

## AHRQ Grant Final Progress Report

Title of the Project: Opportunistic Decision Making Information Needs and Workflow in Emergency Care

Principal Investigators: Amy Franklin Ph.D.  
(PI, 04/29/2015 -01/31/2017)

Jiajie Zhang Ph.D.  
(PI, 9/30/2012-04/29/2015)

Co-Investigators: Todd Johnson Ph.D.  
Cui Tao Ph.D.  
Nnaemeka Okafor M.D. M.S.  
David Robinson M.D. M.S.  
Charles Maddow M.S.

Team Members: Swaroop Gantela M.D.  
Adriana Stanley M.S.  
Vickie Nguyen M.S.  
Kristen Presleigh M.P.H.  
Brent King M.D.  
Debra Simmons Ph.D.

Organization: University of Texas Health Science Center at Houston School of Biomedical Informatics

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Federal Project Officer: Bryan B. Kim Ph.D.

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## 1. Structured Abstract

**Purpose:** In high-risk health care settings, such as the Emergency Department (ED), managing information needs and supporting clinical decision-making is critical for patient safety and health care quality. Our objective was to study information management and decision-making and to develop interventions to reduce cognitive burden, improve communication, and reduce error.

**Scope:** We focused on task-transition decisions (i.e. selection of action between activities) as such choices can impact overall ED function. Our earlier work demonstrated that less than 50% of task-transition decisions are planned. Rather than acting on a global understanding of the department, clinicians respond to information at a local level by making choices such as opportunistic decisions (e.g. selecting the next patient based on proximity). We developed visualizations of patient data to provide improve real-time situation awareness.

**Methods:** We generated a Work Domain Ontology (WDO) for the Emergency Department from interviews, surveys, and ethnographic observation. This WDO provides a representation of the clinical goals, information needs, and clinical operations. It forms the foundation on which we built our collection of visualizations. The evaluation our dashboard displays included formative assessments, eye tracking studies of information seeking, and exploration of the use of these displays in care environments.

**Results:** Five displays were developed and implemented within eleven local hospitals. Our results indicate that these dashboards provide support in the interpretation and evaluation of information for real-time decision-making. There is growing use of these tools within our clinical settings.

**Keywords:** decision-making, situation awareness, dashboard visualizations

## 2. Purpose

Emergency Departments (ED) are high workload, information intensive, time sensitive, interruption laden, multitasking, error-prone, and life-critical environments<sup>1-9</sup>. Managing information needs and supporting clinical decision-making is of great importance for patient safety and healthcare quality. The broad objective of our project was to study information management and decision making in the ED and to develop cognitive interventions to reduce cognitive burden and support decision-making. Our approach utilized theories and approaches from distributed cognition<sup>10-15</sup>, work domain ontology<sup>16-20</sup>, and human-centered visualization<sup>21-24</sup>. We focused on the information needs and cognitive mechanisms of opportunistic decision-making. We believe improved situation awareness can lead to improved task performance and a reduction in human errors<sup>25-29</sup>.

Specially, our aims were to:

- *Develop and validate a Work Domain Ontology (WDO) of the emergency department.* The WDO captures the essence of the work in the ED including the information and resources needed to complete clinical care. It is composed of clinical goals, information objects, and clinical operations (i.e., activities) that are required for the care of patients. The WDO provides an implementation-independent description of the work domain that is both human and machine interpretable.
- *Identify the information needs for task transitions decision-making and understand the mechanisms and impacts of opportunistic decision-making.* Through observation at three hospitals, we explored task transition decision-making and the information needs in making such choices and assessed the impact of opportunistic decisions on the delivery of patient care in the ED. We observed opportunistic decision-making was influenced by environmental factors and its impact on patient care was reflected by decrease of productivity and increase of potential for adverse events. The workflow, information needs, and other aspects of these observations provided the source material for the WDO. These results were integrated with interview and surveys findings.
- *Develop visualizations for increasing situation awareness and supporting decision-making.* Utilizing the information identified in the WDO, we developed a series of dashboard visualizations of patient and department data. These dashboards were initially prototyped and formatively evaluated. The system was then implemented within a local hospital system with a rolling release of features to a slowly expanding user population.
- *Evaluate the impact of the visualizations as cognitive interventions.* Visualizations support pattern recognition, parallel processing, and external memory. They can improve detection, interpretation, understanding, and evaluation of information for decision-making. Our evaluation included experimental and usage based findings.

### **3. Scope**

#### **Background**

##### *Describing the Complexity of ED Work*

ED clinicians perform life-critical tasks that require acquisition, processing, transmission, distribution, and integration of significant amount of data in a distributed team environment in a timely manner. ED clinicians monitor their constantly changing information environment, respond to unpredictably occurring issues, collaborate and communicate with other people in the system as issues arise, and prioritize and solve multiple issues as they occur. Rather than focusing

on a single task at a time, ED clinicians are forced to switch between multiple tasks and usually multiple patients. Many of these task transition decisions are based on unplanned, unorganized, and unpredictable environmental factors. ED clinicians are constantly under information overload, multitasking, time pressure, and information requests. This high level of complexity in the ED is one major factor that contributes to potentially preventable adverse events<sup>30-34</sup>.

