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Early Warning System for Emergency Care: Designing a Timely Monitoring Mobile-Based System

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Abstract. Early Warning Scores (EWSs) systems support the timely detection of patient deterioration and rapid response of the care team. Due to the mobility nature of healthcare settings, there has been a growing tendency to use mobile-based devices in these settings. This chapter aimed to design a mobile-based EWS application (app). This was a descriptive study to design the architecture of the proposed EWS app. The design of architecture was done using the Unified Modeling Language diagrams including a class diagram, use-case diagram, and activity diagram. We evaluated the architecture using the ARID scenario-based evaluation method. The proposed EWS application (app) was the integration of three EWSs, including NEWS2, PEWS, and MEOWS. The workflow of these EWSs systems was designed and integrated into a single app. Also, the static structure of the proposed EWS app was designed by class diagram and the behavioral structure was depicted by use-case and activity diagrams. The class diagram showed the system components and their relationships. However, the use-case diagram displayed the app's interaction with its environment, and the activity diagram illustrated how the EWS app processes were carried out. Evaluation results showed the possibility of designing the architecture for the proposed EWS app. In our app, the EWSs were designed in the clinician’s workflow, and it was integrated with the patient’s Electronic Health Record (EHR). These factors may lead to more use of EWSs. Considering the frequency of alerts represented to clinicians and the user-friendly design of the app, some suggestions can be considered by EWS systems developers in the future.

Keywords. early warning system, unified modeling language, mobile-based application, mHealth, patient deterioration

1. Introduction

Researches showed a high rate of adverse events incidence in hospitalized patients[1, 2]. Derangement of vital signs is the first clinical change that occurs when the patient’s deterioration becomes worse[3]. Physiological parameters derangement from pre-defined thresholds such as heart rate, respiratory rate, body temperature, and so forth usually occurs a few hours before the incidence of a clinical adverse event, such as death

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[3, 6]. Therefore, the rapid identification of basic physiological parameters derangement, along with the timely response of the care team, can have a valuable role in the prevention and control of adverse conditions [7, 9]. This is the goal of Early Warning Scores (EWSs) that are also known as "track and trigger" systems [4,10]. EWSs are tools, assessing the change of a patient's vital signs and alerting the care team if necessary[11]. EWSs systems allocate a score to the health status of a patient based on her/his vital signs derangement. The larger the patient's EWSs score, the higher risk of the patient's deterioration [12,13]. Based on the patient's score, the EWS system recommendations vary, including the escalation of patient's assessment, required expertise clinicians, or rapid reaction of the care team [14,16]. There are many EWSs systems for assessing adults patients' deterioration, such as the National Early Warning Score (NEWS)[17] and Vital Pac Early Warning System (ViEWS)[18]. These EWSs systems are only used for adults. Due to the differences in physiological response in children under 16 and pregnant women, the EWSs systems have been developed for them separately[16]. Modified Early Obstetric Warning System (MEOWS)[19], Maternal Early Warning Trigger (MEWT)[20] as well as Pediatric Advanced Warning Score (PAWS)[21], and Irish Pediatric Early Warning System (PEWS)[22] are examples of EWSs systems for pregnant and pediatric patients, respectively.

There are many approaches to collect vital signs information in a hospital or pre-hospital settings including manual data collection using spreadsheets or using technological approaches such as tablets, personal digital assistants (PDA), and other mHealth equipment[23]. Concerning the mobile nature of healthcare delivery (in multiple places by several clinicians) there is an increasing tendency to use mobile devices in healthcare workflow[24, 26]. The use of mobile devices such as smartphones and PDAs by clinicians not only provides a portable device in the mobile healthcare setting but also has a positive impact on rapid response, error prevention, communication, and data management and accessibility[25]. The results of reviews on the use of handheld devices by medical students and residents in France, the United Kingdom, Ireland, the United States, and Canada have shown that 75-95% of them used personal smartphones in their clinical workflow[24], [27–31]. Integrating EHR with the EWS system allows clinicians especially nurses to document their vital sign assessment in the patient's EHR. This leads to the significant impact of using EWS because of its integration with clinicians' workflow[32,33]. mPEWS-InPro is an EWS mobile-based application for assessing children's deterioration. This EWS system uses the modified Pediatric Early Warning System (mPEWS)-InPro for detecting changes in children's vital signs. This app was developed as a mobile-based app to prevail over the communication problem of care team members. The system has been validated by 108 pediatric patients' information which indicated the high degree of accuracy for this mobile-based system (95%, CI: 0.865 to 1.000, p = 0.001) [34]. Dia-AID is another EWS mobile-based system that was developed to monitor the health status of diabetes patients. This app was a question-answering (Q&A) system that helped diabetes patients by Q&A service to enhance the patient's information about diabetes, assessing patients' risk and managing their health data. The Dia-AID showed a better performance in comparison with the baseline methods[35].

