1. TITLE PAGE

Project Title: Care Transitions and Teamwork in Pediatric Trauma: Implications for HIT Design

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2. STRUCTURED ABSTRACT

Purpose: This project was (1) to describe team work, which is highly cognitive in nature, involved in care transitions of pediatric trauma patients; (2) to develop and test design requirements for future health IT that supports team work for enhancing quality and safety of care.

Scope: Supporting cognitive work of large multi-disciplinary care teams, such as pediatric trauma teams, is essential to increase team performance and improve patient safety. A human-centered design approach is needed to identify the design characteristics of an information technology that supports team cognition for multidisciplinary clinicians involved in pediatric trauma care.

Methods: Guided by multiple conceptual approaches (SEIPS, contextual design, team cognition), we conducted qualitative studies with health care professionals from two participating academic pediatric hospitals that are both American College of Surgeons certified Level I pediatric trauma centers. We then used a participatory approach to design a pediatric trauma team-centric health IT. Different health IT prototypes were developed and formatively evaluated (using scenario-based evaluation) for each participating hospital by two different design teams to be able to compare and contrast design characteristics.

Results: Both prototypes were evaluated positively as participants did think the health IT can increase situational awareness and shared mental model among team members, and can improve patient safety. Although designed independently in two different settings, both health IT prototypes had many common design characteristics, providing support for the generalizability of the study findings.

Keywords: interdisciplinary health team, care transitions, interdisciplinary communication, situation awareness, information technology, user-centered design, pediatric trauma, patient safety

3. PURPOSE

The overall goal of this project was to analyze and model cognitive teamwork and team processes to design health IT-supported pediatric trauma systems using a sociotechnical systems (STS) approach. The specific aims were: ***Aim 1.*** To describe cognitive team work (e.g., information requirements, decision-making, coordination) involved in care transitions of pediatric trauma patients; ***Aim 2.*** To develop and test design requirements for future health IT that supports cognitive team work for enhancing quality and safety of care.

4. SCOPE

4.1. Background. Care professionals need health information technology (IT) that better supports their work. Currently, most health IT is designed to support individuals, however, more and more often, care professionals work in interdisciplinary teams. In this project, we focused on understanding how to better support cognitive teamwork and team processes in pediatric trauma care transitions by IT-based work system redesign.

Trauma is one of the leading preventable causes of children’s death. Pediatric trauma care by its very nature is team-based; but due to the emergent nature of trauma, critical information is often missed in the transition of these patients from one service/ unit to another (ED to OR, OR to PICU, ED to PICU). If designed well, by considering information needs and cognitive demands of the work on team members, IT can support these transitions and minimize information loss while enhancing information gathering and storage. However, health IT has also made healthcare more fragmented, and thus introducing new risks to patient safety (1, 2). New concepts and ideas are needed for the next generation of health IT that are leveraged for teamwork and care coordination over time and across care professionals. Human factors and systems engineering approaches and techniques are most suitable to advance knowledge about health IT design requirements that support interdisciplinary and distributed teams, such as pediatric trauma teams, that work under high time pressure and safety-critical situations. Such knowledge should direct future research efforts aimed at enhancing performance of interdisciplinary care teams to improve patient safety and quality of care.

4.2. Conceptual and Technology Design Approaches. Our project was informed by multiple conceptual and technology design approaches, including, but not limited to the following:

(A). Systems Engineering Initiative for Patient Safety (SEIPS). The overall theoretical framework for the proposed project relies on a socio-technical systems (STS) approach called the SEIPS model of work system and patient safety.(1) According to the SEIPS model, the sociotechnical work system produces processes, which, in turn, shape outcomes including patient safety. The SEIPS model has a similar structure to Donabedian’s structure process outcome model of care quality.(2) The structure component of the SEIPS model is a “work system” composed of persons (e.g., pediatric trauma care team), performing various tasks (e.g., getting information on patient’s status), within a physical environment (e.g., peds ED/ trauma bay), using tools and technologies (e.g., admission/discharge/ transfer record, checklists), within an organizational context (e.g., trauma team activation policies). A STS approach, such as SEIPS, is essential for identifying design requirements in a work system considering potential consequences, feasibility and trade-offs/conflicts between different actors and other work system components.
(B). Team Work Related Conceptual Approaches. Teamwork is essential for ensuring the quality and safety of healthcare delivery and associated care processes, including care transition processes. A team consists of two or more individuals with specific roles working together interdependently and adaptively towards a shared goal. Teams can be partially or wholly distributed in space (i.e., collocated vs. virtual teams) and time (i.e., using synchronous vs. asynchronous communication technologies). Clinical activities not demanding interdependence are defined as *taskwork* (i.e., tasks each team member completes without input from other team members). Dynamic interactions among team members such as coordination and communication events are defined as *teamwork*. *Team performance* is the summation of taskwork and teamwork. The care of a single patient depends on a variety of teams operating within a *multi-team system*.(3) Multi-team systems comprise a network of interdependent component teams that share at least one mutual goal, though each component team may also pursue different objectives at times.(3) For example, a pediatric trauma patient may encounter teams in the ED trauma bay, OR, ICU, and inpatient units. This project uses an interactionist perspective of team process, arguing that studying and aggregating individual team members’ input and cognition only provide limited and indirect information about teamwork.(4)
(C) Distributed Cognition Framework. Distributed cognition is an approach to understand cognitive activities by considering a work unit or a team as a “cognitive system,” in which cognitive activities are carried out jointly by the interaction among team members and their tools. This approach models information processing as distributed in the environment and in the team members' head.(5)
(D). Contextual Design. Nested within our STS approach, we used a specific human-centered design methodology, called contextual design (6) to provide an overall structure to the IT-based care transition design efforts. In particular we used the following 5 steps of this 6-step methodology: contextual inquiry, work modeling, consolidation, user environment design, and prototyping/ iterative development.

5. METHODS

Overall Study design. This multi-site, multi-method 5-year project contained qualitative studies (e.g., interviews), quantitative studies (retrospective analysis of EHR and trauma registries, surveys), health IT prototyping and scenario-based formative evaluation of IT prototype to develop a foundation for innovative health-IT based work system redesigns to improve team work and care transitions in pediatric trauma care. Multiple sub-aims/ sub-studies were done to complete the two main specific aims. Table 1 provides an overview of each specific aim, associated sub-aims/ sub-studies, key methodological elements and key outputs for each sub-aim/ sub-study.

Table 1. An Overview of Sub-Aims/ Sub-Studies within Each Specific Aim

Sub-Aims / Study Purposes	Study #	Data Sources/ Collection Methods	Data Analysis and Summarization Methods	Key Outcomes and Publications
AIM 1. To describe team work (that is highly cognitive in nature) involved in care transitions of pediatric trauma patients				
1A. Preliminary methodological work				
To describe an approach for linking electronically extracted EHR data to trauma registry data at the institutional level and assesses the value of probabilistic linkage.	Study #1	EHR & ped trauma registry	Linked data through combined use of deterministic and probabilistic approaches	(7)
1B. Describing pediatric team composition, complexity, and patient temporal flow				
(i) To understand how care transitions of pediatric trauma patients affect process and team complexity, as indicated by the number of roles providing care in different physical locations *(ii)* To characterize the temporal pathways i.e., the sequence of units in which the patient receives care while in the hospital.	Study #2 Study #3	Interview, archival document, EHR & trauma registry	-Qualitative and quantitative (process mining) analysis -Role network matrix -Process flow chart	(8, 9)
(iii) To identify opportunities for patient flow and triage improvement.	Study #3	EHR & trauma registry	-Process maps based on quantitative analysis that involves process mining -Suboptimal care transition points/ policies	(9)
1C. Examining the impact of the larger work system characteristics on pediatric trauma care transitions and team work				
To identify work system barriers and facilitators in care transitions of pediatric trauma patients	Study #4	Semi-structured interviews	-SEIPS-based process modeling, care transition barriers & facilitators	(10)
1D. Characterizing pediatric trauma team work and collaboration				
To characterize team work and multidisciplinary collaboration trends in pediatric trauma	Study #5	EHR & trauma registry + interviews	Process mining-based network analysis + social network analysis	(11)
To identify and describe diurnal variations in pediatric trauma care teams	Study #6	EHR & trauma registry + interviews		(12)
1E. Examining factors affecting team cognition, team information sharing, team decision making, and team trust in pediatric trauma care				
To characterize the utilization of problem list for pediatric trauma care.	Study #7	EHR & trauma registry	Descriptive statistics, multivariate regression	(13)
To describe physician perceptions of the potential goals, characteristics, and content of the electronic problem list in pediatric trauma	Study #8	Semi-structured interviews	Content analysis to identify problem list goals, characteristics & patient-related information elements	(14)
To identify factors affecting team cognition and information sharing/ info flow in peds trauma	Study #9	Semi-structured interviews	-Qualitative + quantitative analysis -Team cognition barriers and facilitators by care transition type and phase	(15)
To examine care transitions from OR to ICU	Study #10	-Semi-structured interviews -AHRQ Hospital Survey	-SEIPS-based process modeling -Nature of work involved in care transitions	(16)
To assess the challenges of ED team disposition related decision making for pediatric trauma	Study #11	Semi-structured interviews	-Qualitative analysis - Two challenges identified: Timing of decision, leadership and team organization	(17)
To measure perceptions of team trust, psychological safety, and team learning behavior in pediatric trauma teams	Study #12	Questionnaire survey	-Team trust -Psychological safety -Team learning behavior	(18)

