Usability Model for Medical User Interface of Ventilator System in Intensive Care Unit

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Abstract. A usability model is a hierarchical structure encompassing the key elements such as users, user interface and interaction between them. It is a generic template which is independent of usability evaluation methods and provides flexibility for adaptation in different contexts and domains. In this paper, a usability model for medical user interfaces, especially for ventilator systems in Intensive Care Unit (ICU), is proposed based on Norman's action-oriented seven-step model to capture a related medical context. A ventilator system is a therapeutic device, which provides a respiratory support to critically-ill patients. Currently, a usability of user interfaces of ventilator systems is evaluated by typical usability evaluation methods from software industry. These evaluation methods miss out important elements in medical context. Therefore, a need for a specialized usability model for medical user interfaces is fulfilled with a proposed usability model encompassing vital elements such as medical user, user interface, ICU environment and time required. This usability model is validated first, through a human work analysis using videos of selected tasks with medical user interfaces and then, with an overview of critical factors affecting medical user interfaces in ICU. In future, a proposed usability model can be integrated with a suitable usability evaluation method for evaluating medical user interfaces to identify related medical usability problems more effectively.

Keywords: Usability Model, Medical User Interface, Human Work Analysis, Ventilator System, Intensive Care Unit, Usability Evaluation, Video Analysis.

1   Introduction

In Intensive Care Unit (ICU), there are several medical devices such as patient monitoring system, ventilator system, electrocardiogram (ECG) machine, syringe pump, arterial blood gas machine and defibrillator. Most of these medical devices have user interfaces along with related controls and buttons for interaction with medical users. Fig. 1 depicts a ventilator system with on-screen user interface. A ventilator system provides a respiratory support to critically-ill patients. Its user

interface helps medical users to input and control multiple and diversified system parameters during patient care [18]. The user interface also displays vital information related with critically-ill patients. This information includes numeric values, icons, options, menus, messages, graphs, tables or alerts [29] and is really important for communication with medical users.
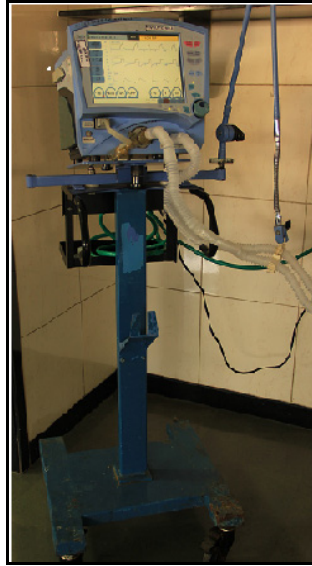

Fig. 1. Ventilator system with its user interface

There are various commonly observed usability problems with medical user interfaces in ICU such as poor legibility or contrast, right-handed design, lack of templates and intelligence, poorly distinguished alarms and alerts, no support in local language and poor feedback about device state and behavior [6, 27, 43]. Such problems may contribute to medical errors. Too many patients have been injured or died because someone pressed a wrong button, misread a number, misplaced a component, skipped a step or overlooked a warning [42] when using medical devices. In fact, medical error is a leading cause of death along with motor vehicle accidents, breast cancer and AIDS [45]. Many physicians, hospitals and even, manufacturers of medical devices may have to face medico-legal cases and liability claims.

Thus, usability of medical devices such as ventilator systems and their user interfaces, is evaluated using several usability evaluation methods such as heuristic evaluation, cognitive walk-through, rapid prototyping, field surveys, usability inspection, Goals, Operators, Methods and Selection rules (GOMS) analysis, computer-based video analysis, usability testing or think-aloud method [2, 19, 22]. Most of these usability methods are typical evaluation methods adapted by software industry and miss out important elements in medical context. Therefore, there is a need for a specialized usability model to bring such missed out medical context into usability evaluation of medical user interfaces in ICU.

In this paper, we have specifically considered touch-screen based ventilator systems. We have proposed a usability model for ventilator system, which encompasses the related medical context along with important elements affecting usability of medical user interfaces in ICU. This model can be used along with a suitable usability method for usability evaluation of medical user interfaces in ICU.

2   Related Work

There are several usability models proposed by researchers. These models are of different types and are discussed in this section.