Concerning the existence of several EWSs systems for different patient categories (based on age and sex and therefore the pregnancy status of women) and the growing trends to use the mobile-based system in healthcare settings, in this chapter a mobile-based EWSs app was proposed and designed to support the possibility of assessing the deterioration status of adults, children (patients under 16), and pregnant women. Thus, this app can be used for a wide range of patients in emergency care without the need to open different EWSs systems. Based on the patient's features, such as age and pregnancy status, the system automatically presents the proper EWSs system to its users. Besides, the proposed EWS app is integrated with the EHR system of patients to record the patient's physiological parameters to include the nurse's workflow.

2. Material and Methods

We have designed the EWS system using the Unified Modeling Language (UML) diagram. UML is a standard language to describe a system plan, visualization, specification, construction, and documentation of a software system[36]. UML has many diagrams to support the documentation of the architecture and behavior of a system. The UML diagram can be categorized as structural and behavioral diagrams. Structural diagrams display the static structure of objects, classes, or components of a system, while the behavioral diagrams present the object interactions with each other and with the environment as well as dynamic aspects of a system[37]. A study showed that the basics of a system can be represented using the five types of UML diagrams including activity diagram (that depicts the activities in a process or data processing), use-case diagram (that presents the interaction between the system and its environment), sequence diagram (that shows the interaction between users and system as well as between system components), class diagram (that displays the object classes in the system and their relationship) and state diagram (that illustrates how the system reacts to the internal and external events)[38]. In this chapter, the class, use-case, and activity diagrams are used to design the proposed EWS system.

Our system is composed of three main modules including the EWS system for adults, children (under 16), and pregnant women. We selected the NEWS2[16], PEWS[22], and MEOWS[19] as the EWSs systems for each module, respectively. Having the escalation guide is the most important criterion for the EWSs selection. Also, our design was according to the latest version of each EWS scoring system guideline.

We summarized the basic physiological parameters, assessed by the three EWSs in Table 1. The NEWS2 is a track and trigger system that calculates the aggregated scores of an adult patient's vital signs and generates appropriate recommendations for the care team based on the patient's health status. The care escalation triggers when the score of patients in one physiological parameter is three or the aggregated score is five to seven. Its configurations cannot be used for children (under 16) and pregnant women[16], [39]. However, the NEWS2 score isn't reliable for patients with spinal cord injury, especially tetraplegia or high paraplegia[39]. The NEWS2 scoring system chart is available from [40].

Table 1. The basic physiological parameters assessed in selected EWSs

Named of EWSs Systems	Target Patients	Basic physiological parameters
NEWS2 [40]	Adults	Respiratory rate, Oxygen saturation, Systolic blood pressure, Pulse rate, Level of consciousness or new-onset confusion (ACVPU), Temperature.
PEWS [41]	Children under 16	**Core PEWS parameters:** Concern, Respiratory rate, Respiratory effort, Oxygen therapy, Heart rate, Conscious level (AVPU) **Additional Parameters:**

		Oxygen saturation, Central capillary refill time, Blood pressure (systolic), Skin color, Temperature
MEOWS [19]	Pregnant women	Temperature, Systolic blood pressure, Diastolic blood pressure, Heart rate, Respiratory rate, Oxygen saturations, Urine, Proteinuria, Urinalysis, Edema, Amniotic fluid, Neuro response (AVPU), Pain score, Lochia, Looks unwell, Trigger

*__ACVPU__: Alert, Confusion, Voice, Pain, Unresponsive; **AVPU**: Alert, Voice, Pain, Unresponsive

The PEWS score cannot be used for adults or neonates. The PEWS score shouldn't replace or undermine the clinician's decision and concerns. Additional parameters are considered for case-by-case children and based on current health condition, treatments, and interventions as well as her/his predicted clinical status[41]. The PEWS scoring chart was shown in[22].

Compared with the other two EWSs systems, MEOWS checks more numbers of physiological parameters to determine the level of pregnant women's deterioration. The MEOWS scoring and trigger chart were described in [19].

