Workflow modeling in critical care: Piecing together your own puzzle

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Abstract

The intensive care unit (ICU) is an instance of a very dynamic health care setting where critically ill patients are being managed. To provide good care, an extensive and coordinated communication amongst the role players, use of numerous information systems and operation of devices for monitoring and treatment purposes are required. The purpose of this research is to study error evolution and management within this environment. The focus is on representing the workflow of critical care environment, which emphasizes the importance such a representation may play in strategizing the management of medical errors. We used ethnographic observation and interview data to build individual pieces of the workflow, dependent on the individual and the activity concerned. Key personnel were intensively followed during their respective patient care activities and the related actions. All interactions were recorded for analysis. These clinicians and nurses were interviewed to complement the observation data and to delineate their individual workflows. These pieces of the ICU workflow were used to develop a generalize-able cognitive model to represent the intricate workflow applicable to other health care settings. The proposed model can be used to identify and characterize medical errors and for error prediction in practice. © 2006 Elsevier Inc. All rights reserved.

Keywords: Medical errors; Critical care workflow; Error prediction; Decision making models

1. Introduction

The paper describes an approach for representing the workflow of critical care environments and emphasizes the importance such a representation may play in strategizing the management of medical errors. The Institute of Medicine's Nov 1999 report on medical errors was not the first study on this topic but it had an especially vivid influence on the problem's public visibility and suggested that medical errors were the eighth leading cause of death in the US [1]. One study has estimated that—for just 18 specific categories of injury—medical errors extend hospital stays by a combined 2.4 millions days per year, adding up to $9.3 billion in hospital charges, and are responsible for 32,500 patient deaths per year [2,3]. In addition to the chorus of evidence in the literature illustrating problems with quality in health care, work is being undertaken to tackle those problems and authorities have issued recommendations aimed at curbing errors. Recommendations include use of information technology and improve understanding of the complex workflow and practice of health care [4]. Pursuing the workflow part of the recommendation, we believe that a visual representation of clinical workflow can aid in its better understanding. Although, an attempt to represent visually the workflow of a complex work environment such as that of a critical care setting is like working on a jigsaw puzzle with no picture to guide you. The same pieces (clinicians/tasks/devices/policies/IT systems) may be used to build more than one final picture, the resulting composite serving as a piece for the still bigger picture.

The question we are trying to answer is how to model workflows in complex environments? Workflow analysis and representation is a complex task, as the number of interacting entities to deal with at any given time is huge. Deciding the level of granularity needed for analyzing work

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flow and participant behavior is what makes the task of representation even more difficult. Using cognitive science principles and methodologies such as cognitive Task Analysis and cognitive Walkthroughs we can assess human behavior, including their interactions with one another and with devices, in the utmost detail [5,6]. A detailed level of analysis is not always required, however, and may in fact make it tedious to understand the workflow of a setting in which there are numerous and varied individuals as well as objects.

Clinical workflow representation requires multiple levels of depiction. These levels of representation need to be interrelated and intuitive in design for optimum utilization by people of different profiles related to the clinical setting. For example medical error analysis of a single event will require a detailed analysis of local factors surrounding the error by an investigator; on the other hand such kind of detailed representation would prove to be detrimental and unnecessarily complicated for use by an administrator who needs to see a more global picture for system wide intervention planning. An analogy to the situation would be planning a road trip. Using familiar online mapping resources, one can select a range of magnification levels starting from street level up to country level. If a person were to travel in a large city from one end to the other, a state level map would be useless to him as it fails to give the level of detail he needs. On the other hand, a detailed street level map may make the reading tedious since he might feel that a city map showing only the major intersections and streets would have sufficed. The key for good analysis is to be able to calibrate the view so that we are able to see, what we need to see.

In this paper we develop a generic model, derived using a cognitive perspective, for representing the workflow in a critical care setting. The objective is to delineate the workflow, role players, devices, protocols, and communications so that we can identify and focus on areas where cognitive aids, technology or interventions may be of assistance. Understanding the workflow will allow smooth incorporation of interventions that promote patient safety and counter medical errors.