Winter et al. have suggested two-dimensional quality meta-model of usability. It describes the user interface (input / output data and states) along with information about the situation of use (context and user knowledge) [44]. Abran et al. have provided a consolidated usability model with a baseline of ISO 9241-11 standard integrated with other relevant usability characteristics from ISO 9126 standard and other sources. These characteristics include effectiveness, efficiency, satisfaction, learnability and security [1]. Federici et al. have described integrated model of evaluation to measure the distance between the designer's and the user's mental models [12]. Ford has provided a detailed conceptual model of usability along with several classified variables. It has focused on three major types of contexts – user, task and environment, and each context is described in terms of classified variables. For example, user is identified with characteristics, knowledge and so on [14]. Clemmensen has proposed Human Work Interaction Design (HWID) model, which shows the characteristics of human work and the interaction during tasks and decision activities, individually or in collaboration. It also highlights impact of theory and environmental context on such interaction [10]. Rasmussen et al. have defined decision ladder model for representing the generic categories of activity that are necessary in a system and suitable for design and execution of actions [32]. A comprehensive study of usability models as briefly summarized above, has led to identification of common characteristics of models.

The usability model provides -

- broad elemental breakup of the activity.
- hierarchical structure between the key elements.
- a generic template which is independent of usability evaluation methods.
- flexibility for adaptation in different contexts and domains.

Table 1 depicts a comparison table for usability models differentiating among seven main models studied based on major aspects shown in first column of the table. Other columns represent usability models identified by names of authors proposing respective models. There are few observations realized during a comparison of usability models. The type of usability model is one from the related group - quality model, user-centered model, action-oriented model or work analysis model. Most of the models are non-iterative models expect Norman's model. Most of them do not

consider work environment or time requirement during the analysis. Most of these models consider a restricted context in terms of task, situation or culture. None of the models consider medical context in usability analysis and evaluation.

Table 1. Comparison among usability models

Aspect of Comparison	Usability Models considered						
	Winter et al.	Ford	Federici et al.	Abran et al.	Clemmensen	Norman	Rasmussen et al.
Type of Model	Quality	User-centered	User-centered	Quality	Work Analysis	Action-oriented	Action-oriented
Levels of Details	Detailed	Abstract	Detailed	Abstract	Detailed	Abstract	Detailed
Iterative Approach	No	No	Partially	No	No	Yes	No
Work Environment	No	Considered	No	No	Considered	No	No
Time required	No	No	No	Indirectly	No	No	No
Context	Considered	Considered	No	No	Considered	No	Considered

Thus, though usability models are quite useful for usability analysis and evaluation, most of them are general-purpose and definitely miss out medical context. These models fail to identify usability problems and medical errors in ICU environment. Such failure may lead to patient injury or death [42]. Therefore, it puts forward an important research question:

How to Adapt the Usability Model in Medical Context?

A user interaction with medical devices through user interface is studied during usability evaluation. Such user interaction involves several tasks such as setting up a device, changing a device mode or parameters, updating patient record, monitoring patient's condition through alarms and alerts or generating reports [42, 45]. A task-oriented work analysis involving medical users can provide a better insight about usability problems as well as medical errors related with therapeutic devices such as ventilator systems. This aspect has directed a selection of Norman's action-based model during research work. This model is iterative and therefore, it can help in detecting usability problems in prototype design and subsequently, improving the prototype during several iterations. Also, it is possible to accommodate medical context in Norman's model in terms of necessary elements (discussed in next section) in ICU environment.

Norman has proposed a seven-stage action model, which is published in Psychological Review [30] and is represented in fig. 2, which was used initially to capture major action slips [31]. Norman's model starts with goal formation. The aspect

of execution contains stages for the formulation of intentions to act, the planning of a sequence of actions, and the execution of actions, while the aspect of evaluation consists of observation of the result, interpreting it and evaluating it to create new goals, if required. **Till-date, many researchers have utilized and adapted Norman's action model with diversified perspectives in various domains such as Organizational Behavior, Telecommunication, Web Design, Public Interfaces, Computer Games, Aeronautics and Medicine** [3, 4, 13, 17, 25, 28, 34, 36, 39, 45].
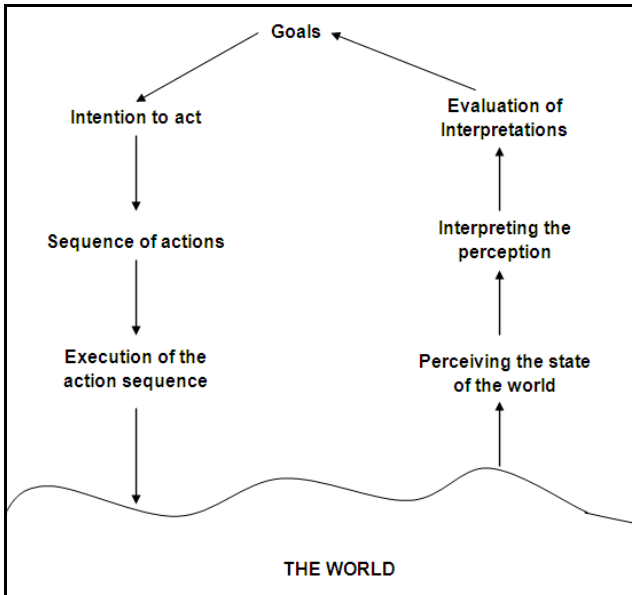