The scenario-based method was used to evaluate the designed architecture. The method is suitable to combine the different interpretations of users from the software capabilities and create a common view of it [42]. A scenario describes the stakeholder's interaction with the designed system. Active Review for Intermediate Design (ARID) is a scenario-based method [43]–[45]. The ARID method concentrates on the detailed design of various parts of the system. Therefore, it can be used to evaluate incomplete architectures in two stages including pre-meeting sessions and review sessions. In the pre-meeting phase, the members of the review session and the scenarios that must be presented at the review session are determined and generally, the preparation for the review session is provided. In the review session, the reviewers and stakeholders evaluate the designed architecture for the system[43].

Two medical informatics professions and one nurse participated in the review session. Three scenarios were selected for evaluation of the proposed architecture described in Table 2. In the first and third scenarios, the clinician assesses a new patient but in the second scenario, an existing patient is assessed. In all scenarios, the clinician saves the results in the patient's EHR.

Table 2. Selected scenarios for evaluation of proposed EWS

#	Patient age	Patient gender	Patient pregnancy status	Other physiological parameters
1	13	Female	-	Concern = yes, Respiratory rate = 32 (Breath per minute) Tachypnea , Respiratory effort = mild, Oxygen therapy < = 2L, Heart rate = 105, Conscious level (AVPU) = Alert, Blood pressure (systolic) = 112 mmHg, Temperature = 38.6 °C,
2	42	Male	-	Respiratory rate = 15, Oxygen saturation = 84.5% (No COVID-19), Systolic blood pressure = 117 mmHg, Pulse rate = 84, Level of consciousness or new-onset confusion (ACVPU) = patient is more confused than before now, Temperature = 38.7 °C.
3	36	Female	Yes	Temperature = 37.5 °C, Systolic blood pressure = 138 mmHg, Diastolic blood pressure = 85 mmHg, Heart rate = 81, Respiratory rate = 15(Breath per minute), Urine = No, Edema = No, Amniotic fluid = clear, Neuro response (AVPU) = Alert, Pain score = 1, Lochia = Normal, Looks unwell = Yes,

3. Results

When a clinician uses our system, automatically the proper EWS system based on the patient’s characteristic will be applied. The designed EWS system is implemented as a rule-based system to determine the severity of a patient’s deterioration. An overview of the designed EWS is shown in Figure 1.

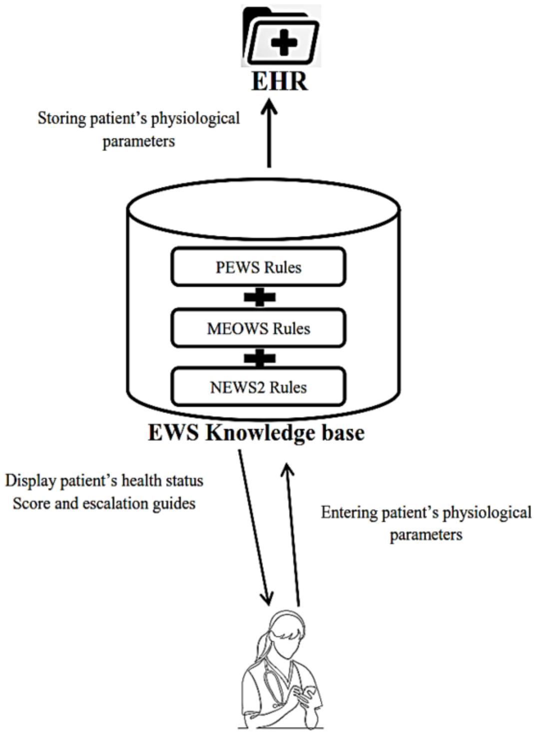

Figure 1. Overview architecture of proposed EWS system. The clinician uses the EWS app. According to the patient’s information including age and pregnancy status, appropriate rules in the EWS knowledge base will be used. Finally, the clinician can store the patient’s vital signs in her/his EHR.

The main stakeholders of developed EWS will be the nurses and multidisciplinary clinical team in hospital wards and ambulances as well as patients. This system can be used as a Clinical Decision Support System (CDSS) helping nurses to manage the patient’s deterioration.

The flowchart of the designed EWS is illustrated in Figure 2. NEWS2 is not reliable to be used for patients having spinal cord injury, especially tetraplegia or high paraplegia. Thus, the EWS system exits if a patient has at least one of these diseases. PEWS and NEWS2 follow almost the same work logic, such that they take the values of a patient's vital signs and calculate the sum of different parameters scores. Unlike the two previous EWSs that calculate the aggregated score of a patient’s vital signs, MEOWS counts the number of vital signs with the values in the yellow and red areas. If two patients’ vital signs have values in the yellow range or one in the red range, then the trigger system is activated.