In order to better reveal system complexity and reflect its structure within an information system design, we needed an abstract description of the clinical and cognitive work performed by clinicians, independent of how the clinical setting is implemented with specific technology, artifacts, and environmental variables. A Work Domain Ontology (WDO) can be used to outline the basic structure of the work that the system together with its human users perform<sup>16-18</sup>. The WDO describes the essential requirements independent of any technology systems, strategies, or work procedures. It tells us the inherent complexity of work; it separates work context (physical, organizational, computational, etc.) from the nature or functions of the work itself. A WDO is composed of goals, operations (or actions), objects, and the constraints that capture the functions of work.

#### *Supporting Cognitive Processing and Decision-Making*

One fundamental step towards reducing the complexity of the ED is providing information as needed to clinicians who make decisions and provide patient care. In our previous work, we found that less than 50% of ED task-transition decisions (i.e. selection of action between activities) were planned<sup>25</sup>. We posited that the clinicians were responding to information at a local level (e.g. responding to interruptions, making opportunistic choices based on proximity), as their access to a global understanding of the department was limited. For example, doctors sometimes checked on patient they were physically nearer to rather than seeking out their next patient based on their extended length of stay or availability of lab results. In this project, we created dashboard visualization tools to support interpretation, understanding, and evaluation of information regarding the status of patients as well as the entire hospital unit.

Information visualization tools are designed to make use of our powerful visual system to efficiently process details that may otherwise require significant cognitive effort. The visual system is powerful because it can process information in parallel, automatically, and unconsciously. Visualizations can provide information that can be readily perceived<sup>14,31-32</sup>, easily recognized, and directly made into inferences<sup>33</sup>. Visualizations can provide short-term or long-term memory aids so that overall load can be reduced<sup>34-35</sup>. Such support can make data more readily consumable, including potentially complex information<sup>36-38</sup>. Additionally, through

interaction with the data by aggregating, filtering, searching or other means of sifting through information held within the display, visualization tools and techniques, as Rind et. al states, “combine(s) the processing power of modern computers with human cognition and visual abilities to better support analysis tasks<sup>39</sup>.”

### **Context**

Appropriate management of care in the emergency department requires the balance between the needs of individual patients, collections of patients (such as all those under the care of a given nurse or doctor), and the unit itself. The selection of the next patient to be seen, recognition of bottlenecks to department flow, and the (non)-adherence of a patient to a quality measure such as length of stay are all effected by task transition decisions such as opportunistic choices. We focus on all three levels of decision making within the ED.

### **Settings**

Three hospital sites within the Gulf Coast Region are at the center of our work including a Level I Trauma Center, a county facility, and a community hospital. These three facilities were selected as they provided insight from training and academic facilities along with community practices. These hospitals varied in the acuity and volume of patients seen. For example, the Level I facility serves approximately 52,000 patients per year. It is one of only two hospitals within the metropolitan area with the Level I designation. The county facility is the state’s busiest Level III trauma center with more than 70,000 emergency patients per year. It is estimated that it serves 3-4 times more patients than any other regional Level III site (including our community site). Nine additional emergency departments from within the same hospital system as hospitals 1 and 3 were included in the iterative development and evaluation of the dashboards. These additional facilities range from small convenient care centers to larger regional facilities.

### **Participants**

Physicians, advanced practitioners, and nurses participated in our studies across all 12 emergency departments. These individuals may provide direct care and/or act as medical directors, emergency department directors, or charge nurses. Resident trainees were also included. We broadly recruited at the facilities and collected data during all shifts. As we audio-recorded during our ethnographic observation, entire clinical teams were consented to our study as they may have been incidentally recorded. Based on the preferences of our sites, we maintained the anonymity of our participants and not collect identifying information such as ethnicity or gender. Our data was collected without identification as participants were coded by their roles (A=attending, N1=nurse 1).

#### **4. Methods**

##### *Understanding of Opportunistic Decision Making and the Work Domain*

Multiple methods were employed in this project. Interviews, surveys, and ethnographic observation were used to capture participant workflows and information needs for completing tasks within the ED. Physicians and nurses were interviewed (n=8) to discover their self-reported information needs, priorities, workflow, and goals in work. Extensive observations of nurses and physicians across each of the three main sites formed the input to the Work Domain Ontology. Participants for each hospital included: 8 attending physicians, 10 residents, 10 nurses for two observations each at hospital 1; 10 physicians for 19 sessions and 10 nurses for two sessions each for hospital 2; 5 doctors, 3 nurses for two sessions each and 2 additional nurses for 1 session for hospital 3. At least 70 hours of data were collected at each site. During our observations, we shadowed physicians, nurses, and advanced practice providers as well as clinically trained individuals in administrative roles (e.g. medical and clinical directors). We used these observations to detail workflows for tasks (e.g. discharging a patient), communication patterns (i.e. interruptions), and the use of health information technology. The commonalities and differences by role and facility were outlined in the WDO. For example, training facilities have certain workflows generated between residents and attending physicians regarding education and oversight of trainees. These tasks, such as a resident presenting a patient to the attending and joint discussions of potential treatment plan, were not seen in the non-training facility. Constraints such as having the attending signature on procedures or orders are only in place for selected roles. Surveys were completed (n=29) to validate the findings with a larger population of providers.

