to map the current practice in emergency department, cardiac ward, and intensive care unit for cardiac patients in Estonia. The results from the semi-structured interviews helped construct the customer journey maps. The results from this stage also answered the second research question: What are the key areas in the management of clinical deterioration that need improvement?

For the second stage, the focus areas in need of improvement were that were mapped in the first stage were paired with solutions to counteract the deficiencies in each of these areas. These pairs represent the opportunities for innovation which the author will then use in different scenarios in which these solutions could be developed in contrast to current practice. These scenarios will provide the final convergence of the findings in this study. The value of these results lies in the fact that they will help developers and stakeholders gain insight into the possibilities to innovate and improve, prior to major investments and efforts to create solutions based on wrongful assumptions of what is needed.

The methodology and tools for each stage will be explained in more detail in their corresponding section.

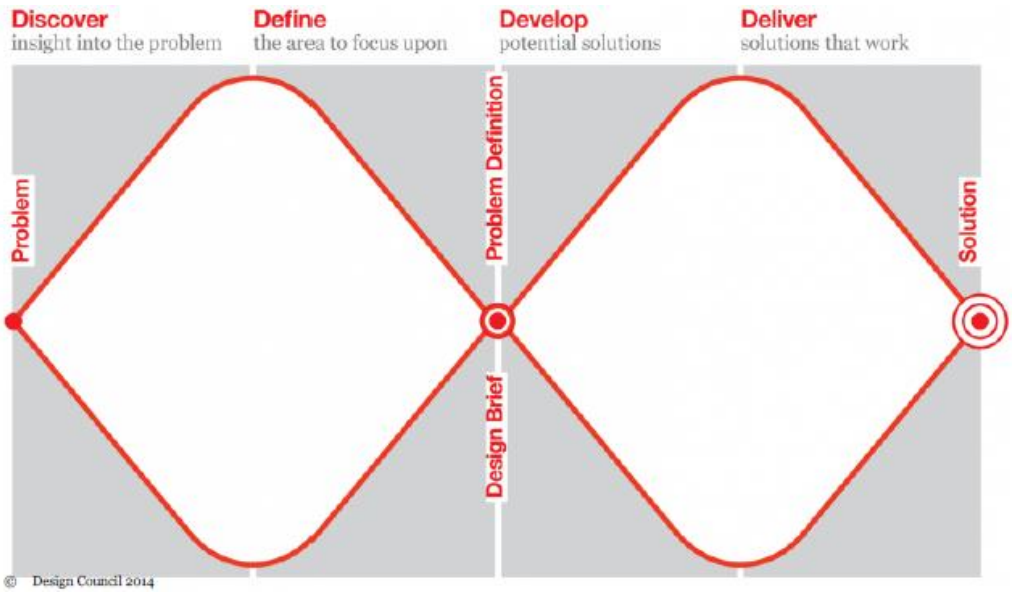

Figure 2 - Double diamond model (source: Design Council 2014)

4 Methodology and tools

The Design Council recommends the use of different methods to discover and define the problems for which a solution is being sought [1]. Among these methods, the use of stakeholder interviews and secondary data (such as literature) are listed [24]. Due to the nature of the problem, the discovery needs to be systematic to lead to evidence-based solutions. As explained in the Conceptual Framework (page 17) a scoping review of literature and 3 semi-structured interviews with nurses of the emergency department, cardiac ward, and cardiac intensive care unit were carried out in the first stage of this study. The methodology is thoroughly explained in the next chapter of this thesis.

5 Stage I: Discover and Define

This section presents the scoping review and semi-structured interviews performed as a part of Stage I of this thesis that aims to provide insight into the interventions and current practice in the management of clinical deterioration.

5.1 Rationale

Existing systematic reviews of literature on current practices for early detection of clinical deterioration focus on summarizing and assessing the effectiveness of specific interventions, particularly the predictive ability and clinical effectiveness of Early Warning Scores on outcomes such as in-hospital mortality. These reviews, however, do not provide a comprehensive overview of the different interventions and current practice in the management of clinical deterioration. Furthermore, it is necessary to consider the differences that might arise in different settings such as the emergency department, the general ward, and the intensive care unit. The purpose of the scoping review and semi-structured interviews was to collect research articles systematically, summarize the findings and map the key concepts regarding the interventions and current practice to answer the research questions required to achieve the aim of this thesis.

5.2 Methodology and tools

5.2.1 Scoping review

A scoping review of literature was performed in the following databases: PUBMED and SCOPUS. The publications included in this review were limited to English language, available in full text, published from 2008 to 2018. Only articles for interventions in adult patients (18 and over) were included. The following keywords were used: “clinical deterioration” AND detection, “clinical deterioration” AND early warning score OR rapid response system OR track and trigger, “clinical deterioration” AND continuous monitoring OR vital signs monitoring. Initial search results yielded 195 results in PUBMED and 92 results in SCOPUS an additional article was found in the Cochrane library that met the inclusion criteria. Articles that didn’t describe interventions to manage clinical deterioration in their summaries were excluded. In total, 269 publications were selected for initial screening. Duplicates, study protocols, studies evaluating pharmacological interventions, those focusing on the aetiology of clinical deterioration, editorial articles were excluded. A total of 64 articles were included in this review.

5.2.2 Nurse interviews

For the semi-structured interviews, participants were recruited over a period of two months using purposive sampling to select the participants and ask if they would be willing to participate in either phone interviews or in person. The rationale behind selection of nurses as the key informants was that nurses are the ones who are most in contact with patients during their transition along different levels of care thus were considered as the richer source of information to contribute to this study and provide a deeper understanding of the processes required to care for the deteriorating patient. Participants were contacted once via email or on social networks to schedule the interview. The participants selected for this stage were nurses that work in tertiary care hospitals in each of the following settings (1) emergency department, (2) inpatient ward and (3) intensive care unit.

5.2.3 Data collection

The following diagram (Figure 3 - PRISMA Flowchart for scoping reviews) summarizes the search strategy and final studies included in the qualitative synthesis.

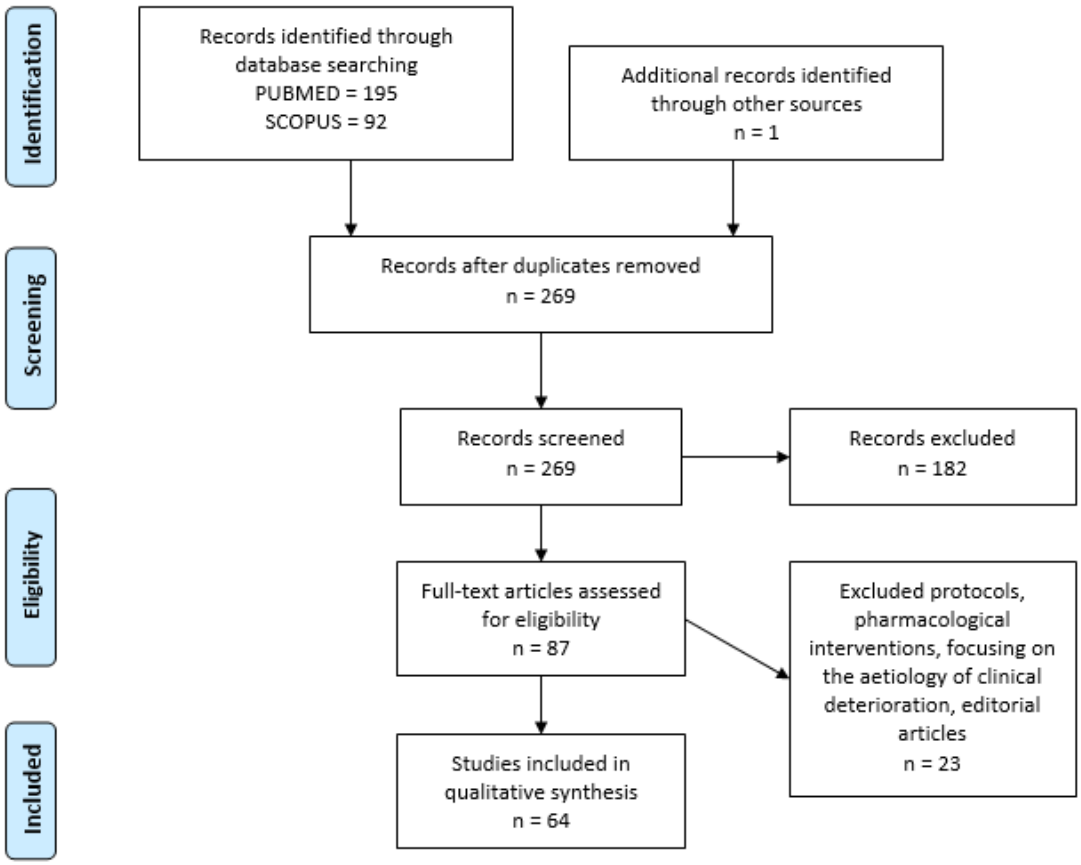

Figure 3 - PRISMA Flowchart for scoping reviews

To collect relevant information from the interviews, a basic Customer Journey mapping template was used [25].

Interviewer		Setting		Persona	
1	Lens				
2	Stage				
3	Doing				
3	Thinking				
3	Feeling				
3	Ideas				

Figure 4 - Customer journey template (adapted from Pattern Mini Experience Map)

The main elements in the Journey mapping template are the following:

- Lens: describes the lens through which the interviewee is viewing the experience. This requires a definition of the persona being interviewed. Interviewees will remain anonymous; however, their persona will be described in the section.
    - Who is the interviewee?
    - In what setting is the interviewee working? (Emergency department or general ward)
    - How are they affected from the issue of unrecognized clinical deterioration?

- Stage: the stages of the journey will be previously defined from the scoping review. There will be different stages for Emergency department and inpatient setting.
    - Emergency department stages: Arrival, Evaluation, Diagnostics, Discharge or admission
    - Inpatient: Admission, Stay, Discharge or Transfer to other levels of care
- Doing: what are the participants doing at each stage.
    - What actions do they take in each stage?
    - What technology do they use?
    - How do they interact with the patient?
- Thinking: describes how the interviewees describe their experience at each stage.
- Feeling: what are the interviewees feeling at each stage. These serves to empathize with the potential users of the solution as well as determine what are the touchpoints (Highs and Lows) at each stage.
- Ideas: This section is for the interviewer. It helps identify what the interviewer learned from each stage. What opportunities are there for improvement? What challenges do the prospective users face?

5.3 Data summary and synthesis

The data collected from the articles included in the scoping review was compiled in a Microsoft Excel 365 spreadsheet for coding and further analysis. The categories of the data extracted from selected articles where the following: year of publication, name of the article, Authors, study type, objective of study, type of intervention, Description of intervention, Focus, Primary outcomes, Secondary outcomes, setting, study participants, demographic information of participants, Type of hospital, who delivers the intervention, Parameters recorded by intervention, Mechanisms of intervention (method, type, and

frequency of monitoring, trigger criteria, response to trigger, and components), Results (composite of adverse events, LOS, unplanned ICU transfer, in-hospital mortality, 30 day mortality) Performance of risk scoring tools if mentioned (sensitivity, specificity area under the receiver operating characteristic curve) and additional comments if relevant.

Additionally, a separate analysis was performed for 6 articles that used an exploratory qualitative analysis of user experiences and perceptions about the management and interventions of clinical deterioration. These results consisted of perceived barriers and facilitators as well as the positive and negative experiences regarding the new interventions. All these articles included nurses as the main participants, and two also collected information from patients and family members.

The interviews were recorded with the authorization of the participants with assurance that all their responses would remain anonymous. The interviews were held with one participant over a video call and with two, they were conducted in person. The author used the predefined template and questions detailed earlier as a guide and allowed the participants to elaborate as much as the wanted in their responses. This allowed the interviewees to explain freely and with minimum director of the interviewer so to prevent responses being influenced by what the interviewees could perceive the interviewer wanted to hear. After the interviews were finalized, they were transcribed into text files and the information was extracted into the customer journey templates.

5.4 Data analysis

This section presents the findings from Stage I. The author made use of descriptive statistics to summarize the data extracted from the articles. The use of frequencies and percentages were the method selected to summarize nominal data. Pie charts were used to present the data for the main intervention groups and the settings in which these interventions took place. To present trends such as the number of publications per year, a line chart was used. From the articles included in the review, six exploratory studies, one feasibility study and one integrative review that performed qualitative assessment of users' experiences with different interventions were analysed separately to identify user perspectives, experience and barriers and facilitators to the use of new technologies and interventions. The findings from the interviews will be presented as the customer journey maps.