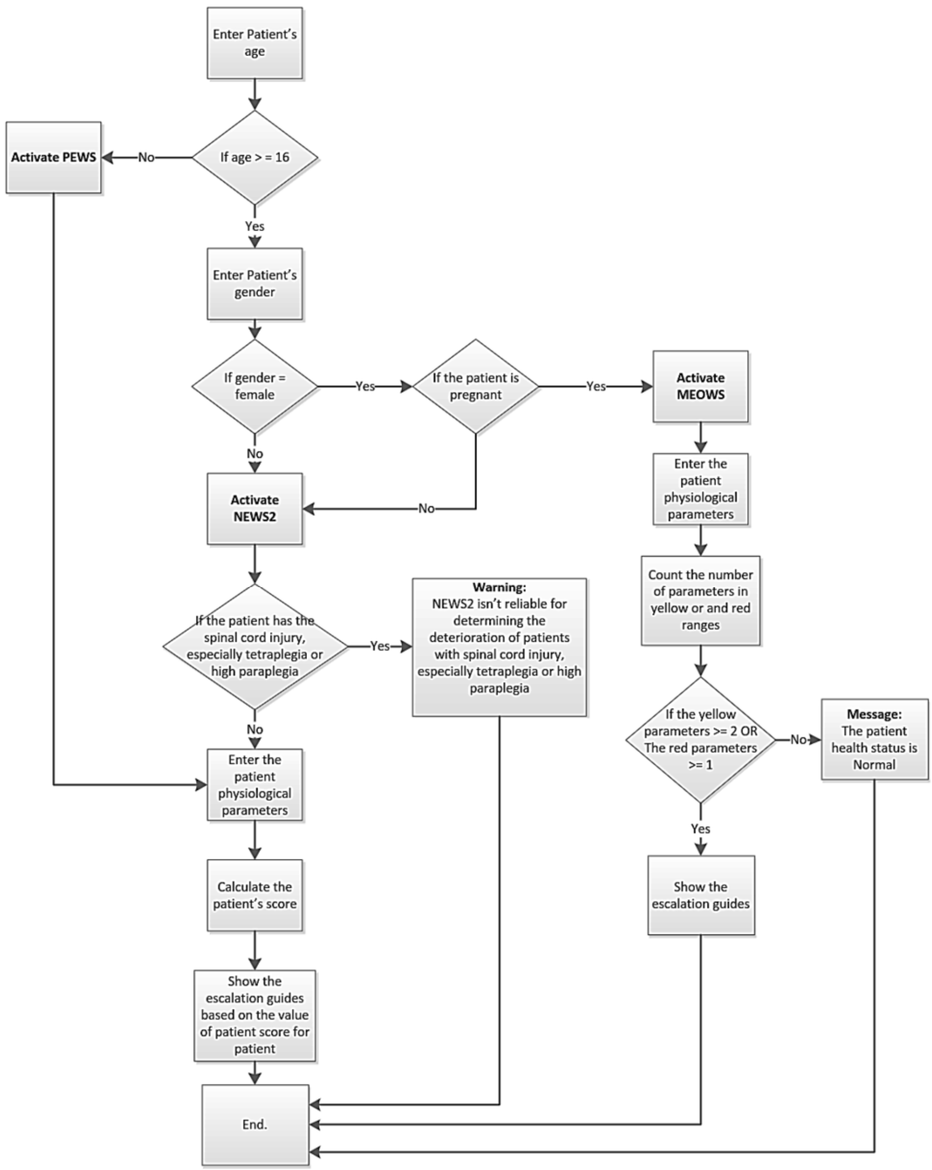

Figure 2. The flowchart of the developed EWS system.

The static structure of the proposed EWS uses a class diagram. Each class represents an entity in the system (see Figure 3). The "person" is an abstract class that represents the mutual features of "clinician" and "patient" classes. In other words, both "clinician" and "patient" inheritance the "person" class features. The numbers used on the connection between two classes indicate the number of each class involved in the relationship. For example, each clinician can assess "n" patient(s) and each patient can be assessed by "n" clinician(s). The "question form" class has a mandatory relationship with the "EWS App" class. This means that the existence of the "question form" class depends on the existence of the "EWS App" class.