The work domain information was represented in the Web Ontology Language (OWL) for a standard and formal representation, where Goal, Object, and Operation are defined as OWL classes, constraints among them are defined as object properties, and attributes were defined as data properties. The ontology was implemented using Protégé. The ED-WDO was built with the additions of the essential classes and their constraints specifically for the Emergency Department work domain. The WDO was also verified and modified with each additional clinical site. As facilities varied considering volume and acuity of patients, location and staffing practices etc., additional constraints in work were noted. This information was reconciled with the existing WDO to generate a generalized description of ED work (i.e. not site specific). The WDO was also validated using the literature by querying our system to determine match between our representation of this knowledge and other similar protocols and work descriptions. For example, we queried our ontology for the constraints around nursing (re)assessment and comparing to literature based protocols.

#### *Developing visualizations to support cognitive work*

We developed an information-rich suite of displays to provide at-a-glance information implemented in the data visualization software Tableau (Tableau, Seattle WA, [www.tableau.com](http://www.tableau.com)). We created five dashboard displays conveying (1) census (i.e. number of current patients, severity score for each patient, current location of patients, available beds etc.), (2) state of laboratory and imaging orders, (3) contributing factors to the unit's current overcrowding score (NEDOCS), (4) throughput measures including the duration of each patient's current stage of care, and (5) workload information for each clinician. Each dashboard was created iteratively by from the WDO considering goals, operations, objects and constraints necessary for each task (e.g. selection of patient for next bed placement.) Each display provides a range of information and supports different types of information and decision-making needs. For example, the census board depicts information about the location and acuity of current patient in the unit and it also provides information regarding admitted patients boarding within the department as they wait for a bed. This information informs decisions such as which patient to place in a room next based on the availability of resources.

The dashboards were iteratively developed following Work Centered Design principles. The aim of the displays was not to provide historical information but rather to provide actionable information for real-time decision-making. Considering the throughput display, our aim was not to provide an explanation for example of why a patient's length of stay had perhaps exceeded a quality threshold (i.e. overall length of stay greater than 240 minute). Our throughput

visualizations were intended to improve the recognition of bottlenecks within stages of care to affect decision-making and decrease the current care times.

Each display contains a number of features or widgets that depicts information. A graph indicating the ebb and flow of patients entering and leaving the unit, a chart listing the boarding times for admitted patients, and the count of patients in waiting room are just some examples of components of these displays. For each widget, we considered cognitive principles in the selection of our designs. Variants of different components were evaluated through testing and feedback. For example, representing time in clinical care encompasses a number of different descriptions of events. Time could be described as a point (e.g. administration of a drug), an interval (e.g. period of a particular cardiac rhythm), duration (e.g. six days of fever), viewed relative to a set point (e.g. before a given date), or aligned with other defined moments (e.g. co-occurrence of two procedures.) For our throughput dashboard, we adopted a model of intervals of care including for example: time from arrival to the department to provider, provider contact to disposition decision, and disposition decision to ED department. We used these intervals to consider (non)adherence to time based goals such as the length of time from being placed in a bed to seeing a provider. Alternatives to stages of care include accumulation of absolute time or percent over goal for a given activity.

#### *Formative Evaluation*

The prototype dashboards were presented to clinicians at 11 Emergency Departments. Participants included medical directors, emergency department directors, charge nurses, clinicians and other potential users of the dashboards. Nineteen participants provided feedback regarding the ability of the dashboard to support their current workflows, challenges they might see in the implementation of the system, and suggestions regarding redesign.

Following the finalization of the initial displays, two trained evaluators performed a heuristic evaluation to determine our own adherence to good design principles. Modifications were made to reflect all feedback.

#### *Implementing the system*

Following development within our research group, the dashboards were then implemented into the local hospital systems enterprise system. The dashboard system was linked to information from the hospital system's Enterprise Data Warehouse (EDW). The EDW captures and stores the information from the electronic health record system and other clinical information systems in near real-time (currently there is a fifteen minute delay between entry into the EHR and reflection



of that data in the dashboard). The release of the dashboards and their uptake by end-users occurred in stages. The initial census dashboard displaying the current status of the department with the number of patients, their severity level, bed assignment and other features was released in June of 2015 to a selected group of clinical and medical directors. Live training was provided. Over the remainder of 2015, the other displays were released in stages to broader audiences including of charge nurses and limited clinical staff.