5.4.1 General characteristics of the studies

There was evidence of a growing number of publications over the last 10 years, most of the studies included in the qualitative summary were published in 2016 with a slight decline in 2017 and none published in 2018. This can be explained by the fact that studies started in the years 2017 and 2018 are still ongoing and have not been published yet. This finding is important, as it highlights a growing interest in finding solutions to unrecognized clinical deterioration. Retrospective cohort studies were the predominant type of articles included in this review, consisting of 39.1% of all the articles. These articles make use of electronic health records or clinical databases to retrospectively evaluate the predictive ability of different risk scoring tools (26% of the articles included). These findings do not asses an intervention prospectively and thus do not reflect the true predictive ability of these tools in real-life implementations. Additionally, only 4 clinical trials and 5 cohorts studies evaluated an intervention prospectively, which means there is not sufficient evidence to determine the real effectiveness of these interventions.

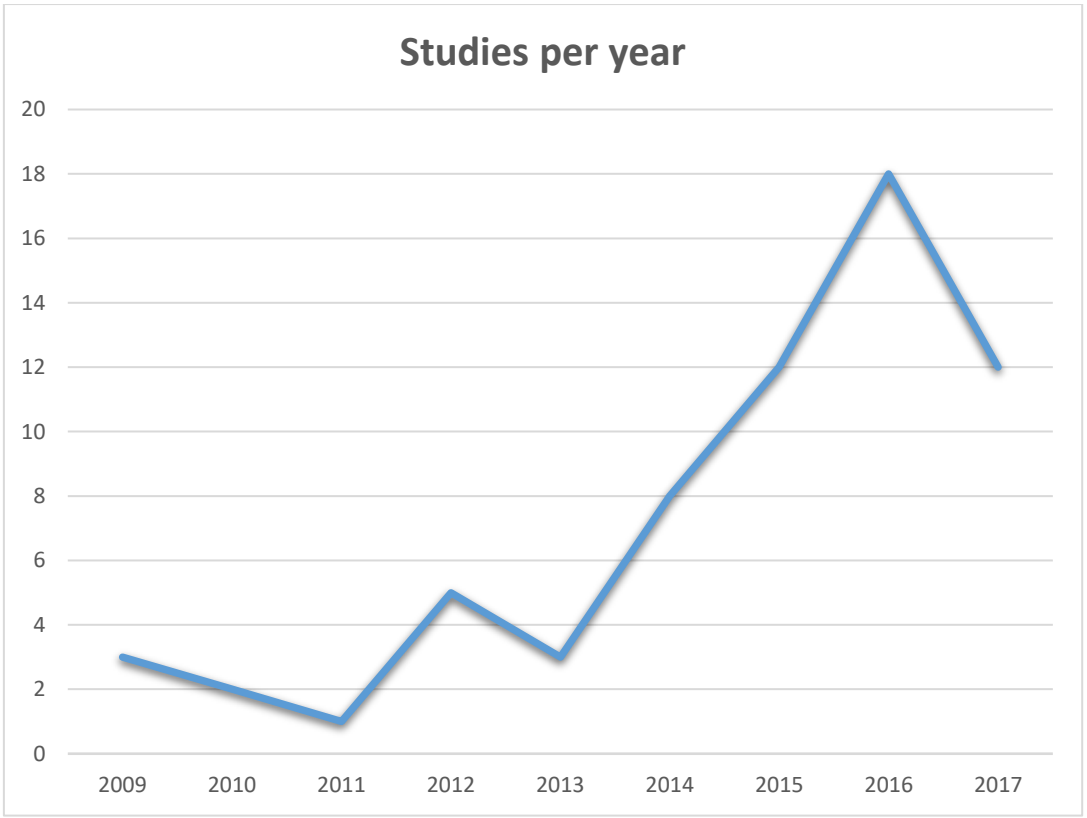

Figure 5 - Studies per year

Table 1 - Types of studies

Study type	n=64	%
Controlled trial	4	6.3
Prospective observational cohort study	6	9.4
Systematic review	5	7.8
Retrospective cohort study	25	39.1
Qualitative exploratory study	5	7.8
Case control study	3	4.7
Prospective black-box validation study	1	1.6
Prospective cohort study	5	7.8
Descriptive cross-sectional study	1	1.6
Pilot	1	1.6
Feasibility study	1	1.6
Technology assessment	1	1.6
Integrative review	2	3.1
Simulation study	1	1.6
Comparative retrospective study	3	4.7

Table 2 - Focus of the studies

Focus	n=64	Percentage
accuracy	3	4.7
adherence to protocol	7	10.9
comparison of methods	7	10.9
feasibility of implementation	2	3.1
impact on outcomes	11	17.2
mitigate unintended consequences	2	3.1
optimization of processes	2	3.1
overall assessment	1	1.6
predictive ability	17	26.6
risk factors	2	3.1
semantics	1	1.6
user experience	7	10.9
validation of risk tool	2	3.1

5.4.2 Interventions

Most of the interventions identified in the review consisted of implementation of aggregate weight risk scoring tools which are presented with a brief description in Table 3. The implementation of new protocols to detect or respond to deteriorating patients consisted of the implementation rapid response systems or track and trigger criteria to escalate care when necessary. The use of new devices was also a type of intervention which focused on new methods of monitoring vital signs. These devices included a

contactless monitoring called EarlySense (EarlySense) that was evaluated in two different studies [26], [27] and one technology assessment[28]. EarlySense (EarlySense), is a device that is placed under a patient's bed and can monitor heart rate, respiration rate and bed motion and is intended for continuous monitoring [26] and is used for low acuity patients. One study assessed the accuracy of Checkme (Viatom), a small device that enables patients in the general ward to measure their own vitals, in comparison to nurse measurements and gold standard methods. [29]. Another study used continuous ECG monitoring to derive cardiorespiratory dynamics and evaluate the predictive ability of these continuous measurements to predict cardiac arrest [30]. Five studies evaluate the use of wearable devices. The three wearable devices in the included studies were VisiMobile (Sotera Wireless, California) [31], Health Patch (Vital Connect) [8] and Fitbit Charge HR (Fitbit, San Francisco, CA) [32]. Finally, the use of different software tools that range in function from trend analysis to data fusion, was also assessed. These software tools included an electronic physiological surveillance system (EPSS) [33] designed to improve collection and clinical use of vital signs, a data-fusion software that collects data from different sources to calculate the patient status index, software that analyses vital signs trends from EHR [34], the eCART which collects vital sign data and laboratory data to calculate the Cardiac Arrest Risk Triage score [35] and an EMR-based early detection system called Advance Alert Monitoring (AAM). [36]

The setting in which most interventions were evaluated in, were inpatient wards for patients that are not critically ill. In general, these wards were grouped as inpatient wards but range from cardiac, surgical, medical, neurosurgical, psychiatric, neurological, and general wards. In these wards the frequency of monitoring was at least once per shift, although in many cases the frequency of monitoring was not specified. All monitoring and wearable devices were evaluated in this setting except for the Fitbit Charge HR (Fitbit, San Francisco, CA) which was tested in the ICU with stable patients who were not yet discharged from the ICU. Two additional interventions evaluated in the ICU were both aggregate weight scores at different times during the ICU stay, once at discharge to determine ability to predict readmission [37] and once prior to transfer to determine predictive ability for mortality in the ICU [38]. Interventions in the emergency department were also identified in 9 studies and included implementation of new protocols (MET calling criteria, track and trigger system, rapid response system), use of aggregate weighted scores in the ED (MEWS, peri-arrest MEWS[39] and the

Predisposition Insult/Infection Response Organ score (PIRO) [40]) to test their utility as standalone risk scoring tools or to complement traditional triage, and the use of data-fusion to collect data to calculate the patient status index [34]. Two of the studies evaluated the usefulness of aggregate weight scores in the ambulance setting. One compared the predictive ability of MEWS [41]compared to clinician judgement and the second used NEWS to determine subsequent deterioration of the patients arriving by ambulance [42]. Only one of the studies assessed the utility of rapid response systems for non-medical patients (visitors and hospital staff) in the hospital campus [43].

Table 3 - Aggregate weight risk scores

Name (Abbreviation)	Description
Sequential Organ Failure Assessment (SOFA)	Assigns a score to the number and the severity of failed organs by using a combinations of vital sign measurements, laboratory tests and assessment of cognitive function. It provides a score for pulmonary system (respiration measured using either PaO2/FIO2 or SaO2/FIO2) coagulation (platelet count), liver (bilirubin), cardiovascular (when hypotension is present), renal function (creatinine or urine output) and central nervous system (Glasgow coma score).[44]
Predisposition/Infection/Response/Organ Dysfunction Score (PIRO)	Assessment of predisposition factors (demographic data, comorbid conditions, and chronic organ insufficiency), insult factors (diseases and organ system), response factors (changes HR and RR) and organ dysfunction (from definitions of severe sepsis)[40]
Simple Clinical Score (SCS)	Assigns a score to different parameters such as age, systolic blood pressure, temperature, oxygen saturation, whether the patient is breathless, diabetes, coma, altered mental state, stroke is unable to stand without assistance and whether he or she spent some part of the day in bed prior to disease onset. [45]
Mortality in Emergency Department Sepsis (MEDS)	Assigns a score to patients age, rapid terminal comorbidity, presence of tachypnoea or hypoxemia, platelet count, presence of lower respiratory

	infection, altered mental status, if the patient is resident of a nursing home, septic shock, and neutrophil bands. [46]
Modified Early Warning Score (MEWS)	Measures Systolic blood pressure, Pulse rate, Respiratory rate, Temperature, Level of consciousness AVPU. EWS less or equal to 3 continue usual observation, if MEWS is equal to 4 then senior nurse reviews and decides whether monitoring continues for 4 hours or to call doctor for assessment decision to admit will depend on this. If score is greater than or equal to 5 call doctors immediately. [47]
Simplified Acute Physiology Score II (SAPS II)	Assigns a score to age, a to the worst value for each physiologic parameter that include heart rate Systolic BP, Temperature, GCS, PaO_2/FiO_2 (if on mechanical ventilation or CPAP) BUN, serum urea, mmol/L Urine output, Sodium, Potassium, Bicarbonate, Bilirubin, WBC, Chronic disease, Metastatic cancer, Hematologic malignancy, immunodeficiency, and type of admission to calculate score. [48]
Acute Physiology and Chronic Health Evaluation II (APCHE II)	Uses 12 parameters that include heart rate, temperature, arterial pressure, respiratory rate, FiO_2, arterial pH, sodium, potassium and creatinine in serum, haematocrit, WBC and GCS to calculate score. [49]
Rapid Emergency Medicine Score (REMS)	Uses blood pressure, respiratory rate, pulse rate and Glasgow coma scale, peripheral oxygen saturation and patient age to calculate score. [50]
National Early Warning score (NEWS)	Assigns a score respiration rate, oxygen saturation, any supplemental oxygen (Yes/no), temperature, Systolic BP, Heart rate and level of consciousness using AVPU as a scale to assess mental status. Three trigger levels are recommended based on score 1-4, 5-6 (or score of 3 in any parameter) and more than 6. [51]
Cardiac arrest triage score (CART)	information from laboratory tests, bedside monitors and admission,

	discharge transfer information were collected in real-time and integrated into a scoring database[35]
Dutch Early Nurse Worry Indicator score (DENWIS)	respiratory rate, arterial oxygen saturation, oxygen supply, systolic blood pressure, heart rate, temperature, and consciousness level and nurse "worry" to calculate a score[52]
Glasgow Coma Score (GCS)	It asses the mental state of patient by calculating a score based on evaluation of motor responsiveness, verbal performance, and eye opening. [53]
Richmond agitation sedation scale (RASS)	Assigns a score based on different levels of agitation and sedation. [54]
Alert voice pain unresponsive (AVPU)	Assess the level of alertness, response to voice, response to pain or if the patient is unresponsive. [55]