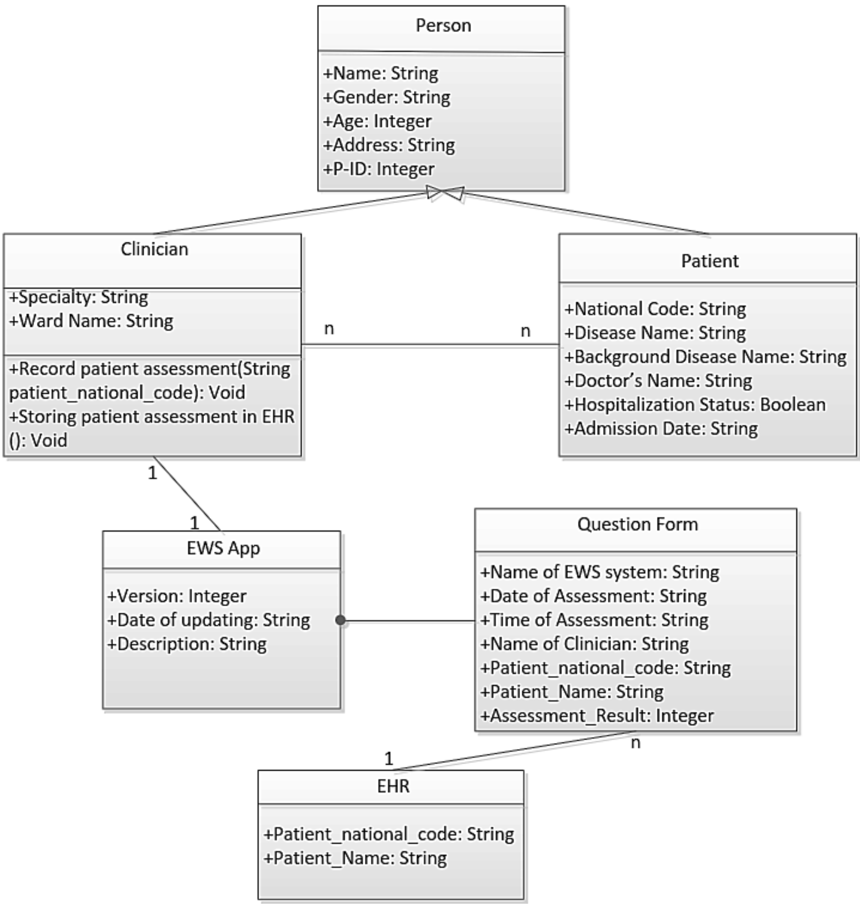

Figure 3. The static structure of the proposed EWS system.

The use-cases are based on the clinician viewpoint (see Figure 4). Figure 5 illustrates how a clinician can assess a new or existing patient, recording the measurements in the EHR and reviewing the trend of physiological parameters for an existing patient.

As shown in figure 5, after login, a clinician can add a new patient to the EWS system. Therefore, she/he must enter the patient's identifier code such as the national ID code. The system examines whether the patient already exists in the EWS system. If the patient is a new case, first the clinician must enter the patient's demographic information. Based on the patient's information, including the patient's age and pregnancy status, the system shows the proper EWS questions (NEWS2, PEWS, or MEOWS) for vital signs assessment. The clinician stores the assessment of the vital signs in the patient's EHR. For patients that are already available in the EWS system, the clinician can also request to view the trend of physiological parameters changes.

To analyze the first scenario, the clinician login to the EWS app (see Table 2 based on Figure 5). Because of assessing a new patient in this scenario, the patient's national ID code and demographic information are entered. The patient's age less than 16 activates the PEWS scoring system. Due to the patient's temperature over 38.5 °C and

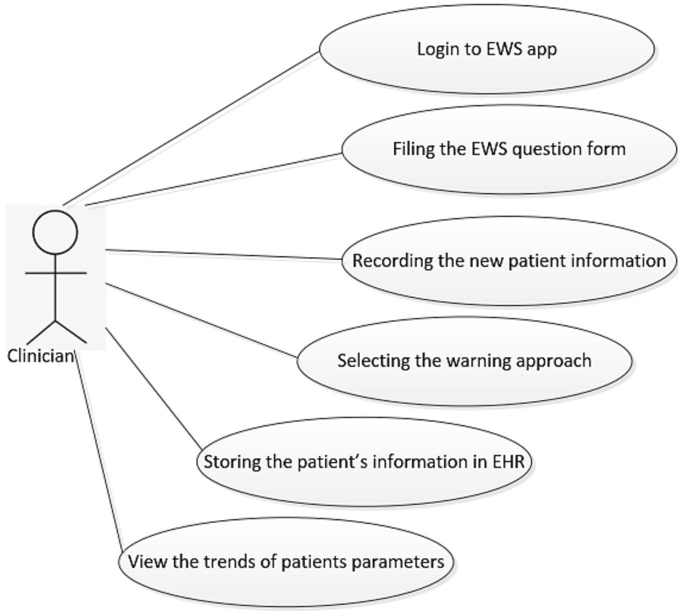

Figure 4: The proposed EWS use-cases from the clinician viewpoint.