### *Evaluation of Displays*

#### *Feedback*

Two months following the release of the dashboards, we solicited feedback. Return visits to the departments occurred at eight of the original facilities. The three smaller departments with lower patient volumes were omitted. Feedback was collected.

#### *Experimental Evaluation*

Situation awareness is difficult to assess in real world environments. It requires cognitive effort to maintain awareness. Methods for assessing situation awareness, such as the Situational Awareness Global Assessment Technique (SAGAT) <sup>40</sup>, often require disrupting the individual to make the assessment. This disruption halts work. Post-test or post-task completion assessments are also difficult in real-world environments given the impact on memory caused by delay before testing. We used using eye tracking to explore the effectiveness of our displays and information access comparing our dashboards with existing ED Tools. Using a Tobii T120 system (Tobii AB, Sweden, [www.tobii.com](http://www.tobii.com)), we recorded ten users answering a series of task relevant questions. For example, participants viewed a snapshot (i.e. single) throughput display and were asked identify the current bottleneck. The users' eye movements were recorded indicating the patterns of information access (e.g. what order did they look at items on the screen) along with duration of gaze to a point (e.g. fixation indicating prolonged attention). Similar questions using the EHR integrated clinical trackboard were also completed.

#### *System Use*

Through out the release of the dashboards we have captured log data to determine total number of users, frequency of use overall, and number of accumulated views for each display.

#### *Observation*

Ethnographic observation was repeated at hospitals 1 and 3. Ten additional physicians and nurses were shadowed in departments with active dashboard systems. Only hospital 1 included both pre and post dashboard implementation observations. Significant turnover within local hospital

systems stymied earlier access to community locations. Hospital 3 was brought into the study following implementation of the dashboards by the hospital system.

## 5. Results

### *Outcomes from Understanding of Opportunistic Decision Making and the Work Domain*

From our observations, interviews, and surveys, we amassed a rich description of emergency department work. We considered specific tasks such as the handoff of patients and care between shifts as well more general processes such as patient assessment and management. We observed that practices were influenced by the physical structure of the department (such as communicating in a pass through within a storage room as it was the shortest path between clusters of rooms), policies and programs in place (e.g. variation when rapid assessments areas are open or closed, team in triage, etc.), and available technology. For example, documentation reflects a rich area of variation across sites as the location of the computers for data entry influence communication patterns (i.e. closely placed stations appear to increase interruptions). Only one of the observed systems (hospital 3) used scribes. To create the WDO and dashboard visualizations, we pared down from these site-specific differences to focus on the shared aspects of ED work.

Goals, operations, and objects for ED work were implemented within an ontology. The example below indicates how staff roles are considered objects within the WDO.

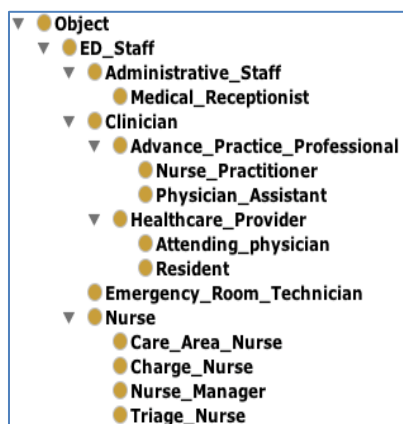


Figure 1 Staff Role as WDO Objects

Table 1 below outlines some of the operations, required objects and goals for the Emergency Department. Relations between required objects for goals and the constraints between goals can occur within a task. These requirements create restrictions within the ontology. For example, for

the Medical Screening Exam (MSE) requires a Clinician<sup>1</sup> as an object as a MSE can only be completed by a qualified medical professional. Further, the MSE is a requirement for administration data collection (i.e. patients must be evaluated for emergent needs and treatment prior to the collection of certain administrative data.) OWL restrictions can be set to define these conditions:

MSE *requireObject* some Clinician

ADMINISTRATION *requiresOperation* some MSE

**Table 1 High Level WDO components**

Operation	Required Object	Goal
Arrival	Medical Receptionist	Check in
Triage	Triage Nurse	Determine Emergency Severity Index Category
Nurse Assessment	Care Area Nurse	Collect initial encounter data
MSE	Clinician	Determine whether an emergency medical condition (EMC) exists
Administration	Admin Staff	Billing
Provider Assessment	Clinician or Nurse	Diagnosis for treatment
Test	Ordered by clinician or nurse	Obtain Information for Assessment and diagnosis
Treatment	Clinician or Nurse	Provide initial treatment/stabilize the patient
Disposition	Clinician	Sign to discharge the patient
Departure	Care area nurse	Instruct the patient for departure

Both high level and granular goals, objects and operations can be combined generate the requirements for simple and complex tasks. From within the WDO it is possible to determine what information and resources (both human and physical) are required to complete work in the ED. When building the dashboard visualizations, used the WDO to help determine what components of information were required within the display to help a provider assess the readiness of a patient for evaluation, consider the factors surrounding a bottleneck in the department or to make other task transitions decisions.