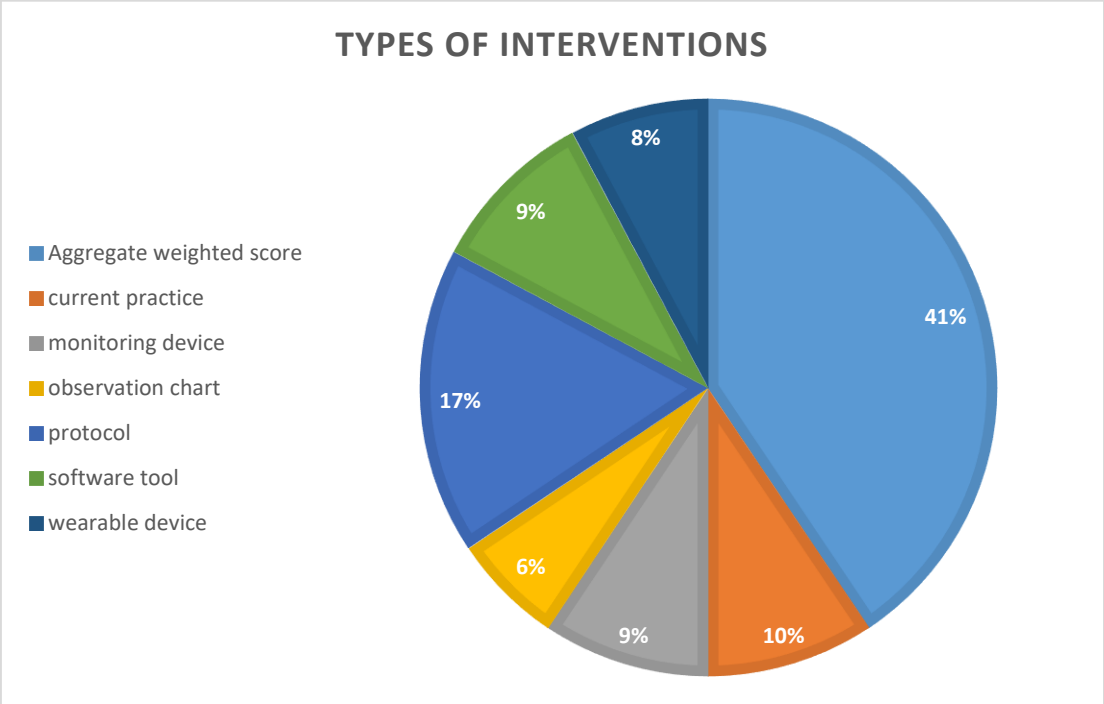

Figure 6 - Types of interventions (source: author)

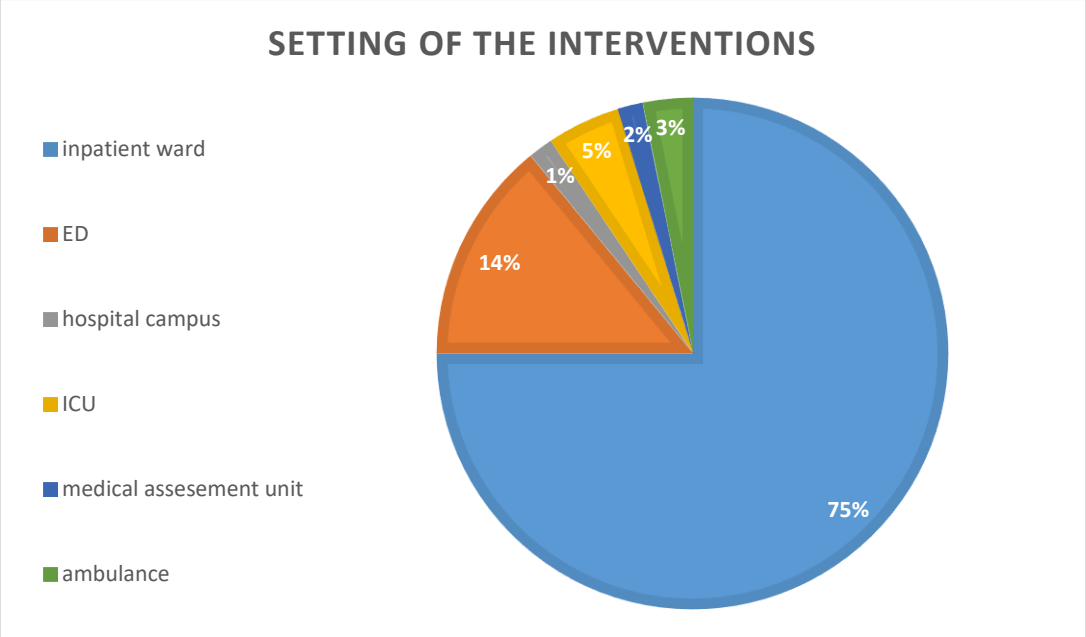

Figure 7 - Settings of the intervention (source: author)

Table 4 - Location of the interventions

Country	n=64	Percentage
Australia	6	9.4
Canada	1	1.6
China	2	3.1
Denmark	1	1.6
Iceland	1	1.6
Israel	1	1.6
Italy	2	3.1
Japan	1	1.6
Netherlands	6	9.4
Norway	1	1.6
South Africa	2	3.1
Singapore	1	1.6
Sweden	4	6.3
Thailand	1	1.6
UK	10	15.6
USA	15	23.4
Multiple	2	3.1
not specified	7	10.9

5.5 Summary of main findings of the scoping review

5.5.1 User experience

Two articles examined the experience of users after the implementation of wearable continuous monitoring devices[56] or the prospect of implementation of these devices in the general ward [57] and found that overall, the response to the use of the devices was positive and listed benefits such as decreased restriction in mobility, feeling of increased safety, possibility to monitor patients remotely and continuously. Some of the concerns noted by clinical staff and patients regarding the use of continuous monitoring wearable devices were the battery life, heaviness of devices, false positive alarms that increase alarm fatigue, device artifacts and the potential for decreased patient-provider contact. The implementation of MEWS [58] and new observational charts [59] were seen as useful in supporting clinical practice.

The table below summarizes the main barriers and facilitators to the implementation and effectiveness of interventions and in current practice for the management of clinical deterioration. The main barriers identified were classified as:

- Technical: mainly referring to the design devices and design of tools either software or hardware, device artifacts, lack of appropriate devices or faulty devices.

- Organizational: structure in which the main theme in all reviewed articles was either increased workload due to current practice or the possibility of increased workload due to inappropriate escalations of care brought on by the implementation of new monitoring devices.

- Human: included the discomfort caused to patients by increased monitoring, alarm fatigue caused by continuous monitoring[56], lack of knowledge or proficiency in the importance and correct practice in the management and response to deterioration[60] and finally negative response from colleagues after escalating care [61].

The main facilitator identified in all review articles was training to enhance skills for recognition of clinical deterioration, knowledge, and adherence to protocols and the use of the tools and supportive and open communication.

Figure 8 - Barriers and facilitators reported by users

Authors	Barriers to implementation and effectiveness of interventions			Facilitators
	Technical	Organizational	Human	
Smith et al. (2016)[3]	lack of manual and digital devices for monitoring and faulty devices	insufficient staff, high workload, and lack of availability of the senior nurses were barriers to monitor and escalate care in a timely manner	discomfort to the patient may be caused by monitoring and that setting regular intervals might make them more comfortable especially for patients with delirium	open communication and increased trust to facilitate the escalation of care
Stafseth et al. (2015)[58]				non-critical attitude, supportive communication from the mobile intensive care nurse and training
Mok et al. (2015)		increased workload and overwhelming feeling caused by current practice of vital sign monitoring may hider proper monitoring and escalation of care	lack of knowledge of the key indicators of deterioration wrong views of the use of pulse oximetry to assess respiratory function	continuous training to improve nurses clinical reasoning and ability to detect deterioration.
Elliot et al. (2016) [59]	chart size and style, use of ranges to graph vital signs was nor precise enough, preference towards numerical values instead of plotting in ranges.			human factors design features for the charts like colour coding for abnormal ranges to act as trigger Training to improve usability and adherence to chart guidelines to support improved detection and response for patients with clinical deterioration.
Weenk et al. (2017) [56]	Heaviness of one of the devices and many wires used by it. Short duration of battery (need to change every)12 to 14 hours Many artifacts Accuracy of devices	The workload of nurses and doctors makes it difficult for them to analyse all the data that is being generated continuously and, in this sense, the predictive value of the devices is lost	large number of alerts and even false-positive alerts could cause alarm-fatigue in nurses. allergies caused by adhesive in one of the devices	Improved design and increased battery life would facilitate or increase acceptance of these devices Lightweight and wireless devices make the patient feel more comfortable and increase possibility to move. Patients are not interrupted by intermittent monitoring and can sleep the whole night which helps them recover faster.
Prgomet et al. (2016)[57]	accuracy of current vital signs monitoring equipment	possibility of increased inappropriate escalations care was seen as a barrier to implement the continuous wearable monitoring devices	Potential for reduced patient-provider contact with the introduction of the wearable device and potential discomfort for the patient using the wearable	Training and improved interdisciplinary communication to implement the devices and appropriate escalation of care
Stevenson (2016)[4]	Cumbersome and confusing EMR design caused nurses to enter data in different sections multiple screen changes for needed for each sign to be documented. system was "awkward " to use		No consensus in which part of the EMR the vital sign data should be documented in	consulting with clinical staff and nurses before acquisition, implementation or development of electronic health records can facilitate acceptance of new technologies. Education on protocols and procedures and consensus on these processes can improve quality of documentation.
Massey (2016)[61]			negative responses from escalating care	Education to improve recognition, optimization of current practice to facilitate monitoring, collaborative environment and accessibility of support can enhance recognition and response to deterioration.

5.5.2 Predictive ability

Most studies focused on the assessing the predictive ability of different risk scoring tools. Some measured specificity and sensitivity of these tools and others the discriminatory ability to predict certain outcomes or a composite of those outcomes. In Table 5 a summary of the risk scoring tools identified in literature and their respective sensitivities, specificities and area under the receiver operating characteristics curve are presented (AUROC). As most of these studies were performed retrospectively, the true predictive ability and the usefulness of these tools is yet to be determined in a real-life situation.

Table 5 - Predictive ability of risk scoring tools

			Composite of adverse events			Cardiac arrest	ICU transfer	hospital death
Study	Setting	Name	Sen (%)	Spec (%)	AUROC	AUROC	AUROC	AUROC
Yu et al. (2014)[62]	general ward	SOFA	-	-	0.78	-	-	-
	general ward	PIRO	-	-	0.75	-	-	-
	general ward	SCS	-	-	0.74	-	-	-
	general ward	MEDS	-	-	0.74	-	-	-
	general ward	MEWS	-	-	0.73	-	-	-
	general ward	SAPS II	-	-	0.73	-	-	-
	general ward	APCHE II	-	-	0.72	-	-	-
	general ward	REMS	-	-	0.67	-	-	-
	general ward	Change in SOFA	75	72	-	-	-	-
Smith et al. (2013)[51]	general ward	NEWS	-	-	0.873	0.722	0.857	0.894
Kovacs et al. [63](2016)	general ward	NEWS	-	-	0.874	-	-	0.902
	surgical ward	NEWS	-	-	0.874	-	-	0.914
	Ambulance	MEWS	-	-	0.799	-	-	-

Fullerton (2012)[41]	Ambulance	Clinical judgement	61.8	94.1	-	-	-	-
	Ambulance	MEWS + CJ	72.4	84.8	-	-	-	-
Spångfors et al. (2016)[64]	general ward	Swedish NEWS	-	-	-	-	0.68	-
So et al. (2014)[41]	emergency department	MEWS	100	98.3	-	-	-	-
Reini et al. [38](2012)	ICU	MEWS	-	-	-	-	-	0.8
	ICU	SAPS III	-	-	-	-	-	0.89
	ICU	SOFA	-	-	-	-	-	0.91
Prytherch et al. [65](2010)	general ward	ViEWS	-	-	-	-	-	0.888
Moss et al. [30](2017)	general ward	CRD	-	-	0.73	-	-	-
Churpek et al. [66] (2013)	general ward	CART	-	-	0.78	0.83	0.77	-
Supattra et al. [37] (2017)	ICU	NEWS ICU dc	93.6	82.2	0.92	-	-	-
Churpek (2016) [67]	general ward	trend model	-	-	0.78	0.77	0.77	0.9
	general ward	current value	-	-	0.74	0.74	0.73	0.87
Kang et al. [35] (2016)	general ward	eCART	-	-	-	0.88	0.8	-
Douw et al. [52] (2016)	general ward	worry	-	-	0.81	-	-	-
	general ward	DENWIS	-	-	0.85	-	-	-
	general ward	worry + DENWIS	-	-	0.87	-	-	-

	general ward	EWS + DENWIS	-	-	0.91	-	-	-
Zadravecz et al. [55] (2015)	general ward	GCS	-	-	0.8	-	-	-
	general ward	RASS	-	-	0.82	-	-	-
	general ward	AVPU	-	-	0.73	-	-	-
	general ward	GCS + RASS	-	-	0.85	-	-	-

5.5.3 Impact on clinical outcomes

The impact on composite adverse events in the interventions included in this review cannot be determined. Two systematic reviews assessed the impact that critical care outreach systems [68] and non-invasive continuous monitoring of respiratory rate [69] on adverse events. These reviews conclude that there is not sufficient evidence to determine whether these methods lead to a reduction in adverse events. Only one study reported positive outcomes for a composite of adverse events showing reduction in unplanned ICU transfers, unexpected hospital deaths as well as increased medical reviews and medical emergency team reviews and improved documentation[70]. It is important to mention that this intervention consisted of comprehensive education programme for users, a redesigned color-coded observation chart to record and calculate MEWS scores and a two-tiered response system.