Sub-Aims / Study Purposes	Study #	Data Sources/ Collection Methods	Data Analysis and Summarization Methods	Key Outcomes and Publications
AIM 2. To develop and test design requirements for future health IT that supports team work for enhancing safety, quality, and patient/ family centeredness of care.				
2A. Human centered design of a health IT prototype to support pediatric trauma teamwork				
To design a health IT prototype using a participatory, human centered design approach (Johns Hopkins team).	Study #13	Key findings from Aim #1 studies + human-centered design sessions + iterative prototyping	-Design requirements for the health IT prototype	Trauma Team Centric Information Technology (TACIT)
To design a health IT prototype using a participatory, human centered design approach (University of Wisconsin-Madison team).	Study #14	Key findings from Aim #1 studies + human-centered design sessions + iterative prototyping	-Design requirements for the health IT prototype	Teamwork Transition Technology (T^3)
To conduct a proactive risk assessment of the health IT prototype developed using contextual design	Study #15	Proactive risk assessment focus group sessions	-Vulnerabilities of T^3	(19)
To examine how multiple perspectives are managed in a team health IT design process.	Study #16	Analysis of recorded 4 team design sessions	-Collaborative activities used in design process (e.g., common ground, perspective clarification)	(20)
To describe the different steps in the co-design process for designing team health IT	Study #17	Multi-method	Steps taken for co-designing team health IT	(21)
2B. Formative evaluation of the pediatric trauma health IT prototype				
To examine if the Trauma Team Centric Information Technology (TACIT) supports team cognition and team work.	Study #18	Scenario-based evaluation	Pluses and minuses of TACIT	(22)
To examine if the Teamwork Transition Technology (T^3) supports teams and team cognition	Study #19	Scenario-based evaluation	Pluses and minuses of T^3	(23)

6. RESULTS

This section briefly describes each sub-study, including their results/ outputs and discussion/implications.

AIM 1.

1A. Preliminary Methodological Work

STUDY 1. (7)

Purpose. To describe an approach for linking electronically extracted EHR data to pediatric trauma registry data at the institutional level and assesses the value of probabilistic linkage.

Scope. *Background.* The trauma registry has been a driving force behind trauma care improvement over the past decades. The widespread adoption of EHR systems, however, has created large volumes of heterogeneous clinical data, structured (e.g., problem list, care team) and unstructured (e. g., radiology reports), that are not captured in trauma registries. These novel data types, when used in combination with trauma registry data, can enable innovative research to improve trauma care. *Setting.* A Level I pediatric trauma center that receives approximately 1,000 patients annually. *Participants/ Sampling*. All patient encounters from Sept 1, 2014 through Dec 31, 2017 that involved a true trauma team activation.

Methods. *Study Design*. Secondary analysis of EHR and pediatric trauma registry data. *Sample/ Data Sources*. Encounter data were independently obtained from the EHR data warehouse (n ¼ 1,632) and the pediatric trauma registry (n ¼ 1,829)**.** *Measures and Data Analysis*. Deterministic linkage was attempted using 9 different combinations of medical record number (MRN), encounter identity (visit ID), age, gender, ED arrival date. True matches from the best performing variable combination were used to create a gold standard, which was used to evaluate the performance of each variable combination, and to train a probabilistic algorithm that was separately used to link records unmatched by deterministic linkage and the entire cohort. Additional records that matched probabilistically were investigated via chart review and compared against records that matched deterministically. Descriptive analyses were performed for the demographic, injury, and encounter

characteristics in both data sets. We compared EHR data to registry data, and records linked deterministically to the records linked probabilistically using Wilcoxon– Ranksum and Pearson’s chi-square tests.
Results. *Principal Findings*. There were 1,829 and 1,632 records in the registry and EHR data set, respectively. Deterministic linkage with exact matching on any three of MRN, encounter ID, age, gender, and ED arrival date gave the best yield of 1,276 true matches while an additional probabilistic linkage step following deterministic linkage yielded 110 true matches. Probabilistic linkage of the entire cohort yielded 1,363 true matches. *Discussion/ Conclusions/ Significance/ Implications.* The combination of deterministic and an additional probabilistic method represents a robust approach for linking EHR data to trauma registry data. Transitions from one EHR to another, the use of tentative identifiers, and concurrent registry data capture have the potential to create inconsistencies between identifying information in trauma registries and EHR systems within the same institution. Linking electronically extracted EHR data to trauma registry data are best accomplished using a combination of deterministic and probabilistic linkages.

1B. Describing pediatric team composition, complexity, and patient temporal flow
Purpose. *(i).* To understand how care transitions of pediatric trauma patients affect process and team complexity. *(ii).* To characterize the temporal pathways i.e., the sequence of units in which the patient receives care while they are in the hospital. (*iii).* To identify opportunities for patient flow and triage improvement. *Background.* In-hospital pediatric trauma care typically spans multiple locations, which influences the use of resources, that could be improved by gaining a better understanding of the in-hospital flow of patients.

STUDY 2. (8)
Scope. *Setting.* A Level 1 trauma center in a 87-bed academic children’s hospital in Midwest. *Participants.* (1) Clinicians who are experts about the pediatric trauma care process. (2) Patients included in the pediatric trauma registry.
Methods. *Study Design.* Mixed methods (semi-structured interviews, archival data, pediatric trauma care registry). *Sample/ Data Sources/ Collection*. **(A)** Interviews. Purposeful sampling was used to identify clinicians who are experts about the pediatric trauma care process. Our sample included the pediatric trauma program manager (a pediatric nurse practitioner by training) and 6 physicians from four services: emergency medicine (2), pediatric critical care (2), pediatric anesthesiology (1), and pediatric trauma surgery (1). Sample size was determined based on theoretical saturation concept. **(B)** Trauma Registry. We included all of the leveled, accidental (i.e., not resulting from abuse) pediatric trauma patients treated between Jan 1, 2013 and Dec 13, 2017. *Measures and Data Analysis.* Semi-structured interview guide developed to understand the pediatric trauma process on each participant’s service. We reviewed all interview transcripts to develop *a flowchart showing the temporal sequences of units* caring for pediatric trauma patients and *a role matrix showing the care team roles directly participating in patient care in each unit*. The trauma registry data were analyzed in Excel© to calculate the frequency of transitions among units.
Results. *Principal Findings.* We identified the 53 roles directly involved in patient care in each hospital unit and described the 3324 total transitions between hospital units and the 69 unique pathways, from arrival to discharge, experienced by pediatric trauma patients. *Discussion and Implications.* We argue *to shift from eliminating complexity to coping with it* and propose supporting three levels of awareness -- individual, team, and organizational-- to enhance the resilience and adaptation necessary for patient safety and describe challenges and potential sociotechnical solutions for each. For example, a challenge to team awareness is inadequate “non-technical” skills, e.g., leadership, communication, role clarity; simulation or another form of training could improve these.

STUDY 3. (9)
Scope. *Setting.* A Level I pediatric trauma center that evaluates approximately 1,000 injured children in its pediatric ED in Eastern US. *Context.* Incoming patients are triaged to one of four trauma activation levels (Alpha, Bravo, Consult, and ED response) that are derivatives of the American College of Surgeons Committee on Trauma guidelines. An *Alpha* activation mobilizes clinicians in the ED, the pediatric ICU (PICU), and the pediatric trauma service for children with severe and potentially life-threatening injuries most often destined for the PICU. *Bravo* activation mobilizes clinicians in the ED and the trauma service for children with less critical injuries. Relatively stable patients activate a *Consult* for the pediatric trauma service, which include patient

transfers from other facilities, whereas patients with minor injuries prompt an *ED response*. *Participants.* Our unit of analysis was the patient encounter. We included encounters managed between Jan 1, 2013, and Dec 31, 2017, with an Alpha or Bravo activation to understand the flow of the sickest patients.
Methods. *Study Design.* Retrospective cohort analysis. *Sample/ Data Sources/ Collection*. Data were extracted regarding the two highest trauma activation levels, Alpha (n ¼ 228) and Bravo (n ¼ 1,713). *Measures and Data Analysis.* An event log was generated from the admission, discharge, and transfer data from which patient pathways and care transitions were identified and described. The Flexible Heuristics Miner algorithm was used to generate a process map for the cohort, and separate process maps for Alpha and Bravo encounters, which were assessed for conformance when fitness value was less than 0.950.
Results. *Principal Findings.* The process map for the cohort was similar to a validated process map derived through qualitative methods. The process map for Bravo encounters had a relatively low fitness of 0.887, and 96 (5.6%) encounters were identified as nonconforming with characteristics comparable to Alpha encounters. In total, 28 patient pathways and 20 care transitions were identified. The top five patient pathways were traversed by 92.1% of patients, whereas the top five care transitions accounted for 87.5% of all care transitions. A larger-than-expected number of discharges from the PICU were identified, with 84.2% involving discharge to home without the need for home care services. *Discussion/ Implications.* Process mining was successfully applied to derive process maps from trauma registry data and to identify opportunities for trauma triage improvement and optimization of PICU use. The large number of patient pathways revealed by this control-flow analysis illustrated the complexity of pediatric trauma care at the study site, and additional complexity may be revealed when other perspectives are considered. Although a patient pathway depends on their needs, the myriad of pathways may increase the complexity of coordinating care for patients. Thus, it is important to focus research on improving this aspect of trauma care, such as redesigning the trauma work systems to minimize (if possible) and improve care transition processes. For example, health IT could be designed to support teamwork and coordination across settings; current HIT solutions are far from optimal. We also identified an opportunity for improvement in patient flow. Although Alpha encounters were more likely to involve PICU admission, our findings revealed that more Bravo encounters were actually admitted and discharged to home from the PICU, which was attributed to the lack of protocols to define criteria for PICU care creating reliance on the provider’s experience, provider preference to err on the side of caution, and parental concern. Given the high cost of care in PICU, further research is needed to better understand these causes and to find ways of optimizing the use of the PICU.