tachypnea, the child has sepsis (according to the physiological parameters used to sepsis diagnosis[22]). Based on the scoring chart of PEWS in[22], each physiological parameter of patient scores. Thus, the general score of patients in the first scenario is 5. As shown in[22] two other warnings are triggered (Table 3). Finally, the clinician stores the results in the patient's EHR.

To analyze the second scenario, based on the designed activity diagram (Figure 5 and Table 2), the clinician login to the EWS app. As the patient has already registered in the EWS system, by entering the patient's national ID code, the NEWS2 is activated (because the patient's age is more than 16 and his gender is male). The patient's SpO_2 is in the 88-92 interval. Accordingly, scale 2 is used to score the patient's SpO_2=2 (the patient is not infected with COVID-19, based on the [40]). The clinician decides on the patient confusion. Therefore, based on the confusion assessment in NEWS2[40], the consciousness score is 3. Also, based on the NEWS2 chart [40], the patient temperature score is 1. Thus, the general score of the patient in the second scenario is 6. As a result, five warnings are triggered (Table 3). Finally, the clinician stores the results in the patient's EHR.

To analyze the last scenario, the clinician enters the patient's national ID code and demographic information, because a new patient is assessed in this scenario (see Table 2 based on Figure 5). The patient pregnancy status activates the MEOWS system. Due to her unwell appearance and based on the MEOWS scoring chart in[19] the patient gives one yellow color (in MEOWS the numbers of yellow and red colors are counted based on the women's health parameters); other physiological parameters are in the normal range. In this scenario, the pregnant woman takes one yellow color, and based on the MEOWS chart in[19] the triggered message states that her health status is normal. Finally, the clinician stores the results in the patient's EHR.