- **ICU Transfers and MET activations**

The implementation of a of a two-tier rapid response system was assessed to determine the impact of the system on medical emergency team call criteria, in this case the study showed that the implementation increased the number of met activations triggered by objective cardiorespiratory criteria and saw a reduction in calls triggered by subjective criteria such as worry additionally the study reported a decrease in mortality of patients admitted to the ICU. [71] The results from this study were similar to a study evaluating the impact of the adult deterioration detection charts (ADSS charts) that were implemented to plot vital signs and trigger MET activation which showed no impact in total MET/Code Blue activations but did show increase in reports of high heart rate and

a decrease in the use of the criteria ‘worried. [72] Both of these results show increases in objective calling criteria. The effect of a rapid response system on health related quality of life was not significant in pre a post implementation cohorts but did find a significant decrease of deterioration in mobility and usual activities six months after discharge [6]. A controlled trial showed a decrease in overall length of stay and days spent in the ICU in comparison to pre-implementation group as well as control group after implementation of a contactless continuous monitoring device for heart rate and respiration rate but found no significant impact on number of ICU transfers [27]. One systematic review that assessed the effectiveness of critical care outreach systems or rapid response systems included review of two cluster randomized control trials, one in which 23 hospitals in Australia participated and another in which 16 wards in the United Kingdom evaluated the impact of rapid response systems on a composite of adverse events and found conflicting evidence in which the trial in Australia found significant impact and the trial in the United Kingdom resulted in reduced hospital mortality in the control group. [68]

- **In-hospital mortality**

A reduction of in hospital deaths was reported after implementation of an electronic physiological surveillance system (EPSS) [33] and a multi-faceted intervention in which a new observation chart to calculate MEWS an education programme and a two tiered rapid response system were implemented. [70] Quality of documentation was improved both studies as well.

5.5.4 Adherence to protocol

Seven articles assessed the adherence to newly implemented protocols. The overall results show a poor adherence to monitoring protocols. Three studies identified a significant percentage of patient records in which incomplete or no vital sign documentation was present prior to arrest [4], [57], [73]. Completion of recordings was suboptimal for proper calculation of MEWS scores with respiration rate being the least recorded parameter in one study [74]. Another study showed that calculation of NEWS score was incorrect in almost one fifth of all patients and the percentage of error increased as a patient’s condition worsened [75]. In another study, the completeness of records was increased as a patient’s condition worsened and at the same time showed suboptimal use of the risk

scoring tool based on incomplete vital sign documentation [76]. The maximum adherence to protocol in two studies ranged from 20.3%[77] in one case, and less than 10% in another [4]. One study found that none of the patient records had all necessary parameters to calculate MEWS [78]. Finally, it was found in 6 out of 7 articles that the least recorded and in most cases inaccurately measured parameter was respiration rate.

5.6 Results from the interviews

The following section presents the completed customer journey templates and a diagram that traces the transition of patients from the emergency department to I, II and III levels of inpatient care. The emergency department information was obtained from a participant that works in a different institution than the participants from I and II, and III level cardiac units and therefore procedures in North Estonian Medical Centre may differ from those of East Tallinn Central hospital. The transition of the patient from the emergency department to higher levels of inpatient care, however, can be generalized for both.

5.6.1 Emergency department

The process in the emergency department as explained by nurse 1, described as a persona in the Lens, consisted of four main stages. The first consists of registration and triage of the patient, the second is the evaluation stage where the patient awaits a diagnosis. If the patient has suffered trauma but not severe, he or she is admitted to the trauma room to receive stitches, or get a cast placed. In the surgery room, patients who require observation perhaps due to abdominal pain will be admitted here. The intensive care room is for unstable patients who require more intensive care, as the name states.

During the Evaluation stage, the participant explained that on several occasions, patients are assigned to an inappropriate room. She mentioned, *"sometimes patients are sent to the surgery room and they really should be in the ICU."*

In the Monitoring stage, the participant expressed and increase sense of security about the health state of the patients since in this room the patients are connected to bedside monitors which emit beeping alarms when there is derangement of a vital sign. She noted that vital signs are recorded perhaps once on paper charts. Another important aspect during this phase is that the participant was unaware if there is any protocol in place to escalate care if a patient's condition is deemed to be deteriorating. She noted, however,

that despite being unaware if there was a formal protocol in place, there was a consensus among her and her peers that the most important vitals to recognize the worsening condition of a patient are blood pressure readings below 90/45 mmHg and oxygen saturation that falls below 93%.

Interviewer	Daniela Gallardo	Setting	Emergency Department	Persona	ED nurse
1	Lens	Nurse 1 works at the general emergency department at IDA Tallina Keskaigla. The general emergency department receives adult patient. The emergency has three main room types, for trauma, surgical and intensive care. Nurse 1 carries out activities in all of these rooms. She is aware of registration and triage but does not perform activities in these areas.			
2	Stage	Arrival	Evaluation	Diagnostics	Discharge or admission
3	Doing	Patients are triaged based on severity of symptoms into 5 different categories.	blood samples are taken if necessary	in surgery room check if patient is not in bad condition. Patient is constantly attached to monitor	Patients that have stroke go straight to neurological department, then get CT scan and are admitted.
		They take complaints	If diagnosis is not clear, patients stay around 4 to 5 hours	most important vital to escalate care is when bp is lower that 90/45 or oxygen level lower than 93%	
		measure BP and oxygen levels, temperature.	Other examinations like radiography or ultrasound might be necessary and patients are directed to these services	When caregivers they detect some abnormality they contact the nurse.	
		EKG depends on what patient is feeling		When patient is stable if they have not had any problems. Vitals are measured only once.	
				Patients in ICU are monitored continuously with bedside monitors	
3	Thinking	not clear how triage level is determined	Some patients are sent to the surgery room and they really should be in the ICU.	There is a lack of available beds sometimes and more beds would be beneficial	
			Patients deteriorate when sent to wrong room	most patients can sit and wait for care in the waiting room	
				more doctors are needed. Only one doctor per room	
3	Feeling	Some days are slow	Increased workload	Increased workload	
			Ocasional stress	Ocasional stress and worry	
			Anger when patients are sent to wrong room	Caregivers alleviate workload	
				warning from monitors indicates the patient needs attention	
				more confidence when patients are connected to bedside monitors	

Figure 9 - Journey mapping ED

5.6.2 Level I cardiac ward

The participant labelled as Nurse 2 has worked in both the I and II level cardiac wards and thus was able to explain the processes and activities in both wards as well as detail the differences in each of these wards. For clarity, two customer journey maps were created for each on the wards and although the same persona is used the Lens in each of these settings varied.

The procedures carried out in this setting are day procedures prescribed to stable patients. These include Holter tests and angiography. In the case of angiographies, the patient is

admitted to the second level care overnight after the procedure as a precaution. Patients have freedom of movement and can walk. They usually stay overnight. This area is for low-acuity patients.

The participant explained that here, only blood pressure in monitored once in the morning and once more during the evening. One of the problems noted was the backing-up of patients unavailable but necessary discharge documentation that requires patients that need to be admitted waiting for prolonged periods of time before they can be assigned a bed. When it comes to discharge, Nurse 2 explained that a document prepared by nurses consists of a word template that is to be filled in manually and noted: *"but it's basically just a word document from a template that nurse has to do from scratch and maybe this patient was taking 8 medicines and you are taking information from different places and searching these charts. It is not digital everything is paper, and this information needs to be input manually and if patient has wound then also details have to be recorded."*

Patients that are also stable and ready for discharge from II and III level care are also transferred to the ward before discharge, so discharge documentation is not only for the low-acuity day patients but also for patients that were transferred from higher level of care.

Interviewer	Daniela Gallardo	Setting	I level cardiac ward	Persona	general nurse in cardiac ward
1	Lens	Nurse 2 works in the I level cardiac ward. This ward is intentded for patients that need day procedures for example angiography, holter tests, echocardiograms. Patients are referred from GP or specialists and do not suffer from an acute condition. Patients can move around freely and are not connected to any monitor. This ward has 30 beds and there are 3 nurses working there so usually 3 nurses per 10 patients.			
2	Stage	Admission	Monitoring and documentation (Stay)	Routine rocedures (Stay)	Discharge
3	Doing	assistant who registers in and register out the patients	register epicrisis and procedure descriptions	take blood for necessary lab tests	Prepare dicharge documents
		Every day approximately 3 new patients	opened nursing documentation, diary and anamnesis	take and temperature, height and weight and blood pressure	
		they just go there, first they go to wardroom and then they were there since the morning wait there in the ward	blood pressure monitored once per shift	diabetic patients need glucose but they usually measure themselves	
			recording is all done on paper charts	administer medicines when necessary	
			Patient rounds at 8 a.m.		
3	Thinking	messy to admit new patient when patients ready to be discharged are still in bed.	doctors need to write down their orders like medications and additional requirements		Data is not stored in one place.
		New patient has to wait a long time to be admitted			Discharge documents have to me prepared from scratch
					problematic when people need to be discharged but the doctor has not prepared the documentation
					"discharge document expainign procedures and epicrises is basically just a word document from a template that nurse has to do from scratch and maybe this patient was taking 8 medicines and you are taking information from different places and searching this charts
3	Feeling	problematic process			messy
					prone to errors
					discharge procedures add more work

Figure 10 - Journey mapping general ward

5.6.3 Level II Cardiac ward

The second level cardiac ward is intended for patients that need observation and continued care. Care in this ward, however, is not critical as these patients are generally stable. Patients in this ward are either admitted after stabilization from the Emergency department or when III level intensive care in no longer necessary.

There is meeting at 8 o'clock to do patient rounds on II level and all patients are seen and their condition is reviewed and checked vitals that were recorded during night and doctor takes decisions if new treatment is needed or how to continue with care. Also, night nurse handed over shift to day nurse.

The night nurse gives an overview and after the day nurse goes on to routine activities like administering day medications, changing if needed dressings and cannulas. After every hour the nurses must mark vital signs in the intensive care sheets (observation

charts) where vital signs are plotted, and the patients' anamnesis is recorded. Every 24 hours this sheet must be replaced and a new one filled out.

"*every 24 hours a new sheet with the name of patient weight allergies, all this anamnesis part, then temperature BP what cannulas he has if there is catheter and what type. Also, if they have had any liquids and how much urine is going, out is created"*

When there is derangement in one of the vital signs, if the nurses consider this necessary, then the ward doctors working from 8:00 to16:00 are called so they can assess the patient. It is not clear whether there is a predefined procedure, but the process was rather subjective from the participants point of view. The nurse stated that these patients rarely deteriorate or need admission to the ICU.

"I don't know if there is a protocol but if the nurse finds abnormal signs then she calls doctor, but it is subjective mainly when nurses consider the patient needs to be seen by doctor"

The hierarchical structure in this ward was thought to make communication between nurses and doctors difficult at times. Another important aspect was the communication of changes in procedures or treatment that were explained verbally to the nurse but in seldom occasions written down in the observation sheets.

"Also, what I have noticed is that when doctors come and give instructions they only say it once verbally but don't write it down anywhere in this sheet they just say do it and it is up to nurse to understand it correctly and if you can do it how doctor wanted but they don't write what changes they make and it is stressful to figure out and keep track of this."

The feelings of stress in the area were caused mainly when there is a full unit (six patients) but only one nurse available.

"One nurse is there 12 hours and the other only 8 hours and if this room is full after second nurse left there is only one nurse there. If one nurse doesn't come also if children are sick or if nurse gets sick, then there may only one nurse for these patients and it gets stressful because it is too much work for one nurse."

Patients in this unit have limited mobility, they may be weak and need assistance to stand up. Patients are connected to different cables and when the patient feels well enough as asks nurses if it is possible to stand or go to bathroom alone, then many wires, cannulas etc. must be removed to allow the patient to move freely.

"they have to be in bed but if they feel okay already they can go to toilet, but nurses have to remove all wires because they were monitored all the time."