1C. Examining the impact of the larger work system characteristics on pediatric trauma care transitions and team work.
STUDY 4. (10)
Purpose. To identify work system barriers and facilitators in care transitions of pediatric trauma patients. *Background*. Transitions between units are transitions from one system to another, with handoff communication between clinicians, and transitions of equipment, support staff, technology and environment all required to transfer authority and responsibility for patient care. Care transitions provide opportunities to detect and correct errors, but risk information loss and may lead to delays in care and information flow, and decreased care effectiveness and efficiency. Process analysis using a systems-based approach can be used to identify opportunities for improvement.
Scope. *Setting.* A level 1 pediatric trauma center in an academic hospital in Midwest. *Participants.* Purposeful sampling of care professionals involved in one or more of the following care transitions: ED to OR, OR to PICU and ED to PICU. **Methods.** *Study Design.* Qualitative (semi-structured interviews). *Sample/ Data Sources/ Collection*. We interviewed 18 care professionals. Because we asked about two care transitions in each interview, we have a total of 34 cases. *Measures and Data Analysis.* We applied the SEIPS process modeling method.(24) All transcripts were cleaned to remove any identifying information, and were uploaded to Dedoose© web-based qualitative data analysis software. Relevant excerpts were then coded to a pre-determined coding scheme: (1) the specific transition; (2) the trauma level and at least one of (3) process/role or (4) barrier/facilitator. The barrier/facilitator excerpts were exported to Excel® by transition (i.e. ED to OR, OR to PICU, ED to PICU). Excerpts from two transcripts were each reviewed to identify and reach consensus about all barriers and facilitators. The analysis resulted in identifying 418 barriers and facilitators. We then conducted a thematic analysis of individual barriers and facilitators grouping similar barriers and facilitators to

identify dimensions that could provide guidance about process redesign or technology solutions. Researchers identified the work system elements most closely involved for each dimension. In order to compare barriers and facilitators in the care transitions, we counted the number of interviewees who mentioned each dimension as a barrier and the number of interviewees who mentioned each dimension as a facilitator for each care transition. **Results**. *Principal Findings.* The ED to OR, OR to PICU and ED to PICU transitions involve similar work: *(1). Preparing the patient for the transition* (e.g., communication and coordination between the sending and receiving units, and gathering necessary equipment). *(2). Physical transition*, which involves moving the patient and family caregiver(s) and a handoff. *(3). Follow-up after the handoff,* which entails the receiving unit assuming and continuing care of the patient and documentation. For ex., the ED to OR care transition involves 25 roles who complete 11 major activities using four technologies – phone, paper notes, fax and EHR. Please refer to (8) for process maps of each care transition and further information. We also identified ***9 dimensions of barriers and facilitators***: *(1) Anticipation* refers to the ability of clinicians to foresee and address in advance needs related to the transition of the patient. For example, when asked about the use of any technologies other than a phone to gather information about a patient who will be admitted to the PICU from the ED, a PICU nurse responded: “Well, I can’t [use the EHR] until they arrive. So, and that’s a pretty significant roadblock… if I sought them out before they had a location, then I think I, I’ve never done this, I don’t know, but I’m guessing they would reprimand me.” (PICU nurse).” Anticipation was also mentioned as a facilitator (i.e., when clinicians were able to anticipate needs for smoother transitions): *“[I]t goes well if a bed is available if everyone is in the loop and is aware of the patient, if there's a heads up prior to from the ER that a patient might be in the PICU, and that once we finalize a decision, it's just a simple call.”* (Surgery resident).
(2) ED decision making refers to factors that influence decisions about patient care beyond the ED and how that decision-making process influences future patient care; this goes beyond deciding where the patient should go after the ED, i.e., the ED disposition. (3) *Interacting with family* refers to factors that influenced how clinicians and the family/ caregivers interacted, or did not interact. *(4) Physical environment* refers to how characteristics of the physical environment (e.g., lighting, noise, layout, distractions) impacted the care and transitions of pediatric trauma patients. *(5)* Role ambiguity refers to factors related to clinicians and staff being clear (or unclear) about their specific roles and related expectations. *(6)* Staffing/resources refers to how having (or not having) available staff and resources impacted the ability of clinicians to care for and transition patients. *(7) Team cognition* refers to factors that influence planning, decision making, problem solving and problem assessment at the team level, etc. – as well as how good or poor team cognition impacts the care transition. *(8) Technology* refers to how characteristics, (lack of) usability and/or (lack of) usefulness of technologies, including health IT, influenced the care transition. *(9) Characteristic of trauma process* refers to inherent properties of caring for trauma patients that impact how professionals provide care and transition patients. *Discussion and Implications*. Approaching care transitions from a SEIPS perspective allowed us to identify a wide range of barriers and facilitators while developing a clear understanding of the process involved in care transitions. Future work could investigate solutions *to enhance team cognition in care transitions*.

1D. Characterizing pediatric trauma team work and collaboration
STUDY 5. (11)
Purpose. To investigate multidisciplinary collaboration in pediatric trauma care by characterizing collaborative EHR usage patterns, understanding predictive factors, and determining how these usage patterns relate to ED length of stay (LOS).
Scope. *Background.* Pediatric trauma care is multidisciplinary involving various care professionals that coordinate across time and care location. Gaps in care delivery are common, particularly for patients with multiple injuries requiring care from multiple specialty services. Individual specialties tend to operate in silos, and transitions between care teams are often fraught with disruptions. Social network analysis based on routinely captured EHR data can be used to evaluate collaboration among care professionals and identify improvement opportunities. *Setting.* A Level I pediatric trauma center receiving approximately 1,000 pediatric trauma patients annually. *Participants.* Pediatric trauma encounters from Oct 1, 2016, to Dec 31, 2017, that were triaged to either alpha or bravo, and ended in direct discharge from the ED.
Methods. *Study Design.* A retrospective cohort analysis of EHR metadata and trauma registry data for a cohort of pediatric trauma patients. *Data Sources/ Collection*. From the trauma registry, we obtained demographic and encounter data including age, sex, trauma activation level, patient origin (scene of injury or

transfer), injury type (blunt, penetrating or others), Glasgow Coma Scale score, injury severity score (ISS), and ED LOS. From the EHR, we collected the metadata of captured clinical activities including 45 different types of notes (e.g., history and physical, consult notes), procedure orders, medication orders, flowsheet entries, and medication administration entries. The trauma registry and EHR data were linked by a record linkage process with high sensitivity and specificity that is detailed in our previous publication (Study #1)(7). *Measures and Data Analysis.* A process mining–based network analysis combined with social network analysis. Process mining is a data science approach that “aims to discover, monitor and improve real processes by extracting knowledge from event logs.” The starting point for process mining is an event log, which is a collection of events that is captured when processes are executed. Each row in an event log represents an event, which is a discrete activity (eg, note writing) in a given process (eg, clinical care) that is performed by an actor (eg, ED resident), and relates to a particular patient encounter (eg, Case ID 1). Each event is often timestamped (eg, medication administered at 10/16/2010 06:52) allowing chronologic ordering. An event log is usually imported into a process mining software, in which specific techniques and algorithms can be applied to investigate the process from various perspectives. In this study, we investigate the organizational perspective (relationships among actors) of the care process for the defined cohort via social network analysis. Social networks can be constructed from an event log by applying 1 of 5 “metrics” to define relationships (ie, edges) between actors (ie, nodes). We defined relationships between actors based on the “working closely together” metric between actors. In operationalizing this metric, we considered the shift rotation as the unit of clinical work and collaboration. We assumed that actors that were involved in the care of a patient during a shift had the opportunity of working together while actors that were captured in the EHR within a similar time interval during the same shift were likely “working closely together.” The EHR metadata were processed into an event log that was segmented based on gaps in the temporal continuity of events. A usage pattern was constructed for each encounter by creating edges among functional roles that were captured within the same event log segment. These patterns were classified into groups using graph kernel and unsupervised spectral clustering methods. Demographics, clinical and network characteristics, and ED LOS of the groups were compared.

Results. *Principal Findings.* Three distinct usage patterns that differed by network density were discovered (Fig 1): fully connected (clique), partially connected, and disconnected (isolated). Compared with the fully connected pattern, encounters with the partially connected pattern had an adjusted median ED LOS that was significantly longer (242.6 [95% CI, 236.9–246.0] min vs 295.2 [95% CI, 289.2–297.8] min), more frequently seen among day shift and weekday arrivals, and involved otolaryngology, ophthalmology services, and child life specialists. *Conclusion and Implications.* The clique-like usage pattern was associated with decreased ED LOS for the study cohort, suggesting greater degree of collaboration resulted in shorter stay. Further investigation to understand and address causal factors can lead to improvement in multidisciplinary collaboration.

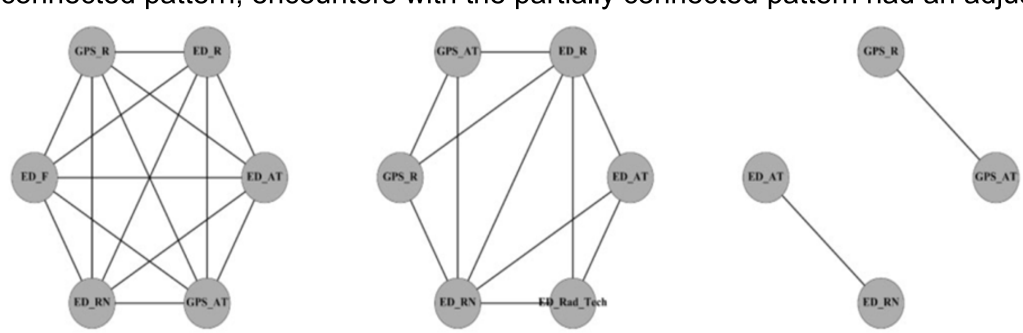

Fig 1. Iconic example of each usage pattern. Left to right: fully connected (clique), partially connected, and disconnected (isolated). AT: attending; ED: Emergency Department; GPS: General Pediatric Surgery; R: Resident; F: Fellow; Rad_Tech: Radiology technician; RN: Registered nurse.