2. Theoretical background

In organizational settings there are two main approaches to fixing a problem; the first one is the patch and move option where an error on discovery is prevented in the future by instituting a policy change or taking related measures. The advantage of this approach is that it can possibly be quickly achieved and generally, it does not require extensive effort or input for implementation. It is best used for dealing with errors on a one to one basis, i.e. an error props up; a solution is designed to prevent it from occurring again. The down side is that it works only in selective situations, it may not necessarily be based on evidential research and may not be generalizable to other situations. An example would be a policy change mandating two co-signers instead of one for blood transfusion orders where, in the past, transfusion errors (the right blood to the wrong patient) were made when a single person signed for blood products.

The second approach is more of a ‘System’ approach where the system encompasses all the policies, activities and entities belonging to the setting. This approach relies on understanding how the setting in question operates and how the users, devices and IT systems interrelate to each other while operating under the organizations policies [7]. It also may involve researching the nature of errors, starting from the cognitive mechanisms operating in the user’s minds prior to, during the evolution of and the completion of the error. The outcome of this research is usually not a single solution but a conglomeration of facts which highlights system latencies and flaws, and gives insight on projected problems as well as provides solutions to current problems. An example of this kind of pro-active approach would be the installation and customization of a clinical information system after researching the study site for need and estimation of possible benefits from such interventions.

Cognitive science methods and theories illuminate different facets of human behavior that govern actions and use of information and thus it plays an important role in conducting research in complex settings like the ICU. It provides insight into the nature of cognitive processes involved in human–human, human–computer interaction and thereby improve the application of medical information systems by addressing the knowledge, memory, and strategies used in a variety of cognitive activities [8]. The power of cognition is reflected in the ability to form abstractions—to represent perceptions, experiences, and thoughts in some medium other than that in which they have occurred without extraneous or irrelevant information (Norman, 1993) [9]. The study discussed in this paper is aimed at modeling the workflow of a clinical setting so as to allow strategic error analysis followed by intervention involving policy changes, decision support tools or IT systems. Increasing the number of information systems or decision support systems is not the approach we are looking for. The two most often repeated reasons for dissatisfaction with computer ordering—longer completion time and considerable workflow disruptions—require careful user–system interaction analysis and complex design changes to meet user needs (Meyer et al., 1998) [10]. Another important concept is that of Distributive Cognition [11]. From the perspective of distributive cognition, clinical workplaces can be viewed as cognitive systems. The cognitive processes do not take place in the individual minds of clinicians alone, but as collaborative team processes in interaction with their tools: the tools are patient records, documentations, laboratory reports, drug lists, medical devices etc., and their physical arrangement in space. Thus, ethnography, a social science research method is particularly useful in such settings:
“When used as a method, ethnography typically refers to fieldwork (alternatively, participant-observation) conducted by a single investigator who ‘lives with and lives like’ those who are studied, usually for a year or more.”—John Van Maanen, 1996 [12].

It relies heavily on up-close, personal experience and possible participation, not just observation, by researchers trained in the art of ethnography. These ethnographers often work in multidisciplinary teams. The ethnographic focal point may include intensive language and culture learning, intensive study of a single field or domain, and a blend of historical, observational, and interview methods [13, 14]. Typical ethnographic research employs three kinds of data collection: interviews, observation, and documents. This in turn produces three kinds of data: quotations, descriptions, and excerpts of documents, resulting in one product: a narrative description. This narrative description is used to create the proposed workflow model.

Before going into clinical workflow modeling it seems prudent to have a look at a model of cognitive engineering. Norman’s (1986) seven stage model of action (Fig. 1) is one such model that illustrates a cyclical pattern of interaction with a system [15]. The action cycle begins with a goal and follows intention, action specification, execution, perception, interpretation and evaluation phases which partly exist in the mind of the user (cognitive) and partly as physical activities. The beauty of the model lies in the fact that it is of a very abstract nature, independent of any system and can be applied in different domains of human function.