Fig. 2. Norman's seven-stage action model

Goldkuhl et al. have presented a general model of social action and have used it to characterize information systems as artifacts employed for organizational action [17]. This general model of social action is influenced by Norman's model. As part of the project AVANTI (AdaptiVe and Adaptable iNteractions for multimedia Telecommunication applIcation), the Norman Cognitive Walkthrough (NCW) method addresses the particular problem - the presence of design teams in different cities, even in different countries [34]. Babu et al. have used Norman's action model to conduct online assessments that guide in understanding the complete interaction between a blind user and the Web in performing an online task [3]. Finke et al. have reported on a series of experiments carried out to determine quantitative and qualitative effects on user performance when interaction is split across large public and smaller private screens. The experimentation is designed based on Norman's action model [13]. Kim et al. have introduced Eye Mouse and user's Thinking (EMT) System that tracks eye and mouse, and records user's thinking. For applying EMT system, EMT tool is developed to help a researcher to do usability test by recording the user's experience and reproducing it visually. For defining perception,

recognition, and behavior of users' experience, Norman's action model is used along with other two models [25]. Salovaara has presented appropriation understood as interpretation process in which user perceives in a tool a new opportunity for action, thus acquiring a new mental usage schema that complements the existing uses [36]. This model is close to Norman's action model, but extended for learning during use. Barr has discussed implications of analyzing computer game actions using Norman's action model [4]. Sherry et al. have discussed about how pilots form 'mental models', the way system behaves and use these models to guide their interaction with the system based on Norman's action model [39].

Norman's action model has been also applied in medical domain. Zhang et al. have developed a preliminary action-based cognitive taxonomy of errors; both for slips and mistakes in the domain of medicine, based on Norman's action model [45]. Malhotra et al. have proposed a cognitive workflow model in critical care environment. The representation of medical users draws inspiration from data processing systems and Norman's action model, defining mental and system activities required for task completion [28].

Thus, Norman's action model has been widely accepted model in several studies as well as domains. This model is selected as it is iterative approach, which helps in identifying usability problems and subsequently improving the prototype design. Also, it is possible to accommodate medical context in the model in terms of necessary elements in ICU environment. The proposed usability model for medical user interface of ventilator system is discussed in the next section.

3   Proposed Usability Model for User Interface of Ventilator System

A usability model for medical user interface of ventilator system is proposed based on Norman's seven-stage action model as shown in fig. 3. In this usability model, all seven stages of actions highlighted in Norman's model are considered along with certain alterations and additions as discussed ahead:

- A 'medical user' is added and a 'physical system' is replaced by 'user interface'. These changes are required as the focus of proposed model is on usability, in which interaction among medical users and user interfaces of ventilator systems is dealt with. Thus, 'medical user' and 'user interface' are important elements in proposed usability model.
- Usability model starts and ends with 'goal' to complete the loop. The interaction with user interface of ventilator system is initiated by medical user, responded by user interface and evaluated again by the user for further action. The model also facilitates further iterations, if required.
- A 'response' is added next to 'user interface' as a response is always generated in the form of display of or change in numerical values, messages, graphs, alerts and alarms with medical user interfaces [29]. Such response is a basis for activities ahead such as perception, interpretation and evaluation

in usability model. The 'user interface' and 'response' are device-related items and therefore, grouped together as shown in fig. 3.

- Three important features observed with 'user interface' of ventilator systems are shown in the model – 'Combination of physical and onscreen interface', 'High risk' and 'Long-distance visibility' [5, 9, 23]. These features are shown connected with 'user interface' in the model.