STUDY 6. (12)

Purpose. To identify and describe diurnal variations in multidisciplinary care teams taking care of pediatric trauma patients using social network analysis on EHR data.

Scope. *Background:* Care of pediatric trauma patients is delivered by multidisciplinary teams with *high fluidity* that may vary in composition and organization depending on time of day. *Setting.* A large academic children’s hospital with a Level I pediatric trauma center in the Eastern US. *Participants*. Pediatric trauma patients.

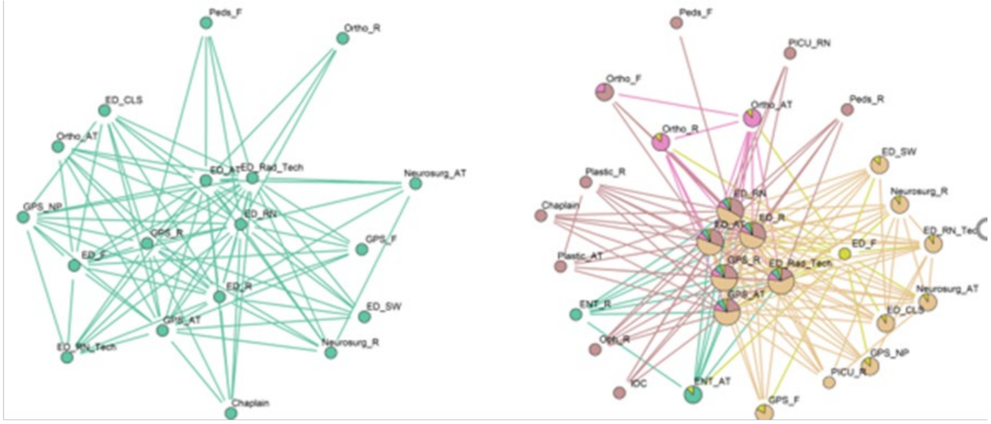

Figure 2. Collaborative care team patterns in the ED. Left: Day shift; Right: Night shift. A single community is seen in the day shift pattern, but 5 communities are seen in the night shift pattern with functional roles from the ED and general pediatric surgery belonging to all 5 communities. In the night pattern, the neurosurgery resident and attending are part of the largest community that includes the ED personnel and allied healthcare workers. _Abbreviations._ *Anes: Anesthesia, AT: Attending, CLS: Child Life Specialist, CM: Case Manager, DT: Dietitian, ED: Emergency Department, F: Fellow, GPS: General Pediatric Surgery, HCC: Home Care Coordinator, IDC: Imaging Data Coordinator, Neuro: Neurology, Neurosurg: Neurosurgery, NP: Nurse Practitioner, Oph: Ophthalmology, Ortho: Orthopedic Surgery, OT: Occupational Therapy, PA: Physician Assistant, Peds: Pediatrics, Pharm: Pharmacist, PICU: Pediatric Intensive Care Unit, PMR: Physical Medicine and Rehabilitation, PPS: Pediatric Pain Service, PT: Physical Therapist, R: Resident, Rad_Tech: Radiology Technician, RN: Registered Nurse, Tech: Technician, SW: Social Work.*

Methods: Metadata of clinical activities were extracted from the EHR and processed into an event log, which was divided into six different event logs based on shift (day or night) and location (ED, PICU, and floor). We limited EHR’s data to encounters with trauma activation levels of alpha, bravo and critical trauma transfers that were managed between Jan 1 and Dec 31, 2017. Demographic and encounter data including age, gender, origin of patient, trauma activation level, injury severity score (ISS), and Glasgow Coma Scale (GCS) score were collected from the registry. Admission, Discharge and Transfer (ADT) data, and metadata of five clinical activities (i.e., notes, procedure orders, medication orders, flowsheet entries, and medication administration entries) captured in the EHR were collected from the EHR data warehouse. For each EHR activity type, we obtained the encounter ID (visit ID), the activity timestamp, and the unique ID and generic clinical role(s) (e.g., attending, resident) of the care professional that performed the activity. The note metadata included the service of the author(s) while the procedure orders, medication orders, and medications administration entries included the care location (e.g. ED, PICU) where the activity was performed. Social networks were constructed from each event log by creating an edge between functional roles captured within similar time interval during a shift. Overlapping communities were identified from the social networks. Day and night network structures for each care location were compared and validated via comparison to secondary analysis of qualitatively derived care team data, obtained through semi-structured interviews; and member checking interviews with clinicians.
Results: _Principal Findings._ There were 413 encounters in the one-year study period with 272 (65.9%) and 141 (34.1%) beginning during day and night shifts, respectively. A single community was identified at all locations during the day, and in the PICU at night, while multiple communities corresponding to individual specialty services were identified in the ED (Fig 2) and on the floor at night. Members of the trauma service belonged to all the communities, suggesting they were responsible for care coordination. _Discussion/ Conclusions._ Social network analysis was successfully employed on EHR data to identify and describe diurnal differences in composition and organization of pediatric trauma multidisciplinary care teams.

1E. Examining factors affecting teamwork
STUDY 7. (13)
Purpose. To characterize the utilization of problem list for pediatric trauma care.
Scope. _Background._ The problem list is a required component of certified EHR systems. It is intended to capture active diagnoses and clinically relevant problems related to the care of patients in order to facilitate care coordination, continuity of care, and support clinical decision making. Meaningful Use Stage 1 and 2 required eligible hospitals and providers to “maintain an up-to-date problem list”. Yet, many hospitals struggle to maintain complete, accurate, and up-to-date problem lists. In the trauma setting, appropriate use of the problem list has the potential to improve care coordination by supporting shared situation awareness, team communication, and improving the follow-up of injuries. Gaining an understanding of the prevailing utilization pattern can provide insight that will inform usage and management practices. _Setting._ A Level I pediatric trauma center in Eastern US that manages approximately 1,000 pediatric trauma cases annually. _Participants._

All pediatric trauma encounters with an initial trauma activation of alpha or bravo, and critical trauma transfers that were managed between Oct 1, 2016 and Dec 31, 2017.
Methods. _Study Design._ Retrospective observational study. _Data Sources/ Collection_. From the trauma registry, we obtained encounter and demographic information including age, gender, trauma activation level, mode of arrival (ground or air transport), injury severity score (ISS), injury type (e.g. blunt, penetrating), Glasgow Coma Scale (GCS) score, ED length of stay (LOS), hospital LOS, and PICU LOS. From the EHR data warehouse, we obtained active problem list items at the time of admission and the problem list actions (addition, resolution and deletion of items) that occurred during the encounter. For each problem list item, we obtained the encounter ID, timestamp, provider ID, provider role (attending, resident, nurse practitioner, etc.), ICD-10 code, and item description. We also obtained metadata of patient notes authored during the encounter that included the provider specialty, which we used to determine the specialty of providers that executed actions on the problem list. Lastly, we obtained the Admission, Discharge, and Transfer (ADT) data containing the timestamp of admission to various inpatient locations where care was provided during the hospital stay. _Measures and Data Analysis._ We generated a timeline of the sequence of locations where the patients received care from the time of ED arrival to hospital discharge. We determined the number of active problem list items at arrival and the number of problem list actions executed during the patient stay. We performed descriptive analyses based on the type of code, time of action, provider roles and patient location for the problem list actions. We categorized the cohort into 2 groups: patients that had at least one problem list item added, and patients that did not. We compared demographic, injury and encounter characteristics for the two groups using Wilcoxon-Ranksum and/or Pearson’s Chi-Square tests. Multivariate logistic regression was performed to determine which encounter characteristics were predictive of having a problem list item added.
Results. _Principal Findings._ There were 517 patient encounters in the cohort, out of which 114 (22.1%) involved patients that had at least 1 active problem list item at arrival and a median of 3 items (IQR 1 – 5). Across all encounters, 975 problem list actions were executed. Out of these, 955 (97.8%) were addition, 15 (1.5%) were resolution, and 5 (0.5%) were deletion of items. Most of the problem list actions, 690 (70.1%) occurred while patients were still in the ED, followed by the PICU, 208 (21.3%). The highest number of items, 306 (31.4%), were added within _the first four hours of admission_. A total of 144 different providers, occupying 18 functional roles, across 7 specialties performed actions on the problem list. Providers in the GPS service executed the most number of actions accounting for 390 (40.0%), followed by providers from the PICU with 309 (31.7%). ED providers accounted for 176 (18.1%) actions. Nurse practitioners (NP) executed over half, 544 (55.8%), of all actions, followed by residents, 245 (25.1%), attendings 142 (14.6%), and then fellows, 44 (4.5%). Among the identified specific provider roles, the GPS NPs and the PICU NPs executed 291 (29.8%) and 253 (25.9%) actions, respectively. A total of 253 (48.9%) patient encounters had at least one item added during the encounter. For these encounters, the median number of items added was 2 (IQR 1 – 4). Compared to encounters where no items were added, these encounters were more likely to involve patients that had either alpha or critical trauma (Level 1) activation. _Discussion._ Almost all (98.8%) recorded problem lists actions were the addition of items. Items were seldom marked as resolved and rarely deleted. The majority of the problem list items were added within the first 4 hours of ED arrival. Hence, the first 4 hours of admission may be the best time for adding items, particularly injury-specific items, to the problem list. It may be less of a burden to providers if this task were formally integrated into the workflow at this point. There seems to be a favorable problem list utilization culture for sicker patients. Across all services, NPs accounted for over half of the actions performed. This suggests that the NPs could play a central role in promoting the usage of the problem list, for example, by acting as super-users or champions, which is pivotal in driving organizational change. In summary, we obtained some useful insights on the existing utilization patterns that can be leveraged to formulate usage and management policy that can build on the existing practices.