Workflow modeling is basically the process of simplifying reality. The modeling is based on facts gathered during observations and we need to accept that this representation can never be perfect. Expectations from a model should be limited to the intentions with which it is designed for, be it problem solving or understanding of system intricacies. There exists a myriad of literature on such models which describe workflows in both business as well as clinical settings [16–20]. Each of them has been developed such that they contain features unique to the native environment/clinical setting to which the author/researcher belongs and has his/her own unique modeling approach and technique. Some studies focus more on specific operational aspects without the need of describing the overall workflow in detail; e.g. Renard et al. [21] discussed how task allocation in the ICU setting can have an impact on overall efficiency and impact on healthcare delivery. All these techniques and generated models are designed to meet the goals of the concerned study and are inspirational but rarely directly usable or applicable to future studies planned in similar domains but with different objectives. This may not be construed as a disadvantage but a universal/generic workflow model would provide an element of standardization and allow reuse in future research in varied healthcare settings. In the real world this may not seem possible considering the intricacies and uniqueness of different health care settings.

This being said, it is somewhat ironic to state that the workflow model we present in this paper is aimed at being generic to critical care settings. This is where we take inspiration from Norman’s 7 stage model. Norman’s model allows a very detailed analysis of a simple tasks/procedures but fails to model higher level workflows (analogy of the map showing main intersections and not the detailed street level). This fact will be more evident in the study design section where on obtaining a clinical workflow model we proceed to a consolidation stage where key features (of generic nature) are consolidated and extracted to derive a cognitive workflow model which similar to Norman’s model will have wide range applicability (although specific for healthcare) at the workflow level rather than individual task level.

3. Methods

Ethnographic observation and semi-structured interviews were used for the study.

3.1. Ethnographic observations

Study site: Cardiothoracic ICU of a tertiary care hospital: Columbia University Medical Center. In the ICU the patient cubicles are arranged around the central nursing station which is equipped with telecommunication resources, information systems, telemetry monitors etc. The available IT systems serve different dedicated functions but also provide some redundancy in terms of available content. IT systems are also available in each
patient cubicle for nursing documentation purposes. Apart from electronic records each patient has a paper chart as well.

Participants: ICU Staff. The ICU is a 16 bed unit with 66 staff nurses, 1 attending physician, one clinical fellow, four residents and one physician assistant.

Ethnographic observations were carried out in two phases: during the first phase a researcher (SM) who is also a physician followed and unobtrusively observed the activities going on at different times and locations within the ICU and took notes of the same. During this phase different clinical team members were followed for periods ranging from two to six hours at various times during the day: starting at morning sign-outs, morning rounds, afternoon patient care activities, evening rounds, post operative procedures and transfers etc. The purpose was to identify and delineate these activities in order to guide and improve efficiency of data collection in the next phase (discussed in more detail in the next section of the paper). The second phase which is similar to the previous one except that the times and locations are guided from the data from the previous and the notes are supplemented by audio recordings of the role players while they carry out their work. Consent from the role players and IRB approval was obtained together with certificate of confidentiality. At the end of each observation key concepts and observations were extracted from the notes and transcribed audio recordings. In this way, analysis and observation were interwoven in keeping with the principles of grounded theory as defined by Corbin and Strauss so as to ensure that theory development was grounded in the data; i.e. emergent in nature [20].

3.2. Semi-structured interviews

Participants: ICU attending physicians, residents, nurses (three each), a total of nine subjects.

The concepts found during the first ethnographic phase were used to design a semi-structured interview. Three ICU attending physicians, three nurses and three residents were considered representative of the ICU task force and were selected for the semi structured interview. These were considered to be representative of the professional groups actively involved during the patient care process. The interview questions are given in Appendix A. The responses were recorded and transcribed at a later time. The transcripts were then coded and the key concepts for each of the interviews were extracted and combined to obtain a workflow model.

4. Study design

Conforming to the study environment, the study design is somewhat complex. As mentioned before the methodology is of an emergent nature and the data collection and analysis is primarily distributed in to the following three stages.

4.1. Stage 1

Preliminary observation and identification of critical zones (CZ). During the initial ethnographic observation period we attempted to delineate situations/events and time periods of the ICU workflow. Observations made during these periods were also used to model the questionnaire meant for interviewing the key personal. These were called critical zones (CZs). The purpose was to improve the efficiency of ethnographic data collection by focusing down on these periods and to segregate key activities of the patient care process. Second, we were able to provide labels to identify or qualify an error or significant event.