Interviewer	Daniela Gallardo	**Setting**	II level cardiac unit	**Persona**	general nurse in CCU
1	Lens	Nurse 2 also works in the II level cardiac unit. In this unit she and another coworker oversee 6 patients, meaning each of them cares for an average of 3 patients. Patients here are in a stable condition but require more advanced care than in he first level. The may come from emergency department if they had cardiac arrest and were stabilized or after they are discharged from intensive care unit (III level).			
2	Stage	Admission to II level	Monitoring and documentation (Stay)	Routine procedures	Transfer to I or III level
3	Doing	receive patients either from emergency department or from ICU	patient is connected to bedside monitors	measuring blood pressure every hour	if patient condition worsens call on call doctor
		Open anamnesis, intensive care sheet and nurse diary	routine recording of vital signs in intensive care sheets	administering medicines	when patient improves doctor approves transfer to I level
			routine recording of procedures in TIS sheet and calculating score	take blood samples	transfer to III level in case condition deteriorates
			daily rounds at 8 am and opening new intensive care sheet and TIS sheet.	measure urine input and output	patients sometimes remain there when there is no space in nursing homes.
				handover shift to night nurse and receive shift from night nurse	
				place catheters and cannulas	
				clean and check wounds	
3	Thinking		doctors are not readily available	one nurse only works 8 hours and the other works 12 so load is not balanced	doctor should be called when patient condition seems to worsen
			doctors dictate new orders but usually don't right anything down	When one nurse gets sick then all workload falls on one person	patients in this ward don't deteriorate usually
			it is hard to keep track of changes when doctor does not right down directions	somtimes it is difficult to do all procedures	hierachy makes communication difficult between nurses and doctors
			TIS score indicates how much care the patient needs but may not be intensive or specialized care just how much work.	family members sometimes want to be updated about patient's condition	not aware if there is a protocol to decide when to escalate care
			Calculating TIS scores is complicated	patients can't move around freely because of all the wires.	
3	Feeling		stressful to interpret doctors orders	stress	lack of team work due to hierarchy
			unsure about the utility of TIS scores	need for more support	care is escalated subjectively
			it is a struggle to calculate TIS scores correctly	fatigue	
			having information in one place could be helpful to prepare discharge papers		

Figure 11 - journey mapping II level cardiac unit

5.6.4 Level III intensive care cardiac ward

In this level, critical cardiac patients are admitted from emergency department or second level cardiac ward when condition worsens. The unit has 1 beds and 6 nurses working permanently on day and night shifts plus one additional day nurse that assists during the

day on an 8-hour shift from 8 to 16:00. The room is big and there are many alarms going off during the day. Nurse 3 was a trainee in this section, so the overview of procedures covers routine activities and perceptions of care but may not be as comprehensive to understand the different protocols in place.

The participant reported few pain points regarding the daily activities in this area. The critical conditions of this patients can be stressful for nurses; however, the team in this unit was described as "*very well coordinated"* and a sense of efficiency was reported.

"sometimes you see 12 people over one person and each one knows what to do. It is very impressive."

The bedside monitors connected to these patients permanently have audible alarms and involve many wires that are permanently attached to the patients. Identifying the origin of the alarm may sometimes be difficult but it was not considered a significant issue. When patients need intubation or artery cannulas, they will always be admitted to III level care.

Documentation of vital signs occurs in observation charts located at the patient's bedside, these charts are updated regular, though interval was not specified. Regarding this paper charts, the participant said that recording the vital signs and plotting this information works well on paper charts and saw no value in the possibility of recording the information on a digital medium.

Interviewer	Daniela Gallardo	Setting	III level cardiac unit	Persona	nurse in intesive care unit
1	Lens	Nurse 3 works in the III level cardiac unit. Intesive care. Patients here require constant and urgent care. These patients need to be monitored constantly. There are 2 nurses per patient in this unit. Patients are connected to bedside monitors that emit many alarms. Total of 6 nurses with one additonal nurse working in morning shift that assists in daily procedures.			
2	Stage	Admission from ED or II level	Monitoring and documentation (Stay)	Procedures	Transfer to II level or death
3	Doing	admission of unstable patients from II level or ED.	recording vital signs and plotting in intensive care sheet	administering medication	stable patients can be transferred to II level
		stabilization of the newly admitted patients	recording procedures in observational charts	taking blood samples	time of death called by doctor
			rounds and handover of shifts	recording urine input and output	
				responding to alarms	
				Assist in resucitation	
				placing cannulas catheters if needed	
				escalating care when resucitation is needed	
3	Thinking		These sheets work well on paper it is not much difference if it is digital or on paper	were organized and well coordinated team	Family members sometimes have to say goodbye to a patient in a huge room with no privacy
			There are many alarms from different monitors in one huge room	mobility is difficult due to patientscritical condition and all monitoring devices plus cannulas and Ivs	
3	Feeling		maybe more experience nurses have more ease when filling observation charts	care is efficient	
			sometimes it is difficult to identify which monitor is beeping	environment is stressful	

Figure 12 - Journey mapping 3 level cardiac unit

5.6.5 Mapping

The following map was constructed based on the information obtained from the journey maps. The arrows indicate the transition of the patient along the healthcare system from one health state to another. This is just a generalized view of the different levels of care through which a deteriorating patient may transition in the healthcare system.

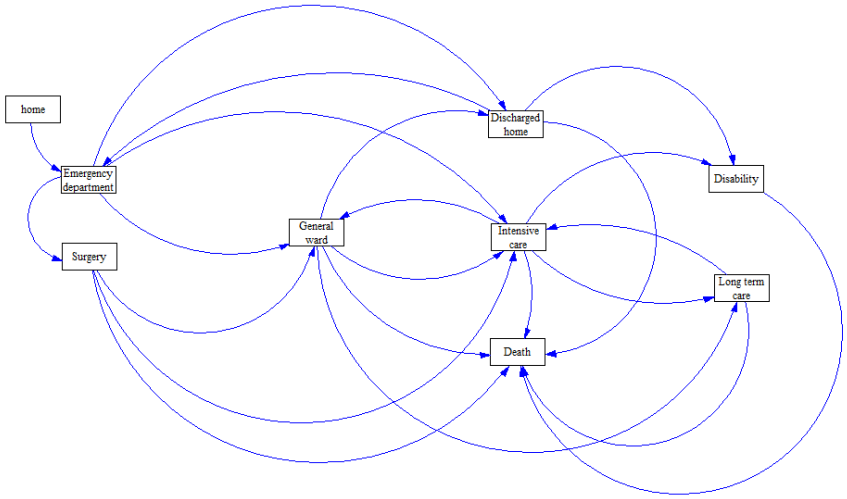

Figure 13 - Deteriorating patient transitions

5.7 Key areas for improvement

5.7.1 User experience

The results from the scoping review and the patient journey maps highlight the need to develop tools that consider the overall experience and workflow of its users. The following tools and the remarks on user experience are as follows:

- **Observation charts**

In the creation of paper-based observation charts, aspects like integration of human factors such as the color-coded used in the chart and the user preferences in recording either numerical values for precision or plotting valued in predefined ranges should be determined [59] and these tools should be piloted and validated before wide-scale implementation. The charts should be easy to understand a fit the daily activities of the nurses, which are the main users of these charts. The scores used in these charts should be explained to the users and training regarding the proper use of these tools is necessary to enhance their effectiveness[61]. In the interviews with nurses, certain deficiencies in these charts were noted such as the difficulty they present for junior nurses when overly complex scores are used.

- **Continuous monitoring devices**

One of the negative aspects regarding the design of wearable devices was the bulkiness of the devices and the wires required to monitor all parameters[56]. The comfort of the patients is necessary, especially in settings were patients are already uncomfortable and unwell. The amount of wires used by wearable devices can limit mobility and comfort of the patient. The other aspect to consider in the design of this devices is how they are attached to the patient. In one of the devices analysed in this review, the use of adhesive cause skin rashes for one patients[56] and so other patients might also experience allergies related to the materials in these monitors. On the clinical staff side, the main concerns with these devices were the amount of artifacts, the friendliness of the user interface[4], the procedures to troubleshoot artifacts that do not resolve on their own, low accuracy [32]resulting in high false alarm rate[69], increased workload and alarm-fatigue[79] and complicated calibration procedures[29]. In the case of those devices that are not wearable but are also employed for continuous monitoring, the same aspects of design should be considered. For devices that integrate multiple parameters intended for use by the patients, the usefulness of these devices could be limited by the fact that they are not autonomous, require the patient to perform his or her measurements regularly, and could potentially lead to infrequent measurements.

- **Aggregate weight tools**

Aggregate weight tools like the National Early Warning System have been evaluated for their predictive ability retrospectively [37], [41], [51] and show they are able to predict adverse outcomes many hours in some cases even over a day before the occurrence of adverse events. Despite these positive results, a major problem when these tools are used in real-life situations is that the documentation necessary to calculate them is often incomplete or is not calculated properly. One factor affecting the effectiveness of these tools is lack of awareness of their purpose and usefulness by the users.[57], [61] Training and awareness must be part of a comprehensive strategy to maximize the effectiveness of these tools. Overly complex tools, despite having good predictive ability, can add to the already heavy workload of nurses instead of supporting them in their daily activities and will be used at sub-optimal levels which limits their effectiveness both for risk prediction and timely escalation of care and to reduce adverse clinical events.

5.7.2 Education

For interventions to be successful, proper training of users is necessary. Most of the studies did not describe a training program when implementing the intervention. The results from the studies regarding adherence to protocol are alarming and can be attributed to many different education related factors. Seven articles were that assessed the adherence to newly implemented protocols were included in the review. The overall results show a poor adherence to monitoring protocols and in many of the studies, the lack of complete documentation of vital signs is highlighted. In 6 out of 7 articles that evaluated adherence to protocols, the least recorded and in most cases inaccurately measured parameter was respiration rate. This shows two important issues, the first is that respiratory function is not being properly assessed and the second is that it is erroneously considered as an unimportant parameter to detect physiological derangement[30], [60], [69]. Additionally, in both the interviews and the scoping reviews blood pressure measurement was perceived as the main indicator of deterioration and neglect of other important parameters occurs.[30], The assessment of nurses' knowledge of physiological instability and proper use of available tools is necessary to detect fundamental weaknesses in the system.

5.7.3 Predictive ability

There is room for improvement of the predictive ability of risk scoring tools. Low sensitivity and specify of the tools can lead to inappropriate activation medical emergency needs and cause unnecessary worry both for nurses and for patients. Evidence shows that the use of trend analyses and increasing the number of parameter used to calculate risk increased the predictive ability of existing risk scoring tools. In the case of DENWIS, for example the combination of worry (which is a subjective criteria) with a score calculated solely from physical parameters showed better predictive ability than the individual use of the tools. [52] There was also evidence of improved performance of different trend models to calculate risk in comparison to models that only use current values [67]. Inclusion of laboratory data can help assess the function of different organs so including these parameters is proven to enhance the accuracy of risk scoring tools. This is the case of the Sequential Organ Failure assessment which outperformed all risk scoring tools and was shown to have better predictive ability when a change in SOFA [44] score was used instead only the current score. Different methods to improve the accuracy of this tools need to be explored and validated. In one of the studies, a comparison of different mental

status scales revealed that although most tools use the Alert, Voice, Pain Unresponsive (AVPU) scale and the indicator for cognitive state to calculate the aggregate weigh score, the use of mental scales like the Glasgow coma score (GCS) and Richmond's agitation sedation score (RASS) were better predictors of mortality, and even more when used in combination. [55]

The thresholds and call criteria in different settings varies, and therefore the tools that are appropriate in one setting such as the general ward might need adjustment for implementation in the emergency department.

5.7.4 Escalation of care and response

Even when clinical deterioration is detected long before the occurrence of adverse events, the detection might have no impact on the patient's outcome because response delayed [2]. Delayed responses can be caused by organizational factors such as communication barriers between nursing and medical staff, hierarchical organization that prevents nurses from contacting doctors for fear of reprehension, and lack of availability of senior nurses[15] or emergency physicians.

5.7.5 Technology

Emerging technologies for early detection of clinical deterioration include continuous monitoring devices, multi-parameter all in one devices[29], data-fusion software[34], trend analysis software[66], [67], handheld or mobile devices to record observations about a patient's condition [72] and record vital signs and software to calculate early warning scores. Monitoring technologies include components such as transmission of data to central displays, wearable or contactless sensors to monitor vital signs, for receiving and visualizing vital sign information from different sources, algorithms, and alarm systems to notify clinical staff of detected abnormalities and software, wireless capabilities among others. Significant improvements are needed to take maximum advantage of these technologies, to make them sustainable and most of all cost-effective. Technology requires large investments, but their design does not fit the real needs of the end users. Technology must be accepted by its users for it to be sustainable[4], but often lack human-centred design. Some barriers to the detection and response to clinical deterioration that relate to technology were the lack of manual and digital devices for monitoring and faulty devices, heaviness of one of the devices and many wires used by

it, short duration of battery (need to change every) 12 to 14 hours[8], [29], [31], many artifacts, the accuracy of devices, cumbersome and confusing electronic health records design among others are main issues limiting the adoption of technology in this field. Another aspect noted is the need for ways to analyse the vast amount of data being generated by continuous monitoring technologies. Finally, the use of technology can have significant benefits, but also present many security risks so it is important to consider a thorough cybersecurity analysis of potential risks when designing these technologies. The findings of this study included technology that is still in early stages of adoption or being piloted in single institutions, therefore cybersecurity threats at these stages might not be evident but should be held as a top priority in the design of new interventions.