STUDY 8. (14)
Purpose. To describe physician perceptions of the potential goals, characteristics, and content of the electronic problem list (PL) in pediatric trauma.
Scope. _Background._ Traumatically injured children generally experience many transitions of care and are treated by multiple clinicians including physicians from different services. One consequence of suboptimal information flow, for example, known injuries and suspected problems, are missed injuries. A possible solution for documenting and communicating information about the patient and his/her injuries is use of the electronic

problem list (PL), a standard part of the EHR. However, accuracy and completeness of the PL remain major issues that impede its more effective and consistent use. PL accuracy and completeness can be improved by better understanding how physicians perceive and would like to use the PL. The PL can potentially be designed to avoid fragmented care planning and support care coordination by integrating priorities from various clinical disciplines. *Setting.* A level 1 pediatric trauma center in an academic hospital located in Midwest. *Participants.* Physicians involved in the pediatric trauma care process, including residents, fellows, and attendings from four services: emergency medicine, surgery, anesthesia, and pediatric critical care.
Methods. *Study Design.* Qualitative study using semi-structured interviews. *Data Sources/ Collection*. A total of 12 interviews were conducted between July and November 2016. We used purposive sampling to interview three types of physicians (resident, fellow, attending) in each of the four services: ED, surgery, anesthesia, and PICU. *Measures and Data Analysis.* Using qualitative content analysis, we identified PL goals, characteristics, and patient-related information from these interviews and the hospital's PL etiquette document of guideline.
Results. *Principal Findings.* We identified 5 goals of the PL (to document the patient's problems, to make sense of the patient's problems, to make decisions about the care plan, to know who is involved in the patient's care, and to communicate with others), 7 characteristics of the PL (completeness, efficiency, accessibility, multiple users, organized, created before arrival, and representing uncertainty), and 22 patient-related information elements (e.g., injuries, vitals). Of the 22 PL patient-related information elements, 10 were mentioned by physicians in the four services: medications, injuries, plan of care, past medical history, allergies, care completed, vitals, labs and imaging, non-trauma issue, and date of birth. Physicians' suggested criteria for a PL varied across services with respect to goals, characteristics, and patient-related information. *Discussion and Implications.* Physicians described the PL as more than a tool to document and share a list of problems or injuries suffered by pediatric trauma patients. Physicians mentioned many other information elements connected to problems on the PL, for example, medications and past medical history. A PL should support physician cognitive work and the collaborative nature of the pediatric trauma care process.

STUDY 9. (15)
Purpose. (Between the ED, OR and PICU), to understand what parts of the care transition processes include barriers and facilitators to team cognition, which will guide future improvement efforts.
Scope. *Background.* Inpatient care of pediatric trauma patients includes care transitions, including from ED to OR, OR to PICU, and ED to PICU, which are important to patient safety and quality of care. We identified work system barriers and facilitators in these transitions; the most common related to team cognition.(10) Team cognition includes cognitive tasks such as planning, decision making, problem assessment and solving, is important for team performance.(4) For example, the simultaneous occurrence of multiple, separate handoff conversations was identified as a barrier to team cognition. We must have a clearer understanding of when in the care transition team cognition barriers and facilitators occur in order to focus efforts to redesign work systems to improve transitions. We, therefore, analyzed 3 transitions using SEIPS-based process modeling: ED to OR, OR to PICU and ED to PICU. *Setting.* A level 1 trauma center within an academic pediatric hospital in Midwest. *Participants.* Purposeful sampling of care professionals. We interviewed 18 individuals, including 7 physicians (1 emergency medicine, 2 anesthesiologists, 2 surgeons, 2 pediatric intensivists), one advanced practice provider (anesthesia), 8 nurses (2 ED, 4 OR, 2 PICU) and 2 support staff from the ED.
Methods. *Study Design.* In-person, semi-structured interviews. We also asked for examples of transitions that went well and poorly, with probing questions about why they went well or poorly, respectively. *Data Sources/ Collection*. Each interviewee was asked about the two care transitions they participated in – interviewees from the ED were asked about the ED to OR and ED to PICU care transitions; interviewees from the OR were asked about ED to OR and OR to PICU transitions; interviewees from the PICU were asked about ED to PICU and OR to PICU transitions. This resulted in 34 cases (i.e., unique combinations of interviewee and care transition). *Measures and Data Analysis.* We have previously described the process analysis as well as the analysis to identify dimensions of work system barriers and facilitators(10) using the SEIPS-based process modeling method.(24) For the current study, we identified the specific step of each care transition in which each barrier and facilitator occurred. These analyses included consensus-based discussions between HFE researchers and clinician collaborators to enhance rigor. Based on the specific step in the processes, we identified the phase of the care transition process (preparation, transition and follow up) and physical location (ED, OR, PICU or patient transport between units) in which each team cognition barrier and facilitator

occurred. We counted the cases that mentioned a team cognition barrier or facilitator for each phase/location combination of all three care transitions. We then conducted a chi-square test to determine if the frequency of barriers and facilitators in the three phases of the three care transitions were independent.

Results. *Principal Findings*. See Table 2 for the team cognition barriers and facilitators for each care transition type and phase. The ED to OR had the highest number of 23 team cognition barriers (12 in preparation, 10 in transition and one in follow up) and 22 facilitators (10 in preparation, 9 in transition and 3 in follow up).

Table 2. Team cognition barriers and facilitators by care transition type and phase

	ED to OR		OR to PICU		ED to PICU		
	B	F	B	F	B	F	**Total**
Preparation	12	10	0	0	6	7	**35**
Transition	10	9	5	13	5	5	**47**
Follow Up	1	3	3	2	1	0	**10**
Total	**23**	**22**	**8**	**15**	**12**	**12**	**92**

Abbreviations: B stands for Barrier and F stands for Facilitator.

The Chi-square test showed significant interaction ($\chi 2(10) = 24.80$, $p = 0.0057$), indicating a significant relationship between phase and transition on the number of barriers and facilitators. The ED to OR transition had more barriers than the other two care transitions, while the OR to PICU had the least barriers. The preparation and transition phases had more barriers and facilitators than the follow up phase. An ED resident highlighted the importance of team cognition in the preparation phase of the ED to OR care transition: “*the biggest key is clear…having all of us on the same page, but having the nursing staff from here, from the* ED*, but also from the OR as well on the same page.*” The ED to PICU had similar challenges, although PICU clinicians were more likely to be able to go to the ED and participate in patient care before the care transition than OR clinicians who would be on-call from home during night shifts. *Discussion and Implications.* The preparation and transition phases of care transitions had more team cognition barriers and facilitators than the follow up phase. The ED to OR and ED to PICU care transitions have more barriers in the preparation phase, suggesting there are opportunities to change the sociotechnical system design to mitigate those barriers. Collocation may not be a sustainable solution to support team cognition in all care transitions. A possible sociotechnical system design change is designing and introducing a technology-based solution specifically to support cognition in distributed teams. This design should be context sensitive to address the unique contextual factors of the specific care transition. In conclusion, this study clearly demonstrates that different sociotechnical system designs and the processes that unfold in these systems created barriers and facilitators related to team cognition in different phases of the care transition processes. Future work should seek to context-specific system design changes that could improve team cognition.

STUDY #10. (16)
Purpose: To examine care transitions from OR to ICU.
Scope: *Background.* While care transitions influence quality of care, relatively little work has focused on transitions between hospital units.
Methods: 29 interviews with physicians (surgery, anesthesia, critical care) and nurses (OR, ICU) followed by administration of the AHRQ Hospital Survey on Patient Safety Culture items on handoffs, care transitions and teamwork.
Results: *Principal Findings.* Physicians defined the transition as starting earlier and ending later than nurses. Clinicians in the OR to ICU transition without a team handoff had more positive opinions about information loss and cooperation. *Discussion and Implications.* Care transitions are complex, spatio-temporal processes involving transition work – i.e., handoff and transport – and preparation and follow up activities– i.e., articulation work. Both types of work are important to quality and safety of care transitions.

STUDY #11 (17) and **STUDY #12** (18)**.**
Due to page limitations, description of STUDY #11 (17) and STUDY #12 (18) were not included in this report. Please refer to the corresponding publications.

AIM 2A. Human Centered Design of Health IT Prototype for Supporting Pediatric Trauma Teamwork
To increase generalizability of study findings, the Johns Hopkins and WI teams designed and developed their health IT prototype independently and compared the outcomes or design requirements for each prototype. *The*

Hopkins teams’ health IT prototype is called the Trauma Team Centric Information Technology (TACIT) and the WI team’s prototype is called the Teamwork Transition Technology (T^3). Below we provide a description of how **TACIT (**see **STUDY #13)** and **T^3** (see **STUDY #14**) were developed independently by two different design teams. Although designed independently in two different settings, both health IT prototypes had many common design characteristics, providing support for the generalizability of the study findings.

STUDY #13.
Purpose. To briefly describe the development process of the Trauma Team Centric Information Technology (TACIT) and its major characteristics.
Methods. *Study Design.* A human-centered design approach. *Prototype Development Process*. Johns Hopkins research team, in close collaboration with frontline clinicians and experts, used findings from Aim 1 studies to iteratively design the prototype. Multiple design sessions (multiple one-to-one meetings with key clinical experts, and focus groups with representation from multidisciplinary pediatric trauma team members and HFE/ design experts) were held. Final design requirements and the prototype wireframes were shared with the UI design team. UI design team created proof of concept UI in InVision (New York, USA), which has gone through 3 iterations with the Johns Hopkins research team, clinical experts, and other Johns Hopkins stakeholders. At this point, TACIT was ready for scenario-based evaluation. After scenario-based evaluation (see details under STUDY #18), we further revised the TACIT prototype.