Fig. 2 gives the schematic layout of the CTICU which has the nursing station along with the information systems in the center and is surrounded by the patient cubicles. The different activities of the clinical team are also depicted. These activities are clubbed into seven critical zones. These CZs are of a generic nature which allows them to be applicable across different healthcare settings to define healthcare activities. Table 1 contains the seven CZs, their descriptions and examples of activities (most of which are given in Fig. 2, the CTICU setting). Broadly summarizing the contents of the critical zones, each day starts with re-orientation (handoff by outgoing team) of the patient and bed situation and carrying out of the orders determined on the previous day. This is followed by re-assessment and formulation of the patient management plan. The activities determined by the management plan are subsequently carried out for the remainder of the day along with work pertaining to the transfer or admission of patients to the ICU. Reassessment of new admissions and a preliminary determination of the next days admission/transfer plan is made sometime in the evening. Finally, information related to the management and care of patients is handed over to the incoming night team which continues the management overnight. Information regarding overnight changes or events gets exchanged once again in the morning the next day when the rest of the medical team returns, and the cycle repeats itself.

4.2. Stage 2

Semi-structured interviews and preliminary coding: This is the stage where we attempt to paint a picture of the subsections of a still larger workflow. Now to define the state of an activity in the ICU including aspects of cognitive load we need the following:

(a) A framework to temporally relate and identify activities: Observations during the first stage and critical zones contribute to this purpose.

(b) Individual workflows with appropriate qualifiers to describe actions, interactions, and communication: transcripts from the interview sessions provide most of this information which is then coded using thematic coding. The categories used for coding were not
### Table 1
**Critical zones (CZs) with their descriptions and examples of activities from the CTICU ethnographic study**

<table>
<thead>
<tr>
<th>Critical zone (CZ)</th>
<th>Examples of activities</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Re-orientation and preliminary planning</td>
<td>Resident change (handoff)</td>
<td>Morning sign-out by (night) nurses and residents to their in-coming counterparts</td>
</tr>
<tr>
<td></td>
<td>Nurse change (handoff)</td>
<td>Re-orientation to patients condition, assessment of criticality</td>
</tr>
<tr>
<td></td>
<td>&quot;ICU assessment&quot; by attending</td>
<td>Preliminary determination of rounding sequence and future admission/discharge plans</td>
</tr>
<tr>
<td>Goal formulation</td>
<td>Morning clinical rounds</td>
<td>Morning rounds (patient management goals determined)</td>
</tr>
<tr>
<td></td>
<td>Procedures and patient care activities</td>
<td>Procedures and patient care activities conducted during rounds.</td>
</tr>
<tr>
<td></td>
<td>Finalization of admission/discharge plan</td>
<td>Finalization of admission/discharge plan</td>
</tr>
<tr>
<td>Goal execution</td>
<td>Post clinical round resident activity</td>
<td>Documentation of management plan, orders for patients, charting carried out</td>
</tr>
<tr>
<td></td>
<td>Post clinical round nurse activity</td>
<td>Patient care activities based on management plan discussed in clinical round are carried out</td>
</tr>
<tr>
<td>Transfers</td>
<td>Patient transfer from OR to ICU</td>
<td>Patients ready for step down care are prepared and transferred</td>
</tr>
<tr>
<td></td>
<td>Transfer of existing patient in ICU to floors (wards)</td>
<td>Transfer summary, continued management plan documented, initiated and communicated to the clinical unit receiving the patient</td>
</tr>
<tr>
<td>Admissions</td>
<td>OR to Nurse information transfer</td>
<td>Information of patients due to be admitted from the operating room (OR) or emergency department (ED) is received</td>
</tr>
<tr>
<td></td>
<td>Receipt of patient by resident</td>
<td>Based on the information preparations to received the patient are made</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Patient handover and determination of preliminary management (or continuation of the management as communicated by the personal handing over the patient)</td>
</tr>
<tr>
<td>Re-assessment</td>
<td>Evening clinical round</td>
<td>New admissions are assessed and initial management determined</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Next days step down/transfer/discharge plan for existing patients discussed</td>
</tr>
<tr>
<td>Evening sign-out</td>
<td>Resident change (handoff)</td>
<td>Information of patients handed off to the incoming night team (residents and nurses)</td>
</tr>
<tr>
<td></td>
<td>Nurse change (handoff)</td>
<td>Overnight patient care activities carried out based on the information provided Documentation of overnight activities and preparation for morning sign-out (handoff to incoming team) are made</td>
</tr>
</tbody>
</table>

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Fig. 2. Schematic layout of the CTICU and key activities during which observations were conducted. Patient cubicles surround the Nursing station where most of the clinical information systems lie. The letters on the human representations signify the following: A, attending physician; R, resident; F, clinical fellow; PA, physicians assistant; N, nurse.
predefined, but emerged during the course of analysis. This was in keeping with the theoretical framework of the grounded theory approach of data analysis [22].