6 Stage II: Develop and Deliver

The second stage of the thesis is the outcome of the findings from the first stage of this thesis where the knowledge on clinical deterioration was expanded and key areas for improvement were defined. The product of this stage will be to present the opportunities to innovate in each key area for improvement. The intention of the author is to provide a holistic view of the issue and its underlying causes, the areas that need improvement to better manage clinical deterioration, what opportunities to innovate exist in each of these key areas and finally to converge scenarios in which these opportunities can converge to create multi-faceted interventions that aim to improve the management of clinical deterioration clinical deterioration. The intention of this stage is not to give a prescriptive solution but to present as much opportunities as possible for those who wish to innovate in the field.

6.1 Opportunities for innovation

In this chapter the opportunities for innovation will be described. The opportunities for innovation listed below were grouped based on the key areas for improvement defined in Stage I of this thesis. Each of these opportunities presents ways in which developers or stakeholders can be informed not only on what needs to be improved but how can this be improved.

6.1.1 Improvement of user experience

- Improved user interface in patient medical records can simplify the process of registering vital signs in the electronic health records. Healthcare records where many different screens need to be opened to enter the patients' information can take a lot of the nurses' time, that could be used to perform more of their clinical tasks instead of spending hours [4] navigating through complex systems to input this information.

- Chart redesign: integrating human design factors will be improve the usability and effectiveness of observation charts as well as improve adherence to standards of care such as appropriate vital sign documentation [59]

- Co-creation: in the studies presented in this paper, 8 studies described users experience when using new applications, devices, charts or adhering to current practice. The results from these studies show the importance of involving the main users of these interventions to increase satisfaction and adoption of new ways of working. In the study published by Stevenson et al. [4] the nurses shared their difficulties with using the electronic health record and reported not being asked about their opinion before acquisition and implementation of these tools.

- Design of devices: designing lightweight and comfortable devices is a facilitator for the adoption of new monitoring methods. With the emergence of clinical grade wearables, aspects of the devices design that will be accepted by patients are just as important as the monitoring capabilities and technical aspects of their development. Elements like weight, size, and comfortable fit and hypoallergenic materials [56] will give new wearables a competitive advantage over devices that may have the same technical capabilities.

6.1.2 Education

Evidence collected during the first stage showed that for interventions in the management of clinical deterioration to be successful, education and training are key factors for their success.[61] [70]. Education needs in clinical deterioration vary from development theoretical skills regarding physiology and signs of deterioration[60], technical skills such as the use of devices to measure vital signs and the proper ways to measure respiration rate[69], non-technical skills such as effective communication between peers involved in

the care of a patient[58], training in the proper use of tools such as observation charts and early warning scores and appropriate protocols to escalate care when deterioration is detected [61]. Opportunities to enhance the skills of nurses, medical emergency teams and even technical staff can be delivered in several ways with room for creativeness and integration of patient simulations, didactic materials, and e-learning tools.

6.1.3 Response and timely escalation of care

- Redesign of units was seen in different ways either by the introduction of medical emergency team or by adding a new role such as a mobile intensive care nurse [58]showed evidence of having a positive impact on appropriate responses to a patients deteriorating condition and or reducing adverse events like overall length of stay and mortality. Interventions should not limit themselves to technical solutions and should incorporate new protocols to deliver care that are able to make the most efficient use of resources. In some cases re-evaluation of their usefulness in different settings should be performed to determine whether they actually deliver value or if new approaches need to be considered [43]. There was also positive evidence about the implementation of two-tiered response systems in which patients with less serious trigger criteria are evaluated by a medical review team and if more critical criteria requires it then the rapid response system (medical emergency team) is activated. [71]

- Exploring new settings: inpatient wards and intensive care units are the settings where most efforts to manage clinical deterioration are directed to, but clinical deterioration is not confined to these settings. Opportunities to create solutions for patients at risk of deteriorating in their homes, long term care facilities, high risk pregnancies and other clinical settings ambulances and emergency departments should be explored. Targeting new developments towards a different type of patient in a different setting requires further research to determine the needs for special sub-groups of patients, but the opportunity to innovate is there. [42], [43], [74]

6.1.4 Introduction of new technologies

- Artificial intelligence: The applications are endless. A person’s healthcare record contains demographic information, stored lab results, history of complains,

history of medications, history of illness, and so much more. When talking about clinical deterioration, there are not just one set of factors like abnormal vital signs that can help predict the risk of adverse events[42], [71]. Patients with different comorbidities, ages, genetics, lifestyles have different factors that may put them at increased risk of deterioration. In the early detection of clinical deterioration, the use of artificial intelligence to integrate all the information available from patients not only from laboratory exams but also lifestyle patterns, eating habits, motion patterns, medications, data collected from sensors and even type of admission into a comprehensive risk analysis presents significant potential for early and accurate prediction of deterioration within an optimal period time. [80] This can be of value especially for older patients in nursing homes and patients with different comorbidities that are either independent or cared for at home.

- New sensors: clinical grade sensors that measure not only vital signs but also detect abnormal motion patterns, sweating and hydration, non-invasive glucose monitoring or even quick point of care tests that can assess renal function, liver function and blood gases can not only provide timelier results but also provide new cheaper alternatives to traditional laboratory exams. These sensors and point of care devices could also ease the process of calculating more complex risk scores that integrate new dimensions of a patient's condition to that could provide more accurate prediction of an adverse event. [40], [44]

- Big data: vast amounts of information are collected by this sensors and hospitals, researchers and clinicians can benefit from the use of this data to investigate pathologies, evaluate effectiveness of this interventions, detect patterns in derangement of vital signs and optimize thresholds to increase sensitivity and specificity of the sensors.

- Lightweight sensors: the bulkiness of the sensors and the need for different wires is uncomfortable to patients. Making lightweight sensors can improve patient comfort and allows patients to move with more freedom which can accelerate their recovery.

- Longer lasting battery: integrating battery with longer lifespan or rechargeable can be of value to nurses since they don't have to worry about changing batteries

so often and they can avoid have to disturb the patients frequently to change batteries while they sleep if battery runs out.

6.2 Scenarios

6.2.1 Emergency department

- Current practice:

  A female patient in her mid-40s arrives to the emergency department reporting abdominal pain. The patient enter triage where her vital signs heart rate, temperature, blood pressure, respiration rate and oxygen saturation are measured. The vital signs are normal and the pain the patient is experiencing is dull non-localized pain. The patient also reports painful urination, so a urine test is requested. The patient is categorized as not urgent (green), suspicion of a urinary tract infection (UTI). There is a long que about 3 to 4 hours wait. The patient has chills and a slight rise in temperature that go unnoticed. After 3 hours the patient starts feeling a sharp pain and tells the nurse, she is admitted to surgery room. She is evaluated by doctor who prescribes an abdominal ultrasound and laboratory analyses, this takes an additional hour before the results are ready. Ultrasound shows abscess in the appendix which ruptured. Patient must be taken to surgery immediately. Patient has an open appendectomy surgery and doctor cleans abdominal cavity. After surgery the patient is admitted to the ICU where strong antibiotics are administered to control the infection. A coma needs to be induced due to sepsis and high fever. Three days pass and patient's infection cannot be controlled due to resistant strain of bacteria. Patient dies from organ failure and sepsis.

  In current practice, despite technological advances, the diagnosis of appendicitis is still a challenge especially in the context of crowded emergency departments. Patient's presenting to the emergency department with abdominal pain have a high chance of being misdiagnosed and even more when these patients are elderly. Studies show that 30% of patients with appendicitis do not present a fever[81]. Moreover, vital sign abnormalities such as tachypnoea or dyspnoea can point to non-abdominal causes of abdominal pain such as cardiopulmonary diseases and

can help orient the diagnosis to discard such conditions. Additionally, clinicians should be vigilant for position, spontaneous movements, respiratory pattern, and facial expression of the patients. The presence of dysuria is common in urinary tract infections (UTIs), however, it may also be present when inflammation close to the genitourinary tract is present like in appendicitis. [82] These thorough examinations in the context of the emergency department may be often difficult due to time constraints and high workload among other reasons, making diagnosis of appendicitis difficult and resulting in a high percentage of misdiagnosed patients or those with delayed diagnosis.

- Proposal: Patient is a woman that arrives in the emergency department reporting some pain in lower abdomen. All patients are registered and triaged. Initial vital signs are recorded and entered into the electronic health record and appear normal. A wearable monitor is placed on the patient while she waits. The sensor measures heart rate, respiration rate, oxygen saturation, temperature, systolic blood pressure, motion, and hydration level. The monitor is part of an integrated system that retrieves information from the electronic health record in a secure way and uses patient demographics (age, sex, etc.), medical history (pregnancies, history of diseases such as UTI infections, comorbidities), medication history as well as current parameter measured by the monitor and symptoms described at triage to calculate the risk of the patient. The results from the urine test show no signs of bacterial infection despite patient presenting dysuria. The system updates the risk analysis. The patient is sitting in the waiting room and there is a long que around 3 to 4 hours wait. Within the first hour of admission the patient has chills, and the sensor detects trend in rising temperature and increased sweating, cardiopulmonary parameters remain normal, and motion sensor detects sudden movements of the patient and restlessness. Risk score is updated, and patient turns from green to orange. Nurse locates the patient and brings her in for evaluation. The patient is administered fluids and blood sample is taken for tests. Patient's results show signs of inflammation. Risk score is updated. Patient is taken to ultrasound where inflamed appendix and abscess is seen. Patient is administered antibiotics before surgery and is admitted for laparoscopic surgery before appendix ruptures. Patient is admitted to the ward where the sensor is placed once again. The data is now visible to the ward nurse as well as history and trends.

Patient is stable and is discharged after the second day. If necessary, she can keep the monitor in case of complications. She is prescribed to wear for one week, since the wearable is waterproof can be easily cleaned and disinfected and is charged by solar energy, the patient has not need to remove it and continues to wear at home. On the third day the monitor detects slight fever. The patient is still visible in nurse monitor where there is a section to monitor patients with early discharge. The patient is called in for check-up. One of the small incision sites seems to be infected. The patient is prescribed antibiotics and sent home where she continues being monitored. Patient can report any abnormal feelings or pain. Patient recovers. Wearable sensors are affordable, and settings can be modified to serve as fitness tracker.

6.2.2 General ward

- Current practice: The patient is admitted to the general ward. Patient may come from the ICU, surgical ward, CCU or Emergency department. The ratio of nurses to patients is 1 nurse per 3 patients. The patient is connected to bedside monitors that measure cardiorespiratory parameter like heart rate, respiration rate and oxygen saturation. The nurse monitors the patients every 4 to 6 hours and records vital signs on a paper chart. It's 8 a.m. in the morning and it's time for medical rounds. The doctor evaluated each patient and gives verbal instructions on how to proceed with the treatment. Medications need to be changed, new laboratory analyses are needed, and wound dressing needs to be changed. The nurse takes notes and then updates the patient charts. The nurse has three patients to oversee and each has different pathologies, ages, and therefore different risk of suffering adverse events. Moreover, each of these patients have different thresholds of normality (e.g. patient with COPD might have a lower level of oxygen saturation than a patient without). One of the patients has abnormal respiration rate and is a bit agitated. When it's time to monitor the patient, the nurse records blood pressure and urine output and they are normal. She plots this information on the paper chart. Inability to detect abnormal trends or derangement of vital signs in these patients leads to unrecognized deterioration. Six hours later the patient arrests. Lack of adherence to protocols to calculate record vital signs leads to an incomplete set of vital signs to calculate EWS. MET is activated the patient

arrests. Patient must be re-admitted to ICU or dies after an arrest or adverse event occurs.

- Proposal 2: Patient is admitted to the general ward were a wearable monitor is placed on admission to the ward. The wearable monitor measures 5 physiological parameters: (1) heart rate, (2) systolic blood pressure, (3) respiration rate (4) oxygen saturation and (5) temperature. Besides the physiological parameters, the wearable has motion sensors. The data is transmitted wirelessly to a centralized computer with a pre-installed software. Additionally, a secure and approved application for mobile phones and portable devices is available for patients and family members. Patients can enter information about what they are eating and how much liquids they are drinking, the can report whether they feel some pain and an image lets them touch where they feel the pain and rate the level of pain. Nurses can also report urine output and additional parameter like reporting whether they are worried of if patient needs supplemental oxygen. The nurse enters this information on a tablet with a graphic and friendly interface like well-designed paper-based charts. It is time for patient rounds and the nurse selects the speech to text function in the mobile app to transcribe what the doctor is saying. She selects her patients on the screen and the speech is entered in the observations section of the patients' electronic chart.