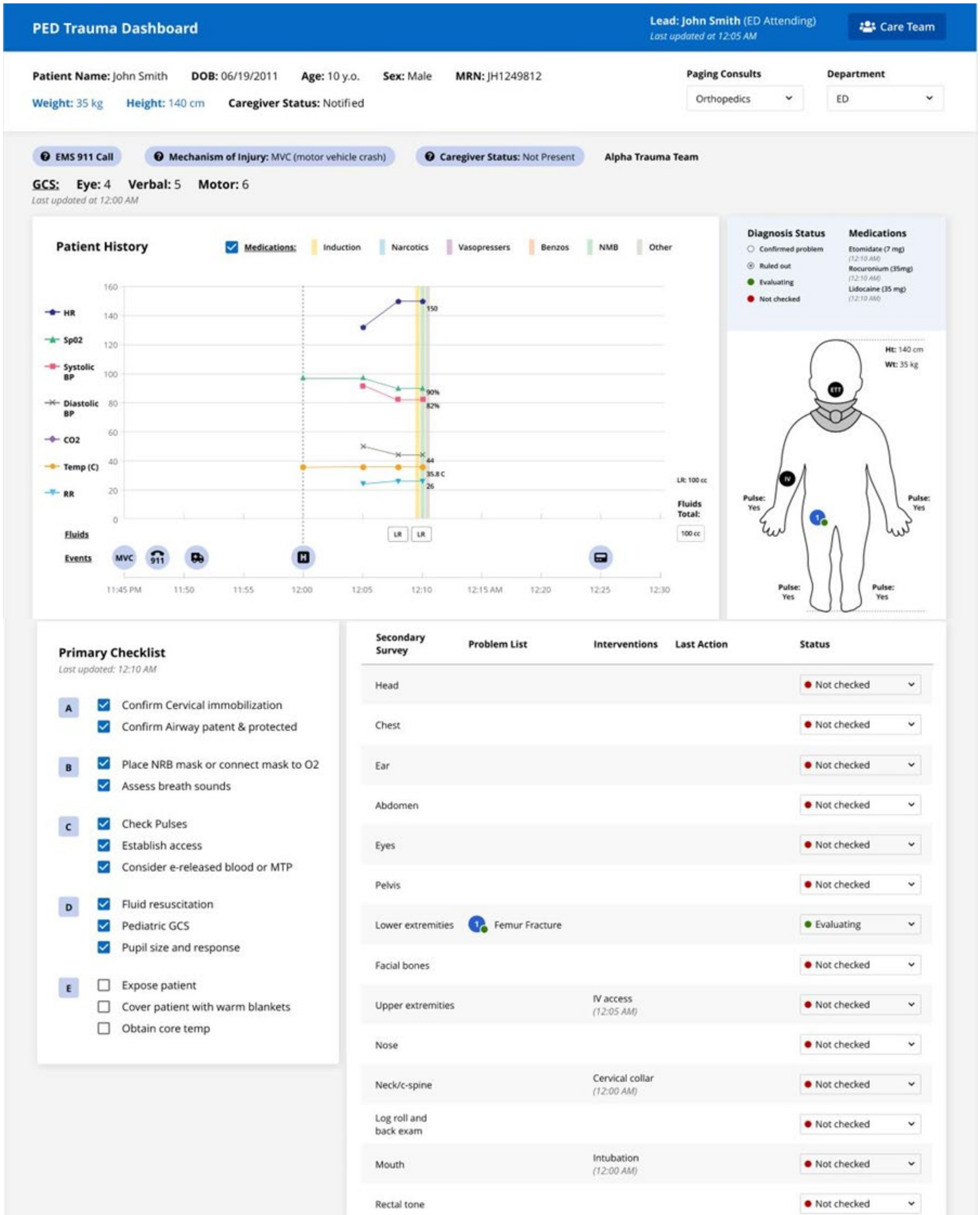

Fig 3. Trauma Team Centric Information Technology (TACIT)

Brief Description of TACIT. See Fig 3 for a snapshot of the TACIT prototype. TACIT features a timeline of major events, vitals, and medications. The primary and secondary surveys are also displayed, and a mannequin displays height, weight, GCS, and the “problem list”. Users can hover over icons on the screen to display more information. The dashboard will be displayed on a large screen in the trauma bay and will have desktop and mobile versions for distributed care team members.

STUDY #14

Purpose. To briefly describe the development process of the Teamwork Transition Technology (T^3) and its major characteristics. **Methods.** *Study Design.* A human-centered design approach. *Prototype Development Process*. University of Wisconsin-Madison research team, in close collaboration with frontline clinicians and experts, used findings from Aim 1 studies to iteratively design the prototype. Multiple design sessions (multiple one-to-one meetings with key clinical experts, and focus groups with representation from multidisciplinary pediatric trauma team members and HFE/ design experts) were held. **Results**. *Principal Findings and Outputs.* T^3 summarizes and organizes information, which mostly exists in the EHR on one (or several) displays that have a preformatted macro-structure. The macro-structure of T^3 includes a banner at the top with patient information, e.g. gender and age, the same way it is displayed in the EHR of the hospital. The top banner also displays information about allergies, pertinent medical history, home medications and –on the right hand side-the acuity level of the patient (level 1 or 2). Below the banner there are three “columns”. The column on the left focuses on “past” information; the column in the middle on current information; and the column on the right on “future” information. In the bottom of the display, a timeline summarizes the vitals of the patient over time and the main events during the child’s stay in the ED. T³ can be displayed on a large screen in the ED, or on a monitor in the OR or PICU.

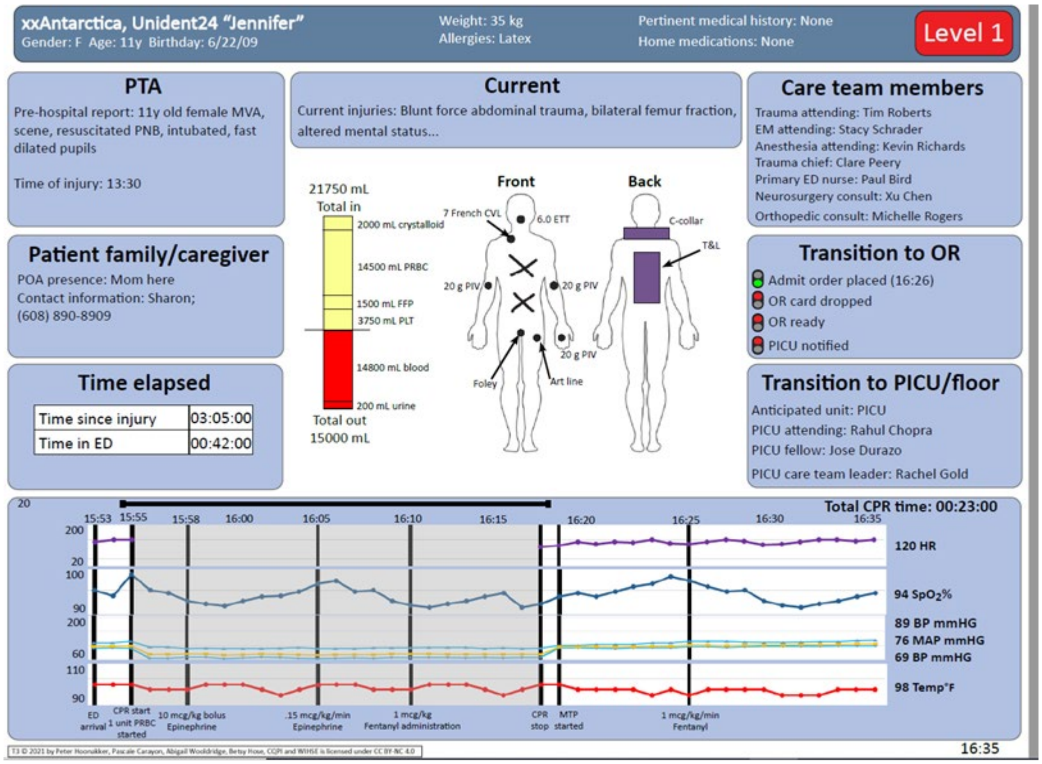

Fig 4. Teamwork Transition Technology (T³)

STUDY #15.

Purpose. To conduct a proactive risk assessment of the health IT prototype (T³). **Scope.** *Background.* Implementation of new technology can disrupt clinical work processes and can have a negative impact on patient safety. Before implementing new technologies, we should evaluate their potential impact on patient safety. HFE methods, such as proactive risk assessment (PRA) can help to anticipate safety problems, and define strategies for dealing with those problems. *Setting.* A level 1 pediatric trauma center of an academic children’s hospital in the Midwest. *Participants.*12: 4 human factors engineers, a peds ED physician, a peds ED nurse, a peds surgeon, a peds anesthesiologist, an OR nurse, two PICU nurses and the peds trauma coordinator.

Methods. *Study Design.* We conducted PRA on the implementation of T3. The PRA focus group sessions were guided by 4 questions: (1) What can go wrong with T3 [vulnerabilities]? (2) What are the possible safety consequences? (3) Why would something go wrong with T3? (4) What can be done to address those issues? *Data Sources/ Collection/ Measures/ Analysis*. At the start of the audio-recorded PRA session, the goals of the PRA were explained, and a brief presentation on the development and design of the T3 technology was given. During the first step of the PRA, participants were asked to come up with issues that could go wrong with the implementation of T³ (vulnerabilities). Once that list was created, we asked about possible safety consequences for every item on the list. Participants reviewed the list of issues to decide whether issues should be rearranged or combined. Each participant then used three dot stickers to identify the three issues s/he believed to have the greatest negative impact on patient safety. During step two, participants discussed the top-rated vulnerabilities identified in step one. Participants were asked, for each top-rated vulnerability, why would something go wrong with T3, and what could be done to address that issue. We used flip charts and Post-it® notes to collect data from the participants during the PRA.