(c) Situational and environmental qualifiers on which performance of an individual will depend (dependencies): Once we know the time, the activity and the actions an individual, the third item we need to define is the situations surrounding these activities since these environmental variables can determine how effectively or efficiently the individual in question will be able to perform a task. This performance will also depend on the inherent qualities and skill of the person in question. Information for these factors will be obtained from both the interviews as well as from the continued observation phase.

Combining the three aspects mentioned above, we obtain an individual’s workflow during the course of a typical day. Environmental variables, points of interaction with devices, shared activities and communication with other personal in the ICU form the sticky locations of the individual workflow model. Using these sticky points we combine each team member’s workflow in order to generate an overall workflow model of the ICU setting.

4.3. Stage 3

Integration of individual workflows and consolidation to form the cognitive workflow model: As mentioned in the last step we use the sticky points of each individual’s workflow as well as the temporal framework obtained by identifying the CZs to obtain an overall model of the ICU’s workflow. Fig. 3 gives a schematic version of these two steps where individual workflows are being combined to form a much more complicated main workflow model. This version will obviously contain surplus content and information regarding the ICU operation but its complexity fails the purpose of providing a consolidated and understandable view of the same.

Therefore, the final stage of the analysis is to consolidate and extract key features to form a cognitive model which is more generic in nature and allows planned interventions for workflow improvement and medical error prevention purposes.

4.3.1. Knowledge-matter-knowledge cycles

Information exists in two forms; mental and documented (matter: electronic medical record or paper notes) form. In the workflow cycles discussed above the key underlying process is transfer of this information, which maybe...
Table 2
Coding scheme used to define individual workflows

<table>
<thead>
<tr>
<th>Codes</th>
<th>Purpose of code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity defining codes</td>
<td></td>
</tr>
<tr>
<td>TIME</td>
<td>Time of the day of the activity concerned</td>
</tr>
<tr>
<td>CIZ</td>
<td>The critical zone to which the activity belongs</td>
</tr>
<tr>
<td>Primary subject and activity</td>
<td>The key person whose workflow is being followed (the interviewee)</td>
</tr>
<tr>
<td>Shared activity/communication person</td>
<td>Communication with other person</td>
</tr>
<tr>
<td>Knowledge transfer codes</td>
<td></td>
</tr>
<tr>
<td>Knowledge transfer</td>
<td>To define whether the process involved knowledge acquisition/transfer/or documentation</td>
</tr>
<tr>
<td>Paper documentation*</td>
<td>Documentation of information</td>
</tr>
<tr>
<td>Information system use*</td>
<td>IT system used and purpose of use</td>
</tr>
<tr>
<td>Problem/error codes</td>
<td></td>
</tr>
<tr>
<td>Task problem*</td>
<td>To define any problems involved with the concerned activity</td>
</tr>
<tr>
<td>Error type*</td>
<td>Type of error</td>
</tr>
<tr>
<td>Other error qualifiers*</td>
<td>Further specifications to define the error</td>
</tr>
</tbody>
</table>

*a These codes were not used in the development of this paper.

complete, lossy,1 skewed, misinterpreted or even non-existent. The knowledge (related to patient conditions) that exists in the healthcare personnel’s mind undergoes degradation with passage of time. This happens with increased work and cognitive load on the person, with increasing number of people it is passed down in the communication chain and is directly proportional to the interim period between knowledge acquisition and its documentation. Documentation solidifies the knowledge in time and provides a new starting point for acquiring further new knowledge, combining the two and then documenting it all over again. While coding the interview and observational data to delineate activities and interactions, we introduced the element of knowledge acquisition/transfer/documentation. Once made part of the workflow model, it will help to visualize CZs where knowledge degradation and consequent medical errors are imminent.