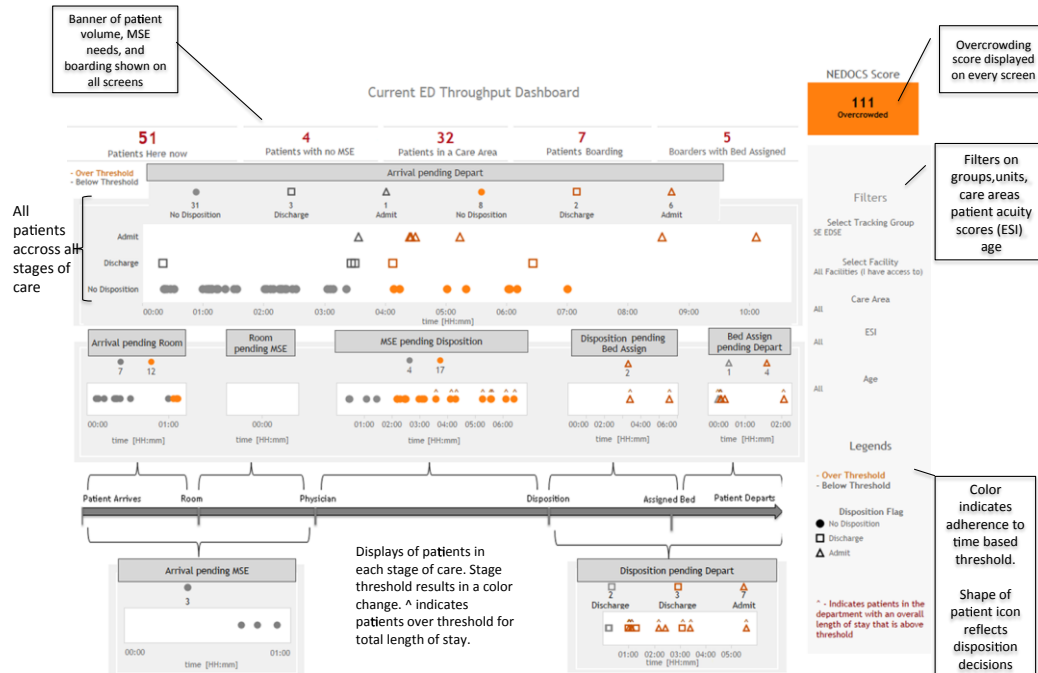
### Dashboard Displays

We created five dashboard displays conveying (1) census (i.e. number of current patients, severity score for each patient, current location of patients, available beds etc.), (2) state of laboratory and imaging orders, (3) contributing factors to the unit’s current overcrowding score (NEDOCS), (4) throughput measures including the duration of each patient’s current stage of care, and (5) workload information for each clinician. Each dashboard maintains a standard banner of

<sup>1</sup> Depending on setting MSE can be performed by doctors or nurses.

information across the top. This includes current counts of patients in the unit, those in need of a medical screening exam, those in a care area, those patients who have been admitted to the inpatient service but are awaiting a bed, those admitted who have a bed assigned but are awaiting transport, and the department's current National Emergency Department Overcrowding Scale Score. This provides some context for understanding the status of the current department.

Figure 2 Throughput Dashboard Example



The example dashboard above (Figure 2) is the Throughput Dashboard. This display provides time-specific details visualized across two panels in the middle and the bottom of screen. It provides both an at-a-glance snapshot of the 'health' of the department and separated stages of care. Patients, indicated by symbols, are viewed within the group. These symbols change based on disposition. This view is then enriched by tool tips and drill downs allowing the user to access individual patient-level detail. We use color to indicate patients above a threshold to create an immediate perception of the state of the unit. Bottlenecks in the department's overall flow are highlighted through the comparison of stages of care. Clustering of patients to the left of each phase without highlights in color would signal all is within range for each interval of care. Salient colors and a shift of the symbols to the right indicate that stays in the department are becoming

lengthy. Drill downs into patient details typically occur at the rightmost boundary, as these patients are at the extremes for their stage in care.

Within a real-time environment, a clinician's means of improving throughput may be to trigger alternative workflows, redirect resources such as adding a nurse to help clear a backlog for lab collections, opening hallway beds, or to work to clear the stacking of patients within a stage. Taking action for that particular patient might then be focused on removing barriers in their progress (e.g. determining source of imaging delays and selecting a different option, a discussion with bed control regarding their status, a call regarding consultant services, etc.) The dashboard is designed to support recognition of these bottlenecks.