- Along with elements - 'medical user' and 'user interface', other two vital elements - 'ICU environment' and 'time required' are also shown in the center of the model. These elements should be considered in each iteration of usability analysis to capture a related medical context.
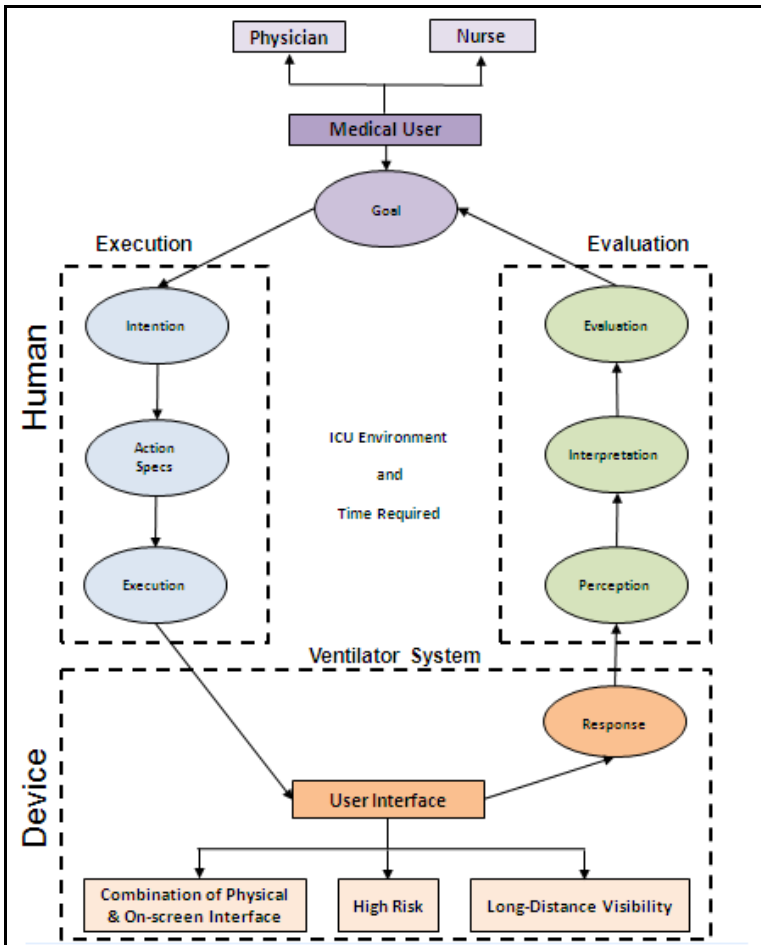
Fig. 3. Proposed usability model for medical user interface of ventilator system

The vital elements considered in usability model are discussed in this section in details.

3.1   Medical User

There are two major users of ventilator systems - physicians and nurses. They are primary users as they actually operate the devices during patient care in ICU [6]. Physicians and nurses differ from each other in mainly six aspects such as gender, language proficiency, education/training, eyesight, average work experience and numbers in ICU as shown in initial six rows of table 2. These comparative aspects are identified based on field study and profiles collected of 12 medical users including 6 physicians and 6 nurses working in intensive care units. The numbers indicated in brackets in table 2 represent positive entries of the related aspect. Remaining two aspects in table 2 depict roles and responsibilities of medical users identified in related literature survey [33, 37].

Table 2. Comparison between medical users – physicians and nurses

Aspect of Comparison	Physicians	Nurses
Gender	Mostly Male (5/6)	Mostly Female (5/6)
Proficiency of Language	English (6/6)	Mostly Hindi /Local Lang. (5/6)
Education / Training	4-8 Years (6/6)	2-4 Years (6/6)
Eyesight	Mostly Myopic (4/6)	Mostly Normal (5/6)
Average Work Experience	About 10 Years	About 5 Years
Number in ICU	Lesser (1 per 4 Patients)	More (1 per 2 Patients)
Role in Diagnosis	Decision-making	Assistive
Role in Therapy & Monitoring	Planning & Supervision	Execution

It can be observed that physicians and nurses differ significantly in their background and approach to patient care, which directly affects the manner in which they interact with medical devices in ICU. There is a noteworthy difference in a way in which they perform the task. For example, selection of ventilation mode may be executed by nurse, but it is generally on the advice of physician. This task is executed only by physicians in some intensive care units.

3.2   User Interface

The user interface considered in proposed model is for touch-screen based ventilator system. **Though ventilator system is mainly a therapeutic device, it also helps in**
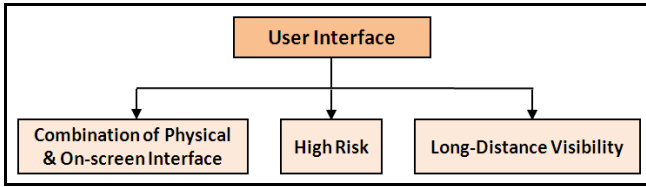
Fig. 4. Features of user interface with ventilator system

monitoring of critically-ill patients [11, 38]. It has a combination of onscreen and physical interface [18]. Physical interface includes a control panel with knobs, buttons, LEDs and/or indicator light. Being a therapeutic device in ICU, it is high-risk device. A long-distance visibility is involved in patient monitoring [9] with alarms and alerts of ventilator systems. These features are shown in fig. 4 and they should be considered in evaluation of user interfaces of ventilator systems.