5. Summary of methods

Just to summarize the three stages of our study design: we collected data from two sources, through ethnographic observation and by interviewing individuals of the clinical team being observed. We delineated the workflow in to different activities during the day and then clubbed them based on their criticality or temporal relevance into seven critical zones. Coding of the interview data and combining it with the observational data allowed us to build individual daily workflows of the each key person of the clinical team. Private (individual) or shared tasks and related communication to other team members were all part of this. Using the critical zones as a template, the different workflows were combined to generate a combined workflow model. As a final stage this model was consolidated to form a more generic version and the element of Norman’s model defining the cyclical mental and physical activities involved in task execution was also added.

6. Data analysis

The transcripts of the interviews were broken down into propositions, each illustrating a specific theme. Each proposition was coded using the codes given in Table 2. Propositional analysis and thematic coding was based on methods used in our past research [23]. These codes are intended to define the activity state of the concerned person in complete totality. Our criterion for completeness include the activity of the person, the people with whom he is interacting, the critical zone during which this activity is taking place, knowledge acquisition or documentation nature of the process, problems or errors related to the activity etc.

Fig. 4 represents the combination of the daily typical workflows of three key personnel in the ICU, an attending doctor, a nurse and a resident. This was built using codes used for defining the workflow (Table 2) and the CZs (critical zones) defined in stage 1 of the study. Basing the combined workflow on the CZs allows us to visualize which activities go hand in hand and which set of individuals are interdependent for the concerned work. The three workflows described in this diagram progress from critical zone one through seven as shown in the left most column with an arrow along side. Individual workflows progress as the day goes on in the direction of the arrow (from CZ 1 through CZ 7). Please note that individual workflows that were constructed for the clinical fellows, nurse managers and other members of the clinical taskforce are not shown here for the purpose of simplicity. Significant overlap exists in terms of training, skill and responsibilities of the different people involved in clinical care which is why an attending, nurse and resident were chosen to be representative from a task and hierarchical perspective. These three have therefore been used for discussion and workflow modeling purpose in the rest of the paper.

Enclosure 1 shows one such workflow (of the attending physician). Each individual’s workflow has activities which are either carried out by the individual alone (shown in white boxes) or are carried out as a collaborative effort with another team member (indicated by shaded boxes). The symbols KA, KT, KD, and A are qualifiers for these activity boxes to indicate whether the task was a knowledge acquisition, transfer, documentation or pure action task, respectively. Enclosure 2 encircles those activities under CZs and can potentially overload the resident both cognitively and physically, depending on the prevailing circumstances. The following are some points that can be drawn from the analysis of this combined workflow model:

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1 Scheme of organizing information in a more compact form where some information is lost to gain higher levels of compaction.
Activities overlap critical zones. The CZ with the maximum overlapping activities is generally the one with the maximum number of people interacting and communication flowing. Medical errors are more likely to occur in these zones.

Following the lines of Norman’s seven stage model, each activity has an action, evaluation and interpretation sequence. In medicine, each action requires a base knowledge for execution. This knowledge comes from the documented notes or is communicated by the person who has previously enacted an action–evaluation–interpretation sequence. If such information gets incorrectly documented in the previous step, the following action cycles may be disrupted and a medical error may ensue.

Highlighting the first point regarding activities overlapping multiple critical zones, we observe that the activities expected from a resident particularly crowd in the zones two through five. Zone 2 (Goal formulation) is a critical step in the whole patient care process. During this step, a management plan is developed by the attending physician, which is based on the patient assessment and the information provided by resident and documentations from Lab and imaging systems. Depending on how skillfully the attending physician orchestrates the clinical round and coordinates the inflow (new admissions) and outflow (transfers/step down care) of the patients, the concentration and stress level on the residents may accordingly vary. In the worse case scenario a resident may be performing knowledge acquisition and documentation related to the management goals as well as conducting procedures and transfers or communicating orders for the same to the nurses, all in close intervals to each other. Increased patient load is an entity which directly may affect performance on all tasks by any of the role players. Enclosure 2 indicates this CZ overlap and multitasking. The resultant cognitive overload may translate into medical errors in any of the tasks which may not be evident at the moment but may cause a chain of events or be of consequence at a later stage. The multitasking we are referring to here is basically the execution of multiple tasks in an interrupted fashion such that a task gets initiated before the previous one was concluded. For example a resident moving on to a procedure on another patient before he has finished documenting his assessments on the current one, may miss out or wrongly enter important assessments when he returns to the patient because of an interruption in the flow of thoughts or due to the inherent limitation of short term memory [24,25]. The wrongly documented fact may propagate to an error as discussed in the previous point.