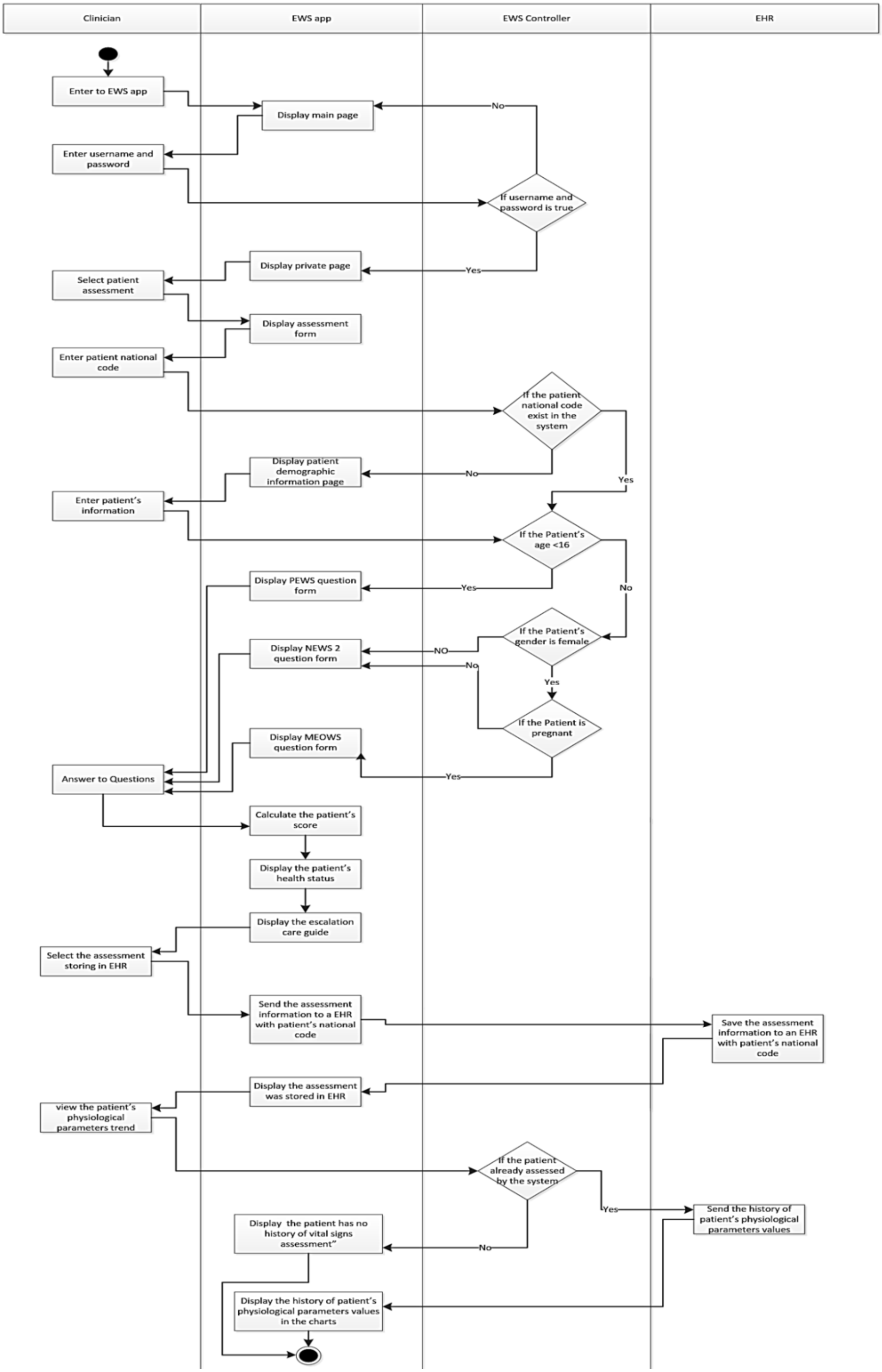

Figure 5. The process of a patient assessment by the proposed EWS app.

Table 3. Analysis results of selected scenarios

#	Patient age	Patient gender	Patient pregnancy status	Other physiological parameters (score)	Total Score	Triggered warnings
1	13	Female	-	Concern = yes (1), Respiratory rate = 32 (Breath per minute) Tachypnea (1), Respiratory effort = mild (1), Oxygen therapy < = 2L (1), Heart rate = 105 (0), Conscious level (AVPU) = Alert (0), Blood pressure (systolic) = 112 mmHg (0), Temperature = 38.6 °C	5	**Sepsis warnings: Within 60 minutes:** **Warning 1:** Take IO or IV blood samples **Warning 2:** Measure the urine output **Warning 3:** Take early SENIOR input **Warning 4:** Give high oxygen flow **Warning 5:** Give IV/IO fluids and consider initial inotropic support **Warning 6:** Give a wide range of IV/IO antimicrobials **General warnings:** **Warning1:** The patient should be assessed at least once every 30 minutes by a nurse and an on-call physician. **Warning2:** Need to urgent medical assessment
2	42	Male	-	Respiratory rate = 15 (0), Oxygen saturation = 84.5% (No COVID-19) (2), Systolic blood pressure = 117 mmHg (0), Pulse rate = 84 (0), Level of consciousness or new-onset confusion (ACVPU) = patient is more confused than before now (3), Temperature = 38.7 °C (1).		**Warning 1:** The patient clinical risk is moderate **Warning 2:** Need to assess the patient at least once an hour **Warning 3:** Need to immediate assessment by the ward physician or the nurse of the acute care team to decide about intensifying the clinical care **Warning 4:** Immediate need and intervention by a clinical team for management of sepsis and immediate transfer to a hospital or clinical area with a high level of care in the hospital **Warning 5:** Transformation of the patient to an environment with more monitoring facilities should be considered

3	36	Female	Yes	Temperature = 37.5 °C (white color), Systolic blood pressure = 138 mmHg (white color), Diastolic blood pressure = 85 mmHg (white color), Heart rate = 81 (white color), Respiratory rate = 15 (Breath per minute) (white color), Urine = No (white color), Edema = No (white color), Amniotic fluid = clear (white color), Neuro response (AVPU) = Alert (white color), Pain score = 1 (white color), Lochia = Normal (white color), Looks unwell = Yes (Yellow color),	**Warning 1:** The patient's health status is Normal.