Results*. Principal Findings.* Together with the PRA participants, we grouped the different issues with the T³ and came up with 9 groups, 3 of which received the highest vote and prioritized. Table 3 summarizes potential safety consequences for each top-rated vulnerability and potential solutions identified by the experts. *Discussion.* PRAs may involve a (relatively) quick process to assess a technology’s potential risk for patient safety, and to identify strategies to address the risks. Especially in situations where technology is designed to support teamwork, it is essential that various team members provide input from their perspective and role in the team. Results of the PRA showed that, by trying to reduce the amount of information on T3, questions will be asked about reliability and validity of the information. A first reaction would be to add information. Evidently, as a result the amount of information on the display could be overwhelming, and team members would not be able to quickly process the information. The only way to find the right amount of information is to test the display, either in a simulation or in real situation. The results of the PRA were incorporated in the next version of T3 before conducting scenario-based evaluation.

Table 3. Most important vulnerabilities of T3, potential patient safety consequences and solutions

What can go wrong with T^3?	Possible safety consequences	What can be done about it? (Not a complete list)
Information reliability: Information on display is missing, not accurate, delayed or not updated.	· Patient care is based on wrong information · Inappropriate care · Delay in getting patient to OR	· Identify the source of data on the display · Indicate on display when the info was last updated · High refresh rate; "push" update · Graphical representation of data validity · Differentiate between data validated and not validated
Identification: Unidentified patient mayappear younger than they actually are.	Wrong doses (medication,etc.)	· Highlight in red the unidentified information elements such ass name, age and date of birth · Write "unknown/unidentified" or leave blank · Write "estimated weight" or "est. age"
HIPAA related. PHI is visible/unauthorized access to T^3	Privacy violation	· Make rule governingunauthorized access · Same risks as existing

STUDY #16 (20)
Purpose. To examine how multiple perspectives are managed in a team health IT design process.
Scope. Most of health IT has been designed for individuals. More and more often, clinicians work in teams, and therefore need health IT that supports teams. Little is known about co-designing health IT for teams.
Methods. Analysis of 4 team design sessions.
Principal Findings. Results show that clinicians use different collaborative activities (establishment of common ground, clarification of perspective, convergence/divergence) to reach a design goal.

STUDY #17 (21)
Purpose: To describe the different steps in the co-design process for designing team health IT
Scope: Most of health information technology (IT) has been designed for individuals. More and more often, clinicians work in teams, and therefore need health IT that supports teams. Little is known about co-designing health IT for teams. In this study we describe the different steps in the co-design of team health IT
Methods. Multi-method (observation, interviews, focus groups, surveys, textual analysis of design sessions)
Results*.* Results shows the different steps that have been taken for co-designing team health IT.

STUDY #18. (22)
Purpose. To examine if the Trauma Team Centric Information Technology (TACIT) supports team cognition and team work.
Scope. *Background.* Before fully developed and implemented, innovative health IT solutions, such as the TACIT, need to be rigorously evaluated. The COVID-19 pandemic has forced almost every aspect of life to be remote and has made testing health IT in situ unfeasible. While remote health IT evaluation has become more common with improving technical capabilities, it is less common for a team-centric tool in a healthcare setting. We adapted our formative evaluation protocol from a team-centric in situ simulation to individual vignette evaluation over video conferencing to evaluate specific design aspects and to elicit valuable feedback on the TACIT. *Setting.* A large academic children's hospital with a Level I pediatric trauma center in the Eastern US. *Participants.* This study took place remotely with 21 healthcare workers who are involved in pediatric trauma care: Peds ED (3 attendings, 2 fellows, 2 nurses, 1 pharmacist), PICU (3 attendings, 1 fellow, 2 nurses), General Pediatric Surgery (2 attendings, 1 fellow, 2 residents, 1 nurse practitioner), and 1 social worker.
Methods. *Design.* Scenario-based and remote evaluation of the Trauma Team Centric Information Technology (TACIT). *Data Sources/ Collection*. We used a "Wizard of Oz" strategy (25) and read a vignette of a simulated pediatric trauma case with each participant over a recorded video conferencing call. The researcher controlled the information that appeared on the screen as the case progressed. Participants were asked: "What information do you need to know, and can you find that on the screen?" They were also asked for informal feedback after the simulation and answered an online questionnaire with a modified System Usability Scale (SUS) (26). *Measures and Data Analysis.* We categorized the transcripts into *user needs, successes, and*

failures for each step in the vignette in a spreadsheet. They also noted *any challenges mentioned* by participants with regards to TACIT. Descriptive statistical analysis was used to analyze the survey data. **Results**. Principal Findings. Overall, participants expressed positive reviews of the TACIT and the ways it might support teamwork. For example, one participant said: “*I like the visualization of a patient and where things are. So, the IV, the ET tube, the collar, where the injuries are, I think that is helpful.”* The survey responses to the adapted SUS were also positive. Six participants (66.7%) rated that they were satisfied with the overall design. Thirteen participants (72%) rated that they were satisfied with the overall design.

The evaluation also elucidated important design feedback and improvement opportunities. Participants mentioned needing patient vitals, and there was some confusion whether missing points on the interface timeline were a device issue or patient signal. In addition, some looked for pulses and breath sounds, which were not available on the screen. Participants mentioned the primary or secondary survey information and were successful in finding them on the screen. Participants had difficulty discerning values on the timeline due to the shared scale and pointed out potential issues with the “hover” interactions during an active trauma. We used these results to inform *our final prototype design* and *a first prototype of a mobile version.* Discussion and Implications. Participants successfully navigated the prototype’s interface and were able to understand and use the information displayed. In particular, the graphical displays of the timeline and the mannequin allowed participants to quickly learn information about the case. The redundant displays of information such as the medications and potential problems appears to have contributed to the successful location of these important pieces of information. We also identified several opportunities to further improve the design. The nature of pediatric trauma and the shared display make certain interactions, such as hover over or clicking, impractical. Participants were unclear what the categories to display diagnostic uncertainty (checked & present, checked & ruled out, checking & unsure, not checked) meant. The temporality of the interventions was confusing, so the next design should have timestamps to be a more reliable narrator of the case’s history. Overall, participants successfully found most of the clinical information they needed on the TACIT and generally reported satisfaction with the prototype. Our remote and scenario-based evaluation over video conferencing did allow testing key design points, information architecture, usefulness, usability, and overall learnability of the system.

STUDY 19. (23)
Purpose. To examine if the Teamwork Transition Technology (T^3) supports teams and team cognition.
Scope. *Background.* Clinicians need health information technology (IT) that better supports their work. Currently, most health IT is designed to support individuals, however, more and more often, clinicians work in cross-functional teams. Trauma is one of the leading preventable causes of children’s death. Trauma care by its very nature is team-based but due to the emergent nature of trauma, critical clinical information is often missed in the transition of these patients from one service or unit to another. The T^3 can help support these transitions and minimize information loss while enhancing information gathering and storage. In this study, we created a large screen technology to support shared situational awareness across multiple clinical roles and departments. *Setting.* Level I pediatric trauma center. *Participants.* We used this technology with 36 clinicians and staff from the different units and departments that are involved in pediatric trauma to examine T^3.
Methods. *Study Design.* In order to evaluate the technology to support the clinical transitions in pediatric trauma, we created a scenario-based mock-up methodology.
Results. *Principal Findings.* Participants agreed that T^3 does support them in their work, and increases their situation awareness.

INCLUSION OF PRIORITY POPULATIONS:

Study Design	Ethnicity	Race	Male	Female	Not collected or not reported	Total # of participants across the two study sites
Retrospective Cohort Analysis based on EHR and trauma registry data	Not collected	Not collected	1770	995	875	3640
Prospective Data Collection (Interviews, Observations, Focus Groups, Surveys)	Hispanic/ Latino: 1 Not Hispanic/ Latino: 30 Not collected: 170	White: 26 Asian: 5 Not collected: 170	68	132	1	201

7. LIST OF PUBLICATIONS AND PRODUCTS.

7.1. Publications and Presentations

Carayon P et al. Human-Centered Design of Team Health IT for Pediatric Trauma Care Transition. To be submitted to JMIR Human Factors, 2021.

Coppola S, Webster K, Gurses AP. Team trust and performance in pediatric trauma. Proceedings of the International Symposium on Human Factors and Ergonomics in Health Care; 2020: SAGE Publications Sage CA: Los Angeles, CA.

Coppola SM, Gurses AP. Remote Usability Testing of a Pediatric Trauma Dashboard. Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021): Volume IV: Healthcare and Healthy Work; 2021: Springer.

Durojaiye AB, McGerorge N, Kristen W, Oruc C, Fackler JC, Gurses AP. Characterizing the Utilization of the Problem List for Pediatric Trauma Care. AMIA Annu Symp Proc. 2018;2018:404-12.

Durojaiye AB, McGeorge NM, Puett LL, Stewart D, Fackler JC, Hoonakker PLT, Lehmann HP, Gurses AP. Mapping the flow of pediatric trauma patients using process mining on trauma registry data. Applied Clinical Informatics. 9(3), pp. 654-666.

Durojaiye AB, Puett LL, Levin S, Toerper M, McGeorge NM, Webster KLW, Deol GS, Kharrazi H, Lehmann, HP, Gurses AP. Assessing the value of probabilistic linkage in linking electronic health record and trauma registry data using indirect identifiers. Methods Inf Med. 2018; 57(5/6): 261-269.

Durojaiye AB. Using process mining to model pediatric trauma care coordination and teamwork, PhD Dissertation, Johns Hopkins University, 2018 (successfully defended).

Durojaiye AB, Levin S, Toerper M, Kharrazi H, Lehmann HP, Gurses AP. Evaluation of multidisciplinary collaboration in pediatric trauma care using EHR data. JAMIA 2019;26(6):506-15.