  The built-in software collects this data and new risk is updated every 10 minutes based on trend analysis and AI risk prediction that integrates patient's vital signs, sleeping patters, medications, patient reported issues such as pain, level of agitation of the patient. The patient has abnormal respiration rate and is a bit agitated, the risk score increases and the patients colour changes from green to yellow and the abnormal trends are highlighted as well.

  The nurse calls the senior nurse which is part of a two-tier response system. The nurse makes and assessment and marks the first-tier doctor that receive a notification on his application, he reviews and prescribes a change in medication and a sedative to allow the patient to sleep. The nurse receives the update on her device. Patient can sleep well, and respiration rate normalized. Patient recovers and can be discharged.

The system can be integrated with the electronic health record in the hospital and send this information which will be stored in patients' records. Unidentified data can be used for research purposes to optimize processes.

7 Results

The use of design thinking as the conceptual framework to achieve the aims of the study allowed the author to use two sets of divergent-convergent thinking to answer the research questions posed at the beginning of this thesis. This in turn allowed evidence to be collected and mapped out which served to deliver two scenarios in which the combination of the different opportunities for innovation could result in improved management of clinical deterioration of patients in different settings.

Expanding the knowledge regarding the different interventions currently used to manage clinical deterioration allowed the author to identify different kind of interventions that were categorized as (1) aggregate weight scores, (2) protocols of care, (3) software tools, (4) standard practice (5) continuous monitoring devices in which a subgroup (6) wearable devices was categorized separately (7) software tools and (8) paper-based observation charts.

The definition of the key areas that need improvements was a product of both the scoping review of literature and the semi-structured interviews whose results were presented as customer journey maps for emergency department, I general ward, II level cardiac unit and III level cardiac intensive care unit. From the qualitative analysis of the results, key areas for improvement were mapped out: (1) user experience, (2) education, (3) escalation of care and response, (4) predictive ability and (5) technology. Opportunities in which innovative solutions could respond to the problematic areas were drafted and later those with potential applicability supported by the findings in the first stage were grouped into opportunities to (1) improve user experience, (2) educate, (3) respond and escalate in a timely manner, and (4) introduce new technology. Finally use of different opportunities were merged into two different scenarios that were contrasted to current practice to show how these opportunities could deliver value to different stakeholders.

8 Conclusions

In the management of clinical deterioration, there is no one-size fits all solution. Complex healthcare problems such as this one requires comprehensive research to understand the multi-dimensionality of the issues and solutions cannot be simply technological or protocol implementation. A bottom-up strategy that is developed in cooperation with the different stakeholders can lead to more successful implementations and produce better results than one-sided decisions to adopt new policies that do not fully fit the real conditions and needs of the users. The use of design thinking for this project was considered as a valuable conceptual framework for the author that helped gain a deeper understanding of the different factors that influence the recognition and response to clinical deterioration. The opportunities describe in this paper do not claim a universal solution to unrecognized deterioration exists, but these findings can help different stakeholders in the design of well-rounded strategies that have the potential of being sustainable and effective. Several opportunities to innovate in the current management of clinical deterioration exist. It is evident though, that these interventions need to be paired with the improvement of technical and non-technical skills of clinical staff to recognize and respond to patients' deteriorating condition as well as training to ensure maximum adherence and understanding of new protocols of care, the use of new monitoring devices as well as the methods to calculate risk using aggregate weighted scores. The findings in this study include the definition of key areas for improvement in the management of clinical deterioration as well as the opportunities where innovation can counteract such deficiencies, but it must be stressed that one solution alone is not sufficient to address the issue and that these factors vary from setting to setting. The final convergence of the different opportunities to innovate in potential scenarios demonstrates how these opportunities can improve current practice and how their implementation can vary in different settings such as the emergency department and the general ward.

9 Limitations

This study has several limitations. There was a total of 64 articles included in this study, most of which have been published in the past 5 years. The rapid growth in the development of new wearable technologies and medical advances means many of the interventions included in this study will be obsolete in a few years and it is hard to reflect the current state of these developments since there might be ongoing studies that already evaluate the use of new technologies to manage clinical deterioration. Additionally, the search strategy might have limited the understanding of clinical deterioration to interventions being piloted in more developed countries but does not accurately reflect the situation and the extent of the problem in developing nations that do not have the infrastructure or resources to pilot and evaluate these technologies. The language restriction also means that articles published in other languages that might have expanded the view on the methods employed for example in Hispanic countries was also excluded. The interviews served to construct basic customer journey maps and were complimentary to findings of the scoping review, however limitations such as sample size and accessibility to senior nurses and physicians could have contributed to examining the situation in Estonia and identifying country-specific opportunities.

10 Summary

The present document is a qualitative and exploratory study in which the main was to identify the opportunities for innovation in management of clinical deterioration by employing a design thinking model known as the Double Diamond model [1] as the conceptual framework. The study used mixed methods of data collection that consisted of a scoping review of literature and purposive semi-structured interviews to collect and map out the evidence regarding the focus areas in need of improvement in the practice of recognizing and responding to clinical deterioration. The thesis was divided in two stages determined by the two sets of divergent-convergent thinking presented in the Double Diamond model. The first stage served to discover the problem by systematically collecting data and performing a qualitative synthesis and analysis from which the main types of interventions were grouped: (1) aggregate weight scores, (2) protocols of care, (3) software tools, (4) standard practice (5) continuous monitoring devices in which a subgroup (6) wearable devices was categorized separately (7) software tools and (8) paper bases observation charts. The key areas for improvement were mapped out: (1) user experience, (2) education, (3) escalation of care and response, (4) predictive ability and (5) technology. In the second stage opportunities in which innovative solutions could respond to the problematic areas were drafted and later those with potential applicability supported by the findings in the first stage were grouped into opportunities to (1) improve user experience, (2) educate, (3) respond and escalate in a timely manner, and (4) introduce new technology. Finally, the emergency department and the general ward were the settings in which a current scenario constructed from the customer journey maps was contrasted to a proposed scenario in which the different opportunities to innovate could converge in a multi-faceted strategy to improve the management of clinical deterioration.

A bottom-up strategy that is developed in cooperation with the different stakeholders can lead to more successful implementations and produce better results than one-sided decisions to adopt new policies that do not fully fit the real conditions and needs of the users.

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Appendix 1 – Summary of articles included in the review

Year	Name of the article	Authors	Study type	DOI
2009	A Trial of a Real-Time Alert for Clinical Deterioration in Patients Hospitalized on General Medical Wards	Thomas C. Bailey, Yixin Chen, Yi Mao, Chenyang Lu, Gregory Hackmann, Scott T. Micek, Kevin M. Heard, Kelly M. Faulkner, Marin H. Kollef	Controlled trial	10.1002/jhm.2009
2009	In-hospital mortality and morbidity of elderly medical patients can be predicted at admission by the Modified Early Warning Score: a prospective study	M. Cei, C. Bartolomei, N. Mumoli	Prospective observational cohort study	10.1111/j.1742-1241.2008.01986.x
2009	Outreach and Early Warning Systems (EWS) for the prevention of Intensive Care admission and death of critically ill adult patients on general hospital wards (Review)	McGaughey J, Alderdice F, Fowler R, Kapila A, Mayhew A, Moutray M	Systematic review	10.1002/14651858.CD005529.pub2.
2010	ViEWS—Towards a national early warning score for detecting adult inpatient deterioration	David R. Prytherch, Gary B. Smith, Paul E. Schmidt, Peter I. Featherstone	Retrospective cohort study	10.1016/j.resuscitation.2010.04.014
2010	A prospective controlled trial of the effect of a multi-faceted intervention on early recognition and intervention in deteriorating hospital patients	I.A. Mitchell, H. McKay, C. Van Leuvan, R. Berry, C. McCutcheon, B. Avard, N. Slater, T. Neeman, P. Lamberth	Controlled trial	10.1016/j.resuscitation.2010.03.001
2011	Nursing documentation prior to emergency admissions to the intensive care unit	Thorsteinn Jonsson, Helga Jonsdottir, Alma D Moller and Lov ¨ ´ısa Baldursdottir	Retrospective cohort study	

2012	Early Recognition of Acutely Deteriorating Patients in Non-Intensive Care Units: Assessment of an Innovative Monitoring Technology	Eyal Zimlichman, Martine Szyper-Kravitz, Zvika Shinar, Tal Klap, Shiraz Levkovich,Avraham Unterman, Ronen Rozenblum, PhD,Jeffrey M. Rothschild, Howard Amital, Yehuda Shoenfeld	Retrospective cohort study	10.1002/jhm.1963
2012	The ability of the National Early Warning Score (NEWS) to discriminate patients at risk of early cardiac arrest, unanticipated intensive care unit admission, and death	Gary B. Smith, David R. Prytherch, Paul Meredith, Paul E. Schmidt, Peter I. Featherston	Comparative retrospective study	10.1016/j.resuscitation.2012.12.016
2012	Is the Modified Early Warning Score (MEWS) superior to clinician judgement in detecting critical illness in the pre-hospital environment?	James N. Fullerton, Charlotte L. Price, Natalie E. Silvey, Samantha J. Brace, Gavin D. Perkins	Retrospective cohort study	10.1016/j.resuscitation.2012.01.004
2012	The prognostic value of the Modified Early Warning Score in critically ill patients: a prospective, observational study	Kirsi Reini, Mats Fredrikson and Anna Oscarsson	Retrospective cohort study	10.1097/EJA.0b013e32835032d8
2012	Identification of deteriorating patients on general wards; measurement of vital parameters and potential effectiveness of the Modified Early Warning Score	Jeroen Ludikhuize, Susanne M. Smorenburg, Sophia E. de Rooij, Evert de Jonge	Retrospective cohort study	doi:10.1016/j.jcrc.2012.01.003
2013	Effects of a rapid response system on quality of life: a prospective cohort study in surgical patients before and after implementing a rapid response system	Friede Simmes, Lisette Schoonhoven, Joke Mintjes, Bernard G Fikkers, Johannes G van der Hoeven	Prospective cohort study	10.1186/1477-7525-11-74
2013	Risk Stratification of Hospitalized Patients on the Wards	Matthew M. Churpek, Trevor C. Yuen, Dana P. Edelson	Systematic review	10.1378/chest.12-1605

2013	Medical emergency team response for the non-hospitalized patient	Tracey A. Dechert, Babak Sarani, Michelle McMaster, Seema Sonnad, Carrie Sims, José L. Pascual, and William D. Schweickert	Retrospective cohort study	10.1016/j.resuscitation.2012.06.022.
2014	Continuous Monitoring in an Inpatient Medical-Surgical Unit: A Controlled Clinical Trial	Harvey Brown, Jamie Terrence,Patricia Vasquez, David W. Bates, Eyal Zimlichman	Controlled trial	10.1016/j.amjmed.2013.12.004
2014	Recongnising clinical deterioration in emergency department patients	Jennifer Hosking, Julie Considine, Natisha Sands	Descriptive exploratory study	10.1016/j.aenj.2014.03.001
2014	Comparison of risk prediction scoring systems for ward patients: a retrospective nested case-control study	Shun Yu, Sharon Leung, Moonseong Heo Graciela J Soto, Ronak T Shah, Sampath Gunda, Michelle Ng Gong	Case control study	doi:10.1186/cc13947
2014	Is the Modified Early Warning Score able to enhance clinical observation to detect deteriorating patients earlier in an Accident & Emergency Department?	Shuk-Ngor So, Chi-Wai Ong, Lai-Yee Wong, Josephine Y.M. Chung, Colin A. Graham	Prospective observational cohort study	10.1016/j.aenj.2014.12.001
2014	Record Review to Explore the Adequacy of Post-Operative Vital Signs Monitoring Using a Local Modified Early Warning Score (Mews) Chart to Evaluate Outcomes	Una Kyriacos, Jennifer Jelsma, Sue Jordan	Retrospective cohort study	doi:10.1371/journal.pone.0087320
2014	Feasibility of using the predisposition, insult/infection, physiological response, and organ dysfunction concept of sepsis to predict the risk of deterioration and unplanned intensive care unit transfer after emergency department admission	Jeffrey Che-Hung Tsai, Shao-Jen Weng, Chin-Yin Huang, David Hung-Tsang Yen, Hsiu-Ling Chen	Retrospective cohort study	10.1016/j.jcma.2013.12.001