#### *Evaluation of the Dashboards*

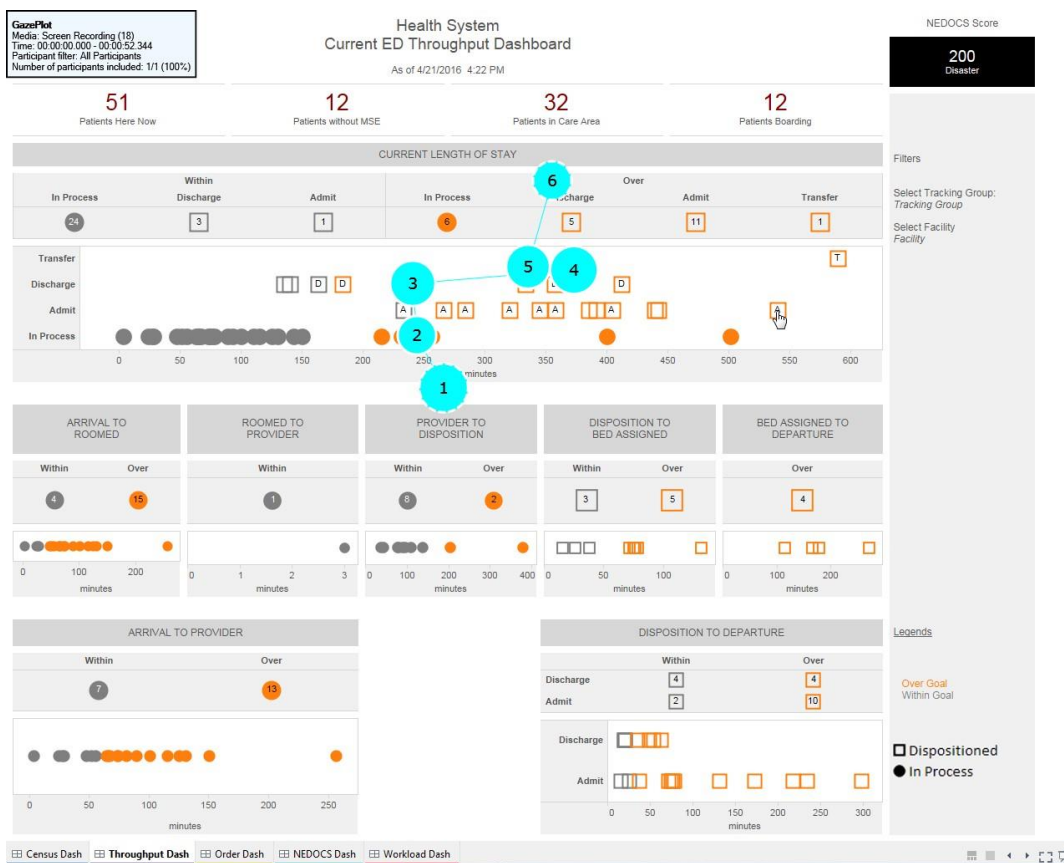
During the prototyping stage, the dashboards were presented to clinicians at 11 Emergency Departments. Nineteen participants including medical directors, emergency department directors, charge nurses, and physicians provided feedback on the designs. Findings from these discussions allowed us to adjust the dashboard to better support the work across sites. For example, in our prototype system, we utilized a 12-hour history for tracking patients currently in the department. That is, as we are pulling from a data warehouse of all the hospital systems, we capture 'current' patients as those currently in the unit with arrival times going back to the previous 12 hours. We had assumed that this would be sufficient history to capture the current length of stay for those patients. From discussion across hospitals, we learned some facilities had extended lengths of stay (15+ hours). We modified the display to include a 24-hour window.

Similarly, we provided multiple view of some of the dashboards for participant consideration. For example, one variation of the throughput board utilized a bottom to top timescale (e.g. patients ending care pushed off the top of the display) rather than the more typical left to right timeline. This variant was strongly rejected in favor of maintaining the more culturally consistent expectation of time following a left to right trajectory.

#### *Post-release feedback*

Following training and implementation of the dashboards, we returned to 8 of the larger facilities to capture feedback following use. Much of the input provided related to missing functionalities (e.g. bed control from the hospital was not showing within the census dashboard) or incorrect parameter settings (i.e. bed count was incorrect.) Some of these problems were triggered by incorrect information such as the inpatient bed count (i.e. the difference between licensed inpatient beds at a facility and actual beds in use.) Other challenges required further development

to solve. One instance was reconciling the posted NEDOCS (overcrowding) score with the manually calculated score generated by nurses every two hours. The automatic NEDOCS score broadly captures patient in need of 1:1 care through a look-up of patients with a ventilator order or other selected orders indicating significant nursing requirements. This orders requirement does not reflect actual nursing demands as patients may require this level of support prior to the placement of orders. The manually calculated score included this knowledge whereas the automated system lacked access. The addition of a feature within the EHR to allow nurses to indicate patients with a 1:1 need (without a required order) aligned the NEDOCS score and allowed the facilities to use our automatically calculated value.