3.3   ICU Environment

In ICU, several environmental factors affect user interaction with medical devices. These environmental factors include lighting condition, ICU layout, noise as well as interruptions and disruptions [9, 41]. There are three levels of lighting conditions in ICU. Low and average lighting conditions are observed at 0-100 lux and 101-500 lux respectively whereas extreme lighting condition is observed at higher range. These lighting conditions are derived based on light readings obtained from three intensive care units selected at various times of the day. The consultation with physicians and the observations of ICU layouts has led to three commonly observed viewing distances, which can be applied in long-distance visibility testing. The first level is 6 feet (1.83 m), which is the length of the bed. The next level is 13 feet (3.96 m), which is quite common monitoring distance in smaller intensive care units [9]. The highest monitoring distance suggested is 20 feet (6.10m) which can be observed in some bigger intensive care units. The next environmental factor is interruptions and disruptions, which include asking questions or for assistance, phone calls, exchange of information with others, presence of other patients [40] and movements of medical staff as well as devices. These environmental factors definitely affect user interaction with medical devices such as ventilator systems; especially during patient monitoring and can lead to medical errors harming patient life. Therefore, such factors are included in proposed usability model for medical user interface.

3.4   Time Required

In ICU, the time is a significant element during performance of tasks. The survival rates of patients are higher in hospitals and intensive care units where the emergency systems are efficient and quicker. In emergencies, physicians and nurses are required to provide a treatment to critically-ill patients in quick time. So, they interact with devices through user interfaces hurriedly during patient care. Such rapid and hasty execution of tasks during interaction increases the chances of medical errors as well

as stoppages or delays creating a threat to patients' life. For example, to set couple of ventilation parameters, it takes about 10 seconds with user interface of ventilator system; but this task may be delayed if nurse fails to understand that screen is locked or there is a delay related with physician's advice. Therefore, a time required for a task is an important element in performance of task and is required to be considered in usability evaluation of user interface in medical devices such as ventilator systems.

4 Validation of Proposed Usability Model

The proposed usability model for medical user interface of ventilator system needs to be validated. This validation is performed using two methods - video analysis and overview of critical factors in ICU, which are described in this section ahead.

4.1 Human Work Analysis through Video Analysis

As proposed usability model is action-based model, one needs to capture and analyze action sequences of selected tasks. Therefore, video analysis method is selected for validation of model through human work analysis. A video provides a remarkably rich and vivid reproduction of an event. It also provides a permanent record of an event and supports reviewing and analysis of data at later times. Kaufman et al. have presented an approach to usability evaluation of computer-based healthcare systems designed for patient use in their homes. This approach includes a video analysis consisting of verbal and non-verbal analysis along with micro-level coding [24]. Rogers et al. have analyzed a blood glucose meter for its usability using video analysis, in which transcription and coding is used [35]. During this research work, selected task performances are video-recorded in real-time ICU environment. Such recordings have captured interaction of users with ventilator systems as well as related display screens in ICU environment. **The names of manufacturers, device models and user identities are not disclosed to maintain confidentiality.** Usability professionals also need to have basic domain knowledge about medical users and devices such as ventilator systems for applying the proposed usability model. This section includes necessary steps involved in video analysis.

4.1.1 Selection of Representative Users

There are two major types of users of ventilator systems - physicians and nurses in ICU. They are primary users and actually operate the ventilator systems during patient care. These users differ on range of aspects such as gender, language proficiency, education/training, eyesight, average work experience and numbers in ICU [33, 37] as seen in table 2. It is not possible to employ a fully representative sample and therefore, a convenient sampling method is used [26]. Two ventilator systems are studied and related videos are captured. Nurse is involved with videos of first ventilator system and physician is involved with videos of other ventilator system.

4.1.2   Selection of Representative Tasks

In patient care, several tasks are performed by physicians and nurses with ventilator systems in ICU. The list of tasks includes setting a system, pretesting of a system, setting a mode, changing parameter values, setting up alarms and alerts, patient monitoring, updating patient record and generating a diagnostic report [11, 38, 42, 45]. It is observed that two tasks - setting up a ventilator system and changing parameter values are most frequently employed tasks by medical users with ventilator systems. During these tasks, medical users extensively interact with ventilator systems though user interface. Such interactions often involve device displays, touch screen interaction or use of controls/knobs and may have effect of surrounding ICU environment. Therefore, these two tasks are selected for video-recording and related two videos are recorded for each ventilator system.