4. Discussion

EWSs systems are used by nurses in hospitals and ambulance care. These systems help to rapidly identify and manage the patient's deterioration by assessing her/his vital signs. Therefore, EWSs provide the possibility of rapid intervention of treatment team to patient's status changes and can prevent the consequence adverse events such as unplanned intensive care unit (ICU), cardiac arrest, and mortality of hospitalized patient [46], [47]. Unlike the previous works that concentrate on only one group of patients, for example, diabetes[35], children[34], pregnant women[48] or adults[49], the designed EWS system in this chapter was the integration of three EWSs systems for adults, children, and pregnant women. the system can help to monitor and manage a wide range of hospitalized patients without the need of switching EWS system by the app user. The designed app automatically loads the appropriate EWS system for each patient based on the patient's features, such as age and pregnancy status. This feature improves the EWSs system's ease of use by clinicians.
Similar to mPEWS-InPro[34] and Dia-AID[35], the proposed EWS was developed as a mobile-based app to meet the healthcare requirements concerning the communication needs of clinicians especially in multidisciplinary treatment teams [34], the mobile nature of healthcare delivery[24]–[26] and the tendency of healthcare providers to use the mobile-devices in their workflow[24], [27]–[31].

Using EWSs systems leads to efficient recording and assessing the patient's physiological parameters as well as improving the response time of the treatment team to the patient's deterioration[46]. Also, studies have shown that in the short term, the EWSs systems increase the nurse's knowledge and competence about rapid response and their confidence in identifying the clinical deterioration and how to respond in these conditions[50]. Therefore, EWSs systems can have a positive impact on nurses' performance, confidence, and knowledge[46], [50]. Also, the integration of the EWSs system with patients' EHR can have a key role in enhancing the impact of EWSs on nurses. EWSs systems can facilitate the regular recording of patients' vital signs in EHRs, which help nurses to document their measurements and have a better response to patients' status changes concerning the physiological parameters.

The user-friendly design of EWS applications, their interoperability, and real-time communication are the important features for developing an EWS system[51]. The proposed EWS app was integrated with EHR, following the standards interfaces and frameworks such as Fast Healthcare Interoperability Resources (FHIR) is necessary to provide the interoperability in the system. Also, using user-centric design methods that engaged the end-users and other stakeholders of a health app in its design and development[52] is a good solution to develop a user-friendly app.

Alert fatigue is an important process affecting an alert system operation in healthcare settings. When the number of a system's alarms is high, the users don't attention to them and alert fatigue occurs[53]. Therefore, alert fatigue leads to ignoring the important alerts of systems that can reduce the system's effectiveness and may have consequences adverse events for patients[54]. A trade-off between reducing the alert's burden and providing the important alerts is a challenge of developing an alerting system[55]. The health setting emergency status (such as a hospital ward, ICU, or ambulance) and the goal of using EWS are important factors in determining the frequency of alerts in EWSs. When the EWS system is used in a hospital ward, and one of the goals is to enhance the nurses' knowledge and confidence, it seems that increasing the sensitivity by presenting more alert is of priority. But in the emergency use of EWS such as ambulance and where the EWSs users are the more experienced clinicians; it is desirable to reduce the alerts burden. Some studies suggested that the EWSs apps should be developed in such a way that its users can set the alerts presentation approach (for example, similar to Capan et al[55] maximum, medium or minimum alert presentation) based on their need. In the initial use of the EWS app, the users can set the app to give the maximum alerts, and over the time and with increasing the EWS's user experience or depend on the health settings and related workload and time sensitive of these settings, the EWS's users can choose the options to display fewer alerts.

The evaluation of our EWS app was carried out by a scenario-based method in the very early stage of developing the app. Implementation of a prototype of a designed EWS app and its evaluation with a real dataset from an emergency unit can provide better insight into the performance and accuracy of our EWS app design.

5. Conclusion

Early detection of patient deterioration in clinical settings can prevent adverse events such as ICU admission or patient mortality. As the vital signs may change a few hours before adverse events [56], the EWSs help to regular monitoring of the patients' physiological parameters. Concerning the tendency to use the mobile device in healthcare settings as well as the mobility of care delivery by several healthcare providers, the goal of this chapter was to design a mobile-based application as an EWS system. The proposed EWS system integrated three EWs systems (NEWS2, PEWS, and MEOWS) to cover adults, children, and pregnant women. Also, the proposed EWSs app was designed in such a way that was integrated with EHR. The clinician can choose their proper warning approach depending on their goal of using the EWS system and the condition (such as workload and time-sensitivity) of their work setting. Integration of EWSs in the workflow of clinicians in a way that it automatically activates the most appropriate EWS system based on the patient status (not as a separate app), as well as its interoperability with other health systems such as patients EHR, can lead to the more using of them. Developing such systems that are integrated with EHR can help to the rapid response of the care team to patient deterioration and better management of patients in acute care. This chapter can have valuable recommendations such as selecting the alert presentation approach, considering a user-centric design approach, and designing the user-friendly interface for EWSs system developers.

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