2014	Individualizing and optimizing the use of early warning scores in acute medical care for deteriorating hospitalized patients	Muge Capan, Julie S. Ivy, Thomas Rohleder, Joel Hickman, Jeanne M. Huddleston	Retrospective cohort study	10.1016/j.resuscitation.2014.12.032
2014	Detection and management of the deteriorating ward patient: an evaluation of nursing practice	Mandy Odell	Retrospective cohort study	10.1111/jocn.12655
2015	A single-centre observational cohort study of admission National Early Warning Score (NEWS)	Tom E.F. Abbott, Nidhi Vaid, Dorothy Ip, Nicholas Cron, Matt Wells, Hew D.T. Torrance, Julian Emmanuel	Retrospective cohort study	10.1016/j.resuscitation.2015.04.020
2015	Exploring the performance of the National Early Warning Score (NEWS) in a European emergency department	N. Alam, I.L. Vegting, E. Houben, B. van Berkel, L. Vaughanc, M.H.H. Kramer, P.W.B. Nanayakkara	Retrospective cohort study	10.1016/j.resuscitation.2015.02.011
2015	Characteristics and Outcomes of Patients Admitted to ICU Following Activation of the Medical Emergency Team: Impact of Introducing a Two-Tier Response System	Anders Aneman, Steven A. Frost, Michael J. Parr, Ken M. Hillman	Retrospective cohort study	10.1097/CCM.0000000000000767
2015	Comparison of Mental-Status Scales for Predicting Mortality on the General Wards	Frank J. Zadravecz, Linda Tien, Brian J. Robertson-Dick, Trevor C. Yuen, Nicole M. Twu, Matthew M. Churpek, Dana P. Edelson	Retrospective cohort study	10.1002/jhm.2415
2015	Impact of introducing an electronic physiological surveillance system on hospital mortality	Paul E Schmidt,1 Paul Meredith,2 David R Prytherch,2,3 Duncan Watson,4 Valerie Watson,5 Roger M Killen,6 Peter Greengross,6,7 Mohammed A Mohammed,8 Gary B Smith9	Retrospective cohort study	10.1136/bmjqs-2014-003073
2015	The experiences of nurses implementing the Modified Early Warning Score and a 24-hour on-call	Siv K. Stafsetha, Sturle Grønbecka, Tine Liend, Irene Randend, Anners Lerdal	Qualitative exploratory study	10.1016/j.iccn.2015.07.008

	Mobile Intensive Care Nurse: An exploratory study			
2015	Use of a single parameter track and trigger chart and the perceived barriers and facilitators to escalation of a deteriorating ward patient: a mixed methods study	Duncan J Smith and Leanne M Aitken	Qualitative exploratory study	10.1111/jocn.13104
2015	Non-Invasive Continuous Respiratory Monitoring on General Hospital Wards: A Systematic Review	Kim van Loon, Bas van Zaane, Els J. Bosch, Cor J. Kalkman, Linda M. Peelen	Systematic review	doi:10.1371/journal.pone.0144626
2015	Periarrest Modified Early Warning Score (MEWS) predicts the outcome of in-hospital cardiac arrest	An-Yi Wang, Cheng-Chung Fang, Shyr-Chyr Chen, Shin-Han Tsai, Wei-Fong Kao	Retrospective cohort study	10.1016/j.jfma.2015.10.016
2015	Factors affecting response to National Early Warning Score (NEWS)	Ivana Kolic, Smiley Crane, Suzanne McCartney, Zane Perkins, Alex Taylor	Prospective observational cohort study	10.1016/j.resuscitation.2015.02.009
2015	Attitudes towards vital signs monitoring in the detection of clinical deterioration: scale development and survey of ward nurses	Wenqi Mok, Wenru Wang, Simon Coopers, Emily Neo, Kim Ang, Sok Ying Liaw	Qualitative exploratory study	10.1093/intqhc/mzv019
2016	Multi-parameter vital sign database to assist in alarm optimization for general care units	James Welch, Benjamin Kanter, Brooke Skora, Scott McCombie, Isaac Henry, Devin McCombie, Rosemary Kennedy, Babs Soller	Simulation study	10.1007/s10877-015-9790-8
2016	Use of a modified early warning score system to reduce the rate of in-hospital cardiac arrest	I. Nishijima, S. Oyadomari, S. Maedomari, R. Toma, C. Igei, S. Kobata, J. Koyama, R. Tomori, N. Kawamitsu, Y. Yamamoto, M. Tsuchida, Y. Tokeshi, R. Ikemura, K. Miyagi, K. Okiyama, et al.	Prospective cohort study	10.1186/s40560-016-0134-7

2016	Recording signs of deterioration in acute patients: The documentation of vital signs within electronic health records in patients who suffered inhospital cardiac arrest	Jean E Stevenson, Johan Israelsson, Gunilla C Nilsson, Göran I Petersson, Peter A Bath	Retrospective cohort study	10.1177/1460458214530136
2016	Accuracy of a Wrist-Worn Wearable Device for Monitoring Heart Rates in Hospital Inpatients: A Prospective Observational Study	Ryan R Kroll, MD, J Gordon Boyd, MD, PhD, FRCPC, and David M Maslove,	Retrospective cohort study	10.2196/jmir.6025
2016	Vital Signs Predict Rapid-Response Team Activation Within Twelve Hours of Emergency Department Admission	James M. Walston, Daniel Cabrera, Shawna D. Bellew, Marc N. Olive, Christine M. Lohse, M. Fernanda Bellolio	Case control study	10.5811/westjem.2016.2.28501
2016	Effectiveness of Continuous monitoring or intermittent vital signs monitoring in preventing adverse events on general wards: a systematic review and meta-analysis	M. Cardona-Morell, M. Prgomet, R.M. Turner, M.Nicholson, K.Hillman	systematic review	10.1111/ijcp.12846
2016	Analysis of a data-fusion system for continuous vital sign monitoring in and emergency department	Sarah J. Wilson, David Wong, Richard M. Pullinger, Rob Way, David A. Clifton, and Lionel Tarassenko	Retrospective cohort study	10.1097/MEJ.0000000000000166
2016	Comparison of a national early warning score in non-elective medical and surgical patients	C. Kovacs, S. W. Jarvis, D. R. Prytherch, P. Meredith, P. E. Schmidt, J. S. Briggs, and G. B. Smith	Comparative retrospective study	10.1002/bjs.10267
2016	Application of the National Early Warning Score (NEWS) as a stratification tool on admission in an Italian acute medical ward: A perspective study	Walter Spagnolli, Marta Rigoni, Emanuele Torri, Susanna Cozzio, Elisa Vettorato, Giandomenico Nollo	Prospective observational cohort study	10.1111/ijcp.12934

2016	The National Early Warning Score: Translation, testing and prediction in a Swedish setting	Martin Spångfors, Lisa Arvidssonb, Victoria Karlssonb, Karin Samuelsona	Retrospective cohort study	10.1016/j.iccn.2016.05.007
2016	Vital signs monitoring on general wards: clinical staff perceptions of current practices and the planned introduction of continuous monitoring technology	Mirela Prgomet, Magnolia Cardona-Morrell, Margaret Nicholson, Rebecca Lake, Janet Long, Johanna Westbrook, Jeffrey Braithwaite, Ken Hillman	Qualitative exploratory study	10.1093/intqhc/mzw062
2016	User acceptance of observation and response charts with a track and trigger system: a multisite staff survey	Doug Elliott, Emily Allen, Sharon McKinley, Lin Perry, Christine Duffield, Margaret Fry, Robyn Gallagher, Rick Iedema and Michael Roche	Prospective cohort study	10.1111/jocn.13303
2016	The value of vital sign trends for detecting clinical deterioration on the wards	Matthew M. Churpek, Richa Adhikari, Dana P. Edelson	Prospective observational cohort study	10.1016/j.resuscitation.2016.02.005
2016	Frequency of early warning score assessment and clinical deterioration in hospitalized patients: A randomized trial	John Asger Petersen, Kristian Antonsen, Lars S. Rasmussen	Controlled trial	10.1016/j.resuscitation.2016.02.003
2016	Real-Time Risk Prediction on the Wards: A Feasibility Study	Michael A. Kang, Matthew M. Churpek, Frank J. Zadravecz, Richa Adhikari, Nicole M. Twu, Dana P. Edelson	Prospective black-box validation study	10.1097/CCM.0000000000001716
2016	Nurses' 'worry' as predictor of deteriorating surgical ward patients: A prospective cohort study of the Dutch-Early-Nurse-Worry-Indicator-Score	Gooske Douw, Getty Huisman-de Waal, Arthur R.H. van Zanten, Johannes G. van der Hoeven, Lisette Schoonhoven	Prospective cohort study	10.1016/j.ijnurstu.2016.04.006
2016	The effect of the quality of vital sign recording on clinical decision making in a regional acute care trauma ward	Claire M. Keene, Victor Y. Kong, Damian L. Clarke, Petra Brysiewicz	Descriptive cross-sectional study	10.1016/j.cjtee.2016.11.008

2017	The effectiveness of physiologically based early warning or track and trigger systems after triage in adult patients presenting to emergency departments: a systematic review	Francesca Wuytack	systematic review	10.1186/s12873-017-0148-z
2017	Can an emergency department clinical “triggers” program based on abnormal vital signs improve patient outcomes?	Jason Imperanto, Tyler Mehegan, Daniel J. Henning, Joh Patrick, Chase Bushey, Gary Stnik, Leon D. Sanchez	Case control study	10.1017/cem.2016.365
2017	Evaluation of a wireless, portable, wearable multi-parameter vital signs monitor in hospitalized neurological and neurosurgical patients	Robert S. Weller, Kristina L. Foard, Timothy N. Harwood	Prospective cohort study	10.1007/s10877-017-0085-0
2017	A smart all-in-one device to measure vital signs in admitted patients	Mariska Weenk, Harry van Goor, Maartje van Acht, Lucien JLPG Engelen, Tom H. van de Belt, Sebastian J. H. Bredie	Comparative retrospective study	10.1371/journal.pone.0190138
2017	Can the prehospital National Early Warning Score identify patients most at risk from subsequent deterioration?	Joanna Shaw, Rachael T Fothergill, Sophie Clark, Fionna Moore	Retrospective cohort study	10.1136/emermed-2016-206115
2017	Cardiorespiratory dynamics measured from continuous ECG monitoring improves detection of deterioration in acute care patients: A retrospective cohort study	Travis J. Moss,, Matthew T. Clark, James Forrest Calland, Kyle B. Enfield, John D. Voss, Douglas E. Lake, J. Randall Moorman	Retrospective cohort study	10.1371/journal.pone.0181448
2017	Adult Deterioration Detection System (ADDS): An evaluation of the impact on MET and Code blue activations in a regional healthcare service	Karen Missena, Joanne. E. Porter, Anita Raymond, Kerry de Vent, Jo-Ann Larkins	Retrospective cohort study	10.1016/j.colegn.2017.05.002

2017	The impact of Early Warning Score and Rapid Response Systems on nurses' competence: An integrative literature review and synthesis	Jørghild Karlotte Jensen, Randi Skar, Bodil Tveit	Integrative review	DOI: 10.1111/jocn.14239
2017	National Early Warning Score (NEWS) at ICU discharge can predict early clinical deterioration after ICU transfer	Supattra Uppanisakorn, Rungsun Bhurayanontachai, Jaruwan Boonyarat, Julawan Kaewpradit	Prospective observational cohort study	10.1016/j.jcrc.2017.09.008r
2017	Widely used track and trigger scores: Are they ready for automation in practice?	Santiago Romero-Brufau, Jeanne M. Huddleston, James M. Naessens, Matthew G. Johnson, Joel Hickman, Bruce W. Morlan Jeffrey B. Jensend, Sean M. Caples, Jennifer L. Elmer, Julie A. Schmidt, Timothy I. Morgenthaler, Paula J. Santrach	Retrospective cohort study	10.1016/j.resuscitation.2013.12.017
2017	Piloting Electronic Medical Record–Based Early Detection of Inpatient Deterioration in Community Hospitals	Gabriel J. Escobar, Benjamin J. Turk, Arona Ragins, Jason Ha, Brian Hoberman, Steven M. LeVine, Manuel A. Ballesca, Vincent Liu, and Patricia Kipnis	Pilot	10.1002/jhm.2652.
2017	Continuous Monitoring of Vital Signs Using Wearable Devices on the General Ward: Pilot Study	Mariska Weenk, Harry van Goor, Bas Frietman, Lucien JLPG Engelen, Cornelis JHM van Laarhoven, Jan Smit, Sebastian JH Bredie, and Tom H van de Belt	Feasibility study	10.2196/mhealth.7208
2016	Technology Assessment: EarlySense for Monitoring Vital Signs in Hospitalized Patients	Mark Helfand, MD, MPH, MS Vivian Christensen, PhD Johanna Anderson, MPH	Technology assessement	
2016	What factors influence ward nurses' recognition of and response to patient deterioration? An integrative review of the literature	Debbie Massey, Wendy Chaboyer, Vinah Anderson	Integrative review	10.1002/nop2.53