**Figure 3 Eye Tracking Access of Information**

*Evaluating dashboard use through experiments*

We used using eye tracking to explore the effectiveness of our displays and information access comparing our dashboards with existing ED Tools. Using a Tobii T120 system (Tobii AB, Sweden, www.tobii.com), we recorded ten users answering a series of task relevant questions. For example in Figure 3 above, participants were asked to determine if patients with a discharge order but have not yet been processed out of the unit are a point of congestion in the department.

We can see here that moving from the center of the screen, first the user considered patient in process, then scanned those over threshold for discharge. We compared across participants and systems (dashboards versus existing EHR tools) to determine if our system provides readily consumable information to support situation awareness. Calculations within the existing EHR required longer sequences of filtering and drill down actions. Some functions such as recognizing adherence to a time-based threshold within a stage of care are not always available in the EHR visualization.

Within the dashboards, we found that in users with experience were readily able (based on order of information access) to locate necessary information within our displays. However, less experience was reflected in search behavior. For example, when a novice user (less than 60 days of use) was asked how many admitted patients were above LOS threshold (i.e. orange symbols on that given line) eye tracking reveal they reviewed each patient symbol on the line. More active users of our system utilize the summary values at the top of the screen. While we did not capture the learning curve for adapting to the system, as the throughput view is a preferred dashboard, we believe with experience the subjective perception of ease of use increases.

#### *Use and User Satisfaction*

Usage data included total number of users, frequency of use overall, and number of accumulating views for each dashboard. Thus far, 255 individuals have viewed the dashboards on 17,559 occasions. The census view, focused on patient placement in units and patient severity score, and the throughput board described above account for 90% of the system use. As the display system has been released, usage is anticipated to continue to grow with greater inclusion of ED clinicians.

In addition to usage logs, we collected anecdotal accounts supporting the dashboards and examples of how the throughput dashboard supported the recognition of patients ‘lost’ within the system. The use of the NEDOCS overcrowding score has replaced the manual calculation of this value for many of the users. The dashboards are also being used in unanticipated ways. Users are able to request a push of a snapshot of the department on a time schedule of their choosing (e.g. an email of the census dashboard sent at particular time). Clinicians, particularly those in administrative roles, often request the receipt of these views before start-of-shift as a means of anticipating the department status upon arrival.

#### *Observation*

Ethnographic observations were repeated at two hospitals. For hospital 1, this occurred nearly 3 years later following our initial observations. Considering task transition decision-making, our initial results indicated that planned decisions accounted for half of the choices in the Emergency Department (mean = .51, s.d. = .06). Approximately 21% of decisions were opportunistic in nature (s.d. = .05) with 25% of decisions being drive interruptions or other breaks in task directing the action of the clinician (s.d. = .07). These numbers reflect a slight reduction from our previous findings of 30% opportunistic decisions<sup>25</sup>. This may reflect changes in the physical environment (previously shown to impact these choices), changes in workflow, or the addition of technology. We had anticipated that the dashboard displays would reduce opportunistic decision-making by making readily available information to support planned decisions. Our results indicate that change. Opportunistic decision-making has dropped to approximately 7% of all task transition decisions (s.d. = .04).

Given that dashboard access was not in place for all team members, we are unable to assess factors of the ED as a whole including rates of left without being seen or similar impacts on patient volume. Extracting provider specific information for pre/post comparison is outside of the scope of our access.

### ***Limitations***

As with any addition of health information technology, the dashboard system described here has faced challenges not only its with its build but also with its implementation. One of the limitations of our study is small number of participants providing pre/post implementation data. User adoption of new systems takes time and support to grow. The roll-out of access to the displays limited the pool of available users. We hope increased availability of the tool will lead to greater system use.

Physical access to the dashboards is also a challenge, the layout of the departments across facilities means the computer stations for using the dashboards are not consistently accessible when engaged in all tasks (e.g. some are farther from patient rooms). The hospital system is exploring increasing the number of displays as we continue to evaluate the usability of the dashboards on smaller devices like cell phones.

Given all the factors influencing emergency department performance, we do not as of yet have the ability to tie the use of the dashboard to specific clinical or quality outcomes. As the displays continue to operate with more users, the intent is to compare pre/post implementation differences



in length of stay and other throughput measures for the entire unit. The study of individual pre/post performance is outside the scope of our access and project.