4.1.3   Conducting a Video-Recording

Setting ventilator systems and make them operational typically takes about 5-10 minutes if no other interruptions or distractions happen in ICU environment. Such setup is tested before video-recording the user interaction. It is very hectic and tricky challenge to get an access to busy intensive care units [8] and to obtain permission for video recording there. A problematic spatial layouts and noise in the surrounding also create hurdles for video-recording process. The primary focus of video-recording has been on tasks performed by medical users through user interaction with ventilator systems. Important activities such as hand movements of users, data presented, selection of options, responses displayed and delayed device responses are captured in video-recording. **The camera model used for video-recording is Pentax Optio M20 with resolution of 7 Megapixels. The file format of the recorded video file is .mov and the software used for video-logging is VLC Media Player 1.1.5.** The video-recording is conducted in late afternoon with an average lighting condition.

4.1.4   Preparation of Observation Table

For each video recorded, an observation table is prepared. A part of observation table related with a video of physician setting up a ventilator system is depicted in fig. 5. There is an attempt to realistically record the observations about interaction between medical users and ventilator system while performing the tasks. Few of the field observations and activities in surrounding environment during recording session are noted. The observation table shows a chronological sequence of activities involved in a particular task. The details of each activity are mapped onto various stages and vital elements of proposed usability model. During the mapping, the stages and elements are divided into five groups. This grouping can be noted in columns represented in the observation table of fig. 5. The grouping is mostly sequential as per the stages of the usability model.
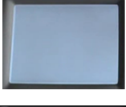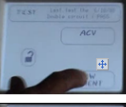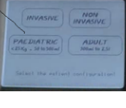
Sr. No.	Start Time (Sec.)	Frame	Mapping with Usability Model for Medical User Interface				
			Medical User Type, Goal & Intention	Action Specifications (A) & Execution (E)	User Interface & Response (R)	ICU Environment & Time	Perception, Interpretation & Evaluation
1	0		Physician is *right-handed*. Physician is *setting up a ventilator system*.		R - Two green LEDs are ON. The screen is blank.	The LEDs can be observed from a *distance* (max. 6 feet) during patient monitoring.	Two green LEDs indicate 'Power ON' and 'AC' as a power source.
2	21			A - Physician presses a start button on side of the monitor using *index finger of right hand*.		A beep is heard.	A beep indicates a start of ventilator system.
3	23			A - Physician waits for system response.	R - Screen is still blank.	A physician is *waiting* for response on the screen. The LEDs can be observed from a *distance* (max. 6 feet) during patient monitoring.	
4	28				R – The icon 'lock' can be observed at top right corner with a start ventilation option on the screen. The option 'ACV' is also displayed.	The discussions among nurses and physicians can be heard generating some noise.	The 'Lock' icon does not look like a lock, more like a bag. Full form expression for describing the parameter is not available.
5	35			A - Physician unlocks the screen by touching the 'Lock' icon using index *finger of right hand*.			The screen is locked. *Information displayed* before setting ventilator system is *not helpful* to physicians.
6	37				R - Screen turns white.	A physician is *waiting* for response on the screen.	
7	40				R - The icon 'lock' can be observed at left-center position of the screen with handle open. Screen shows two options – 'ACV' and 'New Patient'.		The screen is unlocked and Icon – 'Lock' is shown at changed location in the center.
8	92		Physician requires to *select patient type*.	A - Physician selects an option – 'New patient' through touch with index *finger of right hand*.			
9	94				R - Screen shows four options – 'invasive', 'non-invasive', 'Paediatric' and 'Adult' for selection of patient configuration in capital letters.		It is not clear about how many options to be selected for patient configuration. The options are difficult to read.

Fig. 5. Part of observation table related with a video involving physician setting up a ventilator system

In the first column of mapping, medical user, goal and intention are grouped together as such details are necessary in a preparation before execution of task. The related entry in fig. 5 is - 'Physician is right-handed. Physician is setting a ventilator system'. The next column has two stages - Action specification (A) and Execution (E) as these are closely associated with execution of task. One such action is unlocking the screen. The next column has a group of entities related with user interface and related response. For example, on-screen user interface shows six options for selection of ventilation mode and selected mode is highlighted on the screen as a response.