The crowding of activities and their overlap in to neighboring critical zones is not entirely dependent on the coordination skills and performance of the staff. Factors that are not under the control of the clinical team such as scheduling of patients in the OR, availability of beds on the floors (step down care in clinical wards), criticality of ICU patients and non-routine events (NREs) [16]
may all contribute to cognitive overload and is part of the ‘distributed’ workflow of the clinical team members. NRE is defined as any event that is perceived by care providers or skilled observers to be unusual, out-of-the-ordinary, or atypical and contribute to inefficiency or possibility of errors. Difficulties finding anesthesia or medical supplies, providers bumping into or tripping over IV poles are considered good examples of these events.

7. Building the cognitive workflow model

The building blocks for the workflow model are: the key personnel, their activities and the critical zones of operation. The representation of an individual draws inspiration from data processing systems and Norman’s model defining mental and system activities required for task completion. The clinical team members are similar to data processing systems where given a set of inputs they process the information to perform actions (the output). The input is basically the knowledge acquisition (KA) process, the source being: documents and information systems (paper or electronic), communication from other clinical team members and active assessments of patient condition. In Fig. 5 we see the depiction of the knowledge acquisition (KA), knowledge transfer (KT), the mental workings, and related dependencies of a clinical personnel. The attending has been used as an example in this Fig. 5; a similar representation would apply for fellows, nurses or residents. The dependencies affecting each of their workings would however be different. This representation of the individual (Clinical personnel) is used in the cognitive workflow model, developed and illustrated in Fig. 6.

Fig. 5 details the processes in the minds of the clinical personnel from a mechanistic point of view. For this representation, we draw on three basic elements from Norman’s model: the first containing the elements of perception, interpretation, and evaluation; the second specifying the intention, action specification, and execution modalities; the third is the connecting segment where the processing is represented along with the dependencies which will determine the outcomes of the first two parts. Knowing the dependencies of both the perception (KA) and the information processing segments, this can be important in determining what kind of errors may occur in the presence of a faltering dependency. By plugging-in the representations of the key individual into the workflow model, we are attempting to predict medical errors with relation to the critical zones. These are based on the knowledge of these dependencies.

The consolidated version of the cognitive workflow model is illustrated in Fig. 6. The green boxes are the critical zones that we developed in stage 1 of the study and the blue boxes adjacent to them are the activities occurring during those CZs. The CZs are clubbed into three groups denoted by differing background colors (yellow, blue, and grey) to show that significant overlap in the zone activities.

Fig. 5. The internal workings of the attending that take place in order to accept, interpret, process, and act upon the information arriving from a source. The dependant factors (dependencies) for perception of the arriving information as well as the processing of the information is also depicted. Similar depiction would apply for any other member (resident/nurse) in the clinical workflow; although the dependencies for the concerned individual may differ. KA: Knowledge acquisition marks the information input for the individual and KT: knowledge transfer and ACT: actions show the processed outputs.
may occur, i.e. certain activities of different CZs in the group can occur at the same time. Knowledge exchange is denoted by connecting lines.

8. Interpretation of the model

Instead of attempting to absorb the model as a whole, we need to narrow down to the level of abstraction we require. There are four levels of abstraction: (1) the complete model as the top level, (2) the three different background colors (yellow, blue, and grey, i.e. grouping of CZs) form the next level where we can observe activities and parts of the workflow that may be carried out or/and take place at the same time. This view can provide leads to where and when medical errors are likely to occur if an individual is multitasking between different CZs and is cognitively overloaded. (3) The third level of abstraction narrows down to the individual critical zones. Here, we can observe the interplay of the different members of the healthcare team and follow the information flow chain. (4) The final level is that of an individual member of the clinical team. It allows us to focus on his/her incumbent dependencies (from Fig. 5) and outcomes related to knowledge acquisition–processing–execution–communication. Depending upon his position in the model, we may predict which part of the workflow may breakdown because of a faltering dependency. As mentioned previously this model utilizes the attending, nurse and resident for representing the clinical task force. Other members such as clinical fellows have not been included (although were part of data collection) because of significant overlap in their role; they may operate partly as an attending or for some tasks similar to a resident. Other personnel such as nurse manager’s follow suit. The purpose of the model is to simplify workflow depiction which is why by using the attending, resident, nurse hierarchical setup we steered away from using ‘new’ qualifying titles apt for their roles or by including all actual members involved in clinical care. The model’s cognitive foundation allows the discussion and incorporation of cognitive science facets to any planned workflow research if used as a standard template with appropriate modifications.