## **Discussion and Conclusions**

In this study, we were able to capture the complexity of work in the Emergency Department utilizing theories of distributed cognition and work domain ontology methods. We generated a WDO to represent the goals, operations, objects and relations between the concepts that define ED care. Across facilities of varying size and volume serving different populations, we were able to create a shared ontology and translate this information into a series of dashboard visualizations. While our formative assessments indicated some degree of fine-tuning was needed to fully encompass the needs of 11 different departments, the dashboards were readily accepted by all. Through collaboration with a local hospital system, we moved quickly from prototyping into implementation at a level unexpected at the time of our proposal. Although we did not complete the anticipated simulation based testing, our experimental studies using eye tracking were able to provide support for the effectiveness of our displays. Our results indicate although training is necessary to acclimate users to the rich content within the dashboards, users quickly make use of the features within the tools such as automated calculation of NEDOCS score and determination of patient outliers to threshold goals. While the deployment of the system into live environments was greater than anticipated, it has been a limited release to select users at each facility. Without large-scale adoption, the impact of the dashboards on overall ED flow is difficult to determine. Many socio-technical factors are at play within these environments and it is challenging to fully understand the positive impacts as well as unintended consequences of the additional technology. For example, although we see the anticipated decrease in opportunistic decisions (based hopefully on improved situation awareness), other factors within the department may also be contributing factors. Long term use of the dashboards along with evaluation of quality measures such as overall throughput, patient satisfaction scores, and a reduction in reported errors remain as goals for this system.

## ***Significance***

*Theoretical Advances.* Our Work Domain Ontology (WDO) based approach to information needs analysis and the Distributed Cognition oriented analysis of complex information systems together provides a theoretical framework for describing, analyzing, and understanding cognitive work in complex systems. Distributed cognition deals with how information and processes are distributed across people and machines, across teams, and across space and time, but it does not provide a formalism to specify the elements, processes, and structures of the complex systems. WDO

provides a formalism for extracting and describing essential components of a work domain, but it does not deal with how information is or should be allocated and distributed to maximize the performance of a distributed system. Our project brought these two approaches together as a unified framework and apply to the study of a real world setting – the ED.

*Methodological Innovations.* WDO is not only a framework but also a concrete method for identifying information needs as well activities in a work domain. These information needs and activities in the WDO provided the foundation for understanding ED decision making and were translated into information conveyed within our displays.

*Empirical Findings.* We produce a taxonomy of task transition decision-making in the ED and identified a collection of environmental factors that affect opportunistic decision making. Through our observation and eye tracking studies, we generated detailed descriptions of information access. These factors are important not just for behavioral outcomes (decision making) but also hold clinical consequences.

*Application.* With thanks to our clinical collaboration site, our project was able to be implemented in 11 hospitals settings. This provided a real world assessment of our tools success which continues to emerge with increased use.

*Design Recommendations.* Our project provides design recommendations for visualizations related to situational awareness, information needs, and decision making to improve healthcare quality and patient safety.

## **6. List of Publications and Products**

Franklin A, Gantela S, Shiffaraw S, et al. Visualizations: supporting real-time throughput decision-making. J Biomed Inform in press.

Nguyen V, Okafor N, Zhang J, et al. Using TURF to understand the functions of interruptions. AMIA Annual Symposium Proceedings 2014 Nov; 2014: 917-923. PMID: 25954399.

Tao C, Okafor N, Mehta A, Maddow C, Robinson D, King B et al. A work domain ontology for modeling emergency department workflow. Proceedings of the International Workshop on Semantic Web Applications and Tools for Life Sciences (SWAT4LS); 2014 Dec 9-11; Berlin, Germany.

Gantela S, Johnson T, Okafor N, et al. Comparison of Emergency Department Throughput Visualizations. American Medical Informatics Association; 2016 Nov 12-16; Chicago, IL.

Nguyen V, and Franklin A, Multi-Agent (Team) Microworld Environments for Healthcare. American Medical Informatics Association; 2015 Nov 14-18; San Francisco, CA.

Gantela S, Johnson T, Okafor N, et al. Dashboard Visualizations of Emergency Department Throughput Metrics. American Medical Informatics Association; 2015 Nov 14-18; San Francisco, CA.

Mehta A, Okafor N, and Franklin A. Projecting to Action: Situation Awareness and Emergency Room Dashboards. American Medical Informatics Association; 2015 Nov 14-18; San Francisco, CA.

Presleigh, K., Nguyen, V. Okafor, N., Mehta, A., Zhang, J., and Franklin, A. Task Transition Decision Making During Downtime: Impact of EHR systems on Performance. Workshop on Interactive Systems in Healthcare; 2013 Nov 16-20; Washington, DC.

Nguyen, V. and Franklin, A., Building for the Team: Developing a Model to Support Collective Effort. American Medical Informatics Association; 2013 Nov 16-20; Washington, DC.

### **Presentation**

Franklin, A. Opportunistic Decision Making, Information Needs, and Workflow in Emergency Care. National Web Conference on Using Health IT to Support Improvements in Clinical Workflow. Agency for Healthcare Research and Quality. Webinar; 2015 July.

### **Products**

Dashboard visualizations of Census, NEDOCS, Throughput, Workload, and Labs in place in 11 hospitals within a large metropolitan area.

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