The factors related with ICU environment and time required, are highlighted in fourth column. The LEDs for power source can be observed from a shorter distance (6-10 feet) during patient monitoring and therefore, are not suitable for long-distance visibility of alerts. Time required for an activity during user interaction is facilitated by a response provided through a user interface. At times, a physician needs to wait for few seconds to get the required response. The last column has a group containing stages - perception, interpretation and evaluation as these stages are related with evaluation of response provided by user interface. At times, an inquiry or a confirmation of details in this column is required and it is achieved through interviews of medical users. Physician has confirmed the confusion about how many options to be selected for patient configuration. The options displayed in capital letters for patient configuration are difficult to read. Also, icons are not used for providing these options though well-accepted icons for 'Paediatric' and 'Adult' [7] are easily available.

Thus, observation tables have several important observations about user interactions with ventilator system. These observations are analyzed to capture related medical context as discussed in next section.

4.1.5   Data Analysis

The details of activities segregated into five groups in observation table are studied and analyzed. Many observations in the table highlight some important usability problems associated with vital elements. The findings in data analysis are discussed in this section.

Medical User: In data analysis, many aspects of medical users are revealed. Nurse uses a middle finger; instead of index finger to operate touch screen as shown in fig. 6. But, other fingers are more error-prone than index finger during touch screen interaction [16]. The use of middle fingers by Indian nurses with touch screen interface may be associated with **'Kumkum/Bindi effect'** [20, 21] observed among Indian women. Traditionally, women apply kumkum on forehead of oneself or other women using a middle finger in India. Such effect may be carried over to interaction of nurses with interfaces of medical devices such as ventilator systems. Though nurse is right-handed, she has to operate the user interface using left hand due to space constraint. Nurse has also fumbled during selection of ventilation parameters as she failed to understand that screen is locked.

User Interface: In data analysis, many usability problems are identified in user interface of ventilator system. The arrangement of multiple options in menu can be improved. The three options in the dialogue box for 'Patient Select' are quite distant from each other and six options arranged in dialogue box - 'Screen select' are asymmetric as depicted in fig. 6.
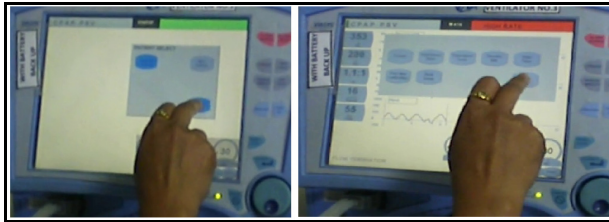

Fig. 6. Inappropriate grouping and symmetry of options in menu

Ventilator system is therapeutic device with important high-risk therapeutic tasks such as a selection of ventilator mode and setting up ventilation parameters. A confirmation of such tasks or actions is desirable, which is not provided in user interface of one of the ventilator systems studied.

ICU Environment: There are several factors related with ICU environment, which are highlighted in observation tables. The light reflections are noticed on and around the device screen and they obstruct the visibility of data on the screen. This is highlighted in the observation – 'Glossy screen reflects face of the nurse'.
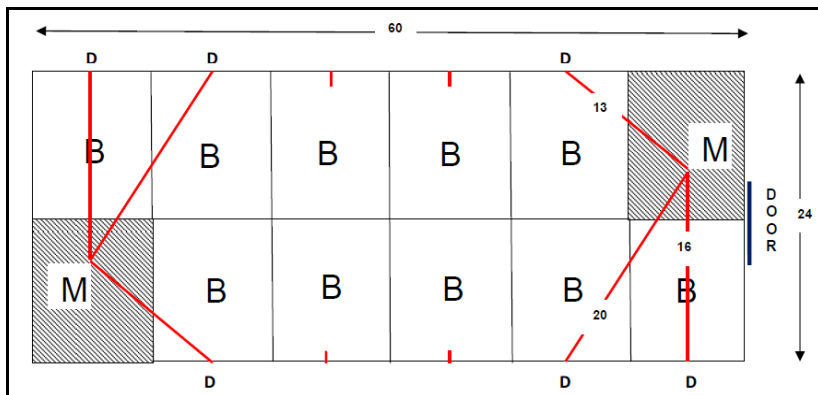

Fig. 7. Layout of ICU depicting dimensions and positions

Another factor highlighted in observations is ICU layout, which affects the viewing distance in ICU [9]. One of such ICU layouts, where this study is conducted, is provided in fig. 7. This layout is developed to understand the room dimensions and positions of doors, monitoring stations, beds as well as medical devices. In ICU layout, B stands for Bed position; D stands for Device position; M stands for

Monitoring station. The lines between monitoring stations (M) and devices (D) show the viewing distances in feet. The horizontal and vertical arrows depict the spatial dimensions of ICU in feet. A monitoring station is a place in ICU from where nurses or physicians monitor conditions of critically-ill patients. It is at minimum of 13 feet (3.96m) from devices as seen in fig. 7. From the observation table shown in fig. 5, it is clear that the LEDs indicating power source or visual alert in ventilator system can be observed from a short distance of 6 feet (1.83m) only and are not suitable for a long-distance visibility (upto 20 feet/ 6.10m). Another environmental factor highlighted in observations is interruptions and disruptions. Discussion among medical staff in a surrounding contributes to noise in the ICU environment as indicated in fig. 5. Multiple and undesirable alarms also generate noise.