9. Discussion

Two main features of picture puzzles are that (1) they can be broken down into individual pieces with each jigsaw piece having almost unique edges which link it to other pieces, thus defining its place in the picture, and (2) some pieces can be combined to form a sub-section of the picture.
that is sensible and informative. To summarize our approach in this paper our research involved working on something quite similar to the picture puzzle, where we divided the whole workflow into individual activities, then tried segregating these activities into temporal events (times) and locations based on their critical importance, and then combined and built individual workflows in these critical zones. Finally, we viewed the relationships of the critical zones to one another based on the elements that composed it and all this contributed to forming the complete workflow picture of the critical care setting.

The proposed consolidated cognitive workflow model is generic in nature but its application in different clinical domains may require some adjustments or reconfigurations. For most settings the only modification required may be the removal of a critical zone or two, while other workflows might even contain additional zones of importance. Similarly additional members or activities can be made part of the model when deemed appropriate for the clinical workflow problem that is being studied or monitored. The environmental and situational factors (external dependencies) upon which an individual’s performance depends may also differ. For a given situation, knowledge of these dependencies can inform us about the nature of the individual’s performance. Following the chain of events we could possibly predict which of his/her activities are likely to suffer (communication, documentation or action, etc) in those circumstances. The model aids in pattern recognition; if a certain situation or medical error is recognized in one segment of the model, similar circumstances can be identified at other locations within the workflow allowing early intervention and heightened caution. For example if an error was documented on a previous occasion where an intern was admitting three new patients after midnight, an onsite pharmacist is unavailable and he/she is cross covering on two critical patients; then using the model we can map his activities such that if a similar situation arises again we can consequently predict which part of the workflow may breakdown and spawn a medical error. An error in those weak links can be prevented by providing additional support (e.g. policy/staff changes; alerts to supervising residents/fellows).

Our continued research lies in the area of developing a taxonomy and identifying root causes of medical errors. Combining it with this cognitive workflow model we hope to contribute to error prediction and prevention (or management) in medicine. Future course of the study aims at carrying out a detailed qualitative analysis in the ICU domain followed by its evaluation and application in other clinical settings. Decision support tools, alerts or cautionary advice can then be developed and dispensed in specific areas which are prone to medical errors.

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Appendix A. Interview questions

General:

1. Describe a typical day in the ICU? Your activities, interactions with other people, information systems and devices?
2. Are there any problems in the current workflow of the ICU?
3. Is there any thing that can be done to improve the problems you mentioned?
4. Is any aspect of the workflow impeded by ‘less number’ of individuals or ‘less time’?
5. Which information is most frequently used by you and for what purpose?
6. Which Clinical Information do you prefer to use and why?

IT system, documentation and communication specific questions:

1. Do you think that certain events or times during the patient care process are associated with medical errors or potential errors as against other times?
2. Is there any problem with multiple information systems? If yes, any suggestions for improvement? Integration? Removal?
3. In paper documentation of patients file do you consider any information sheets unnecessary that simply add to the bulk?
4. What aspects of the patient file (lab values, discharge summary... etc?) need to be frequently accessed? Which ones are hardly ever seen?
5. How would you like to receive/give orders regarding patient management keeping in mind efficiency and certainty of communication:
   a. Written orders, always except in emergencies
   b. Written orders, always
   c. Written orders, with post-activity mandatory double checking
   d. Verbal Orders with post-activity double checking
   e. Verbal Orders with mandatory double checking
   f. Verbal Orders (with instant Digital voice record documentation)
   g. Other

References