Time Required: In time-critical environment like ICU, most of the tasks are performed hurriedly in minimum time. Physicians and nurses are quite often busy in patient care and dealing with emergency. A nurse or physician needs to wait as ventilator system takes time to start-up or boot-up. It makes the user little impatient.

4.1.6   Result

A data analysis of videos recorded shows that the proposed usability model is able to capture more aspects of medical context in ICU environment. Such aspects or observations include light reflections, noise, arrangements of options, use of different fingers with touch screens, therapeutic actions, long-distance visibility and delays in device responses. Thus, a proposed usability model is validated through human work analysis using videos and it definitely captures required medical context in ICU.

4.2   Overview of Critical Factors in ICU

Table 3. Critical factors related with distinct elements in ICU

Vital Element of Proposed Usability Model	Related Critical Factors in ICU
Medical User	• Physicians with varying levels of critical care training • Skills of nurses • Familiarity of equipment, procedure or environment
User Interface	• Therapy applied/ usage • Complex work and information flow • Design of alerts and alarms • Correctness of default thresholds
ICU Environment	• Interruptions and distractions • Lighting condition and noise • Room layout
Time required	• Emergency • Urgent high-risk decision making

A comprehensive overview of critical factors is taken with a literature survey of relevant research publications about ICU. The critical factors, which affect user interface design of medical devices such as ventilator systems, are identified. These critical factors are categorized with a due consideration to vital elements of proposed usability model such as medical user, user interface, ICU environment and time required. This categorization of critical factors is depicted in table 3.

The categorization of critical factors is discussed in this section. Few critical factors are related with medical users and may affect user interaction with medical devices. There are various types of physicians such as specialists, ICU physicians, resident physicians and interns with varying levels of critical care training. The 'skills of nurses' is a critical factor, which affects a patient care in ICU. These skills include safe medication, patient monitoring, respiratory or orthopedic care, record keeping, assistance to physicians and patient or family counseling [33]. Familiarity of equipment, procedure or environment of the medical user can affect one's task performance. Such user skills or features as highlighted by critical factors should be considered in design, analysis as well as evaluation of medical user interfaces.

Several critical factors affect the user interfaces of medical devices. Ventilator systems provide a respiratory support to critically-ill patients. A mode of usage or therapy applied is required to be considered in interface design of ventilator systems. A complex work and information flow provides a challenge for interface designers to incorporate it into effective user interface. Alert and alarm design demands a special attention as they are needed in patient monitoring in ICU. A correctness of default thresholds in parameter values is required for efficient patient care in ICU.

Environmental factors in ICU are also important. A major factor is interruptions and disruptions, which include questions asked for assistance, phone calls, exchange of information among medical staff [40], presence of other patients, noise from medical devices and surrounding people. Other environmental factors include lighting condition and ICU layout [41], which also affect the long-distance visibility of user interfaces in ICU.

Emergency with critically-ill patients puts a constraint on the time provided for performing a task by medical users. The tasks such as setting up a ventilator system providing respiratory support to patient need to be executed immediately. An 'urgent high-risk decision-making' is a factor affected by processes like cognitive tunneling, which is a tendency of physician to focus on only one hypothesis or solution at a time and ignoring other possibilities [15]. Such decisions affect the time required for a therapy provided by medical devices such as ventilator systems.

These critical factors in ICU affecting user interface can be categorized as per vital elements related with proposed usability model for medical user interface of ventilator system as observed in table 3. The consideration of vital elements in a proposed usability model can direct usability professionals to many of these critical factors affecting user interfaces of ventilator systems and can help in capturing a required medical context in ICU.

5   Conclusion and Future Work

Usability model for user interface of ventilator system is proposed based on Norman's seven-stage action model. This comprehensive model brings related medical context into human work analysis in terms of vital medical elements such as medical user, user interface, ICU environment and time required. It captures usability aspects like light reflections, noise, arrangements of options, use of different fingers with touch screens, therapeutic actions, long-distance visibility and delays in device responses. This model can be used as a template with medical user interfaces effectively by usability professionals for improved results. In future, a proposed usability model for ventilator system can be integrated with a suitable usability evaluation method to identify related usability problems with medical user interfaces more effectively.

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