Durojaiye AB, Fackler JC, McGeorge N, Webster K, Kharrazi H, Gurses AP. Examining diurnal differences in multidisciplinary care teams at a pediatric trauma center using EHR data: Social network analysis. JMIR, Accepted, subject to revisions, 2021.

Hoonakker PLT, Wooldridge AR, Carayon P, Hose B-Z, Eithun BL, Brazelton TB, Dean SM, Kelly MM, Kohler JE, Ross JC, Rusy DA, Gurses AP. Things falling through the cracks: information loss during pediatric trauma care transitions. International Ergonomics Association (IEA); 2018 Aug 26-30; Florence, Italy. Cham (CH): Springer.

Hoonakker PLT, Wooldridge AR, Carayon P, Hose B-Z, Eithun BL, Brazelton TB, Dean, S.M., Kelly, M.M., Kohler, J.E, Ross, J.C., Rusy, D.A., Gurses, A.P. Information Loss during Pediatric Trauma Care Transitions: Things Falling Through the Cracks. Internal and Emergency Medicine. 2019;14(5):797-805.

Hoonakker PLT, Carayon P, Hose B-Z, Ramsey JC, Eithun BL, Kohler, J.E., Ross, J.C., Kim, M.K., Rusy, D.A., Soetenga, D.J., Reisman, M.M., Nieman, J.A, Koffarnus, K.S.. Proactive Risk Assessment of Team Health IT for Pediatric Trauma Care Transitions (T^3). In: Cotrim TP, Serranheira F, Sousa P, Hignett S, Albolino S, Tartaglia R, editors. Health and Social Care Systems of the Future: Demographic Changes, Digital Age and Human Factors. Cham, Switzerland: Springer International Publishing; 2019. p. 213-21.

Hoonakker, P.L.T., Hose, B.-Z., Carayon, P., Eithun, B.L., Rusy, D.A., Ross, J.C., Kohler, J.E, Brazelton, T.B., Dean, S.M., Kelly, M.M. Scenario-based Evaluation of Team Health IT to Support Pediatric Trauma Care Transitions. Applied Cinical Informatocs, July 2021 (submitted).

Hose B-Z., Carayon P, Hoonakker P, Wooldridge AR, Ross J, Kohler J, Brazelton T, Eithun B, Kelly M, Dean S, Rusy D, Gurses A. Information Needs of Physicians in Pediatric Trauma. Poster presented at the Human Factors and Ergonomics in Healthcare, New Orleans, LO, March 5-8, 2017.

Hose, B.-Z., Carayon P, Hoonakker PLT, Wooldridge AR, Ross JE, Kohler JC, Brazelton TB, Eithun BL, Kelly MM, Dean SM, Rusy DA, Gurses AP. Challenges of Disposition Decision Making for Pediatric Trauma Patients in the Emergency Department. 20th Congress of the International Ergonomics Assoc.: pp. 339-345, Florence, Italy, August 26-30, 2018.

Hose B-Z, Hoonakker PLT, Wooldridge AR, Brazelton III TB, Dean SM, Eithun B, Fackler, J.C., Gurses, A.P., Kelly, M. M., Kohler, J. E., McGeorge, N., Ross, J.C., Rusy, D.A., Carayon, P. Physician Perceptions of the Electronic Problem List in Pediatric Trauma Care. Appl Clin Inform. 2019;10(01):113-22.

Hose B-Z, Carayon, P, Hoonakker PLT, Brazelton TB, Dean SM, Eithun BL, Kelly MM, Kohler JE, Ross JC, Rusy DA. Evaluation of Teamwork Transition Technology (T^3) to support Team SA during Pediatric Trauma Care Transitions. HFES Healthcare Conference; Online 2020.

Hose B-Z. Collaborative Design of Team Health IT: The Case of Pediatric Trauma Care Transitions. PhD Dissertation, UW-Madison (to be defended in Aug 2021).

Hose B-Z et al. Multiple Perspectives in the Design of a Team Technology. To be submitted to Design for Health. 2021.

McGeorge N, Durojaiye A, Fackler J, Xie, A., Rosen, M.A., Hunt, E. A., Stewart, D., Puett, L.L., Wooldridge, A.R., Carayon, P., Hoonakker, P., Gurses AP. Pediatric Trauma Care Transitions: Understanding Teamwork for Health IT Design. Poster presented at 7th Annual Johns Hopkins Medicine Patient Safety Summit: Working Together to Achieve Zero Preventable Harm, October 2016, Baltimore, MD.

McGeorge N, Durojaiye A, Fackler J, Stewart D, Puett L, Gurses AP. Supporting clinicians and teamwork through better HIT design: Understanding the trauma care system at a Level 1 pediatric trauma center using a mixed methods approach. Poster presentation at the 4th Annual Meeting of the Pediatric Trauma Society, Nov 2017, Charleston, SC. ***(Poster Award Winner).***

Wooldridge AR, Gurses AP, Carman EM, Waterson P, Sesto M, Hoonakker PLT, editors. Designing and managing healthcare transitions. Organizational Design and Management Conference; 2017; Banff, CA.

Wooldridge AR, Carayon P, Hoonakker P, Hose B.-Z, Ross J, Kohler J, Brazelton T, Eithun B, Kelly M, Dean S, Rusy D, Gurses A. Understanding Team Complexity in Pediatric Trauma Care. Poster presented at Human Factors and Ergonomics in Healthcare, March 5-8, 2017, New Orleans, LO.

Wooldridge, AR, Carayon P, Hoonakker P, Hose B.-Z., Gurses A. Redefining the Scope of the Care Transition Process: A Study of Pediatric Trauma Care Transitions. Human Factors and Ergonomics Society Annual Meeting: 62 (1): 551-555, Philadelphia, PA, Oct 1-5, 2018

Wooldridge AR. Team Cognition Distributed in Spatio-Temporal Processes: A Macroergonomic Approach to Trauma Care. PhD Dissertation, UW-Madison, 2018 (successfully defended).

Wooldridge AR, Carayon P, Hoonakker P, Hose B, Ross J, Kohler JE, Brazelton T, Eithun B, Kelly MM, Dean SM, Rusy D, Durojaiye A, Gurses AP. Complexity of the pediatric trauma care process: Implications for multi-level awareness. Cogn Technol Work. 2019; 21(3): 397-416.

Wooldridge AR, Carayon, P, Hoonakker, P.L.T., Hose, B.-Z., Brazelton, T.B., Eithun, B.L., Dean, S.M., Kelly, M.M., Kohler, J.E, Ross, J.C., Rusy, D.A., Gurses, A.P. Team Cognition as a Barrier and Facilitator in Care Transitions: Implications for Work Systems Design. Human Factors and Ergonomics Society Annual Meeting; 2019: Sage Publications.

Wooldridge AR, Carayon, P, Hoonakker, P, Hose, B.-Z., Kelly, M.M., Brazelton, T.B., Eithun, B.L., Dean, SM, Kohler, JE, Ross, JC, Rusy, DA, Gurses, AP. Contextual Factors Influencing Barriers and Facilitators in Paediatric Trauma Care Transitions. Organizational Design and Management Conference; 2020.

Wooldridge AR, Carayon P, Hoonakker PLT, Hose B-Z, Eithun B, Brazelton T, et al. Work system barriers and facilitators in inpatient care transitions of pediatric trauma patients. Applied Ergonomics. 2020;85 (Special Issue on Care Transitions):103059.

Wooldridge AR, Carayon P, Hoonakker PLT, Hose B-Z, Schroeer K, Brazelton T, Eithun B, Rusy D, Ross J, Kohler J, Kelly M, Dean S, Rahal R, Springman S, Gurses AP. Care Transitions of Trauma Patients: Processes with Articulation Work Before and After Handoff. Appl Ergo, Jun 2021 (submitted).

7.2 Products

1. Trauma Team Centric Information Technology (TACIT).
2. Teamwork Transition Technology (T^3)

REFERENCES

1. Carayon P, Schoofs Hundt A, Karsh BT, Gurses AP, Alvarado CJ, Smith M, et al. Work system design for patient safety: the SEIPS model. Qual Saf Health Care. 2006;15 Suppl 1:i50-8.

2. Donabedian A. The quality of care. How can it be assessed? JAMA. 1988;260(12):1743-8.

3. Marks MA, DeChurch LA, Mathieu JE, Panzer FJ, Alonso A. Teamwork in multiteam systems. Journal of Applied Psychology. 2005;90(5):964.

4. Cooke NJ, Gorman JC. Interaction-based measures of cognitive systems. Journal of cognitive engineering and decision making. 2009;3(1):27-46.

5. Hutchins E, Klausen T. Distributed cognition in an airline cockpit. Cognition and communication at work. 1996:15-34.
6. Holtzblatt K, Beyer H. Contextual design: defining customer-centered systems: Elsevier; 1997.
7. Durojaiye AB, Puett LL, Levin S, Toerper M, McGeorge NM, Webster KLW, et al. Linking Electronic Health Record and Trauma Registry Data: Assessing the Value of Probabilistic Linkage. Methods Inf Med. 2018;57(5-06):261-9.
8. Wooldridge A, Carayon P, Hoonakker P, Hose BZ, Ross J, Kohler JE, et al. Complexity of the pediatric trauma care process: Implications for multi-level awareness. Cogn Technol Work. 2019;21(3):397-416.
9. Durojaiye AB, McGeorge NM, Puett LL, Stewart D, Fackler JC, Hoonakker PLT, et al. Mapping the Flow of Pediatric Trauma Patients Using Process Mining. Appl Clin Inform. 2018;9(3):654-66.
10. Wooldridge AR, Carayon P, Hoonakker P, Hose BZ, Eithun B, Brazelton T, 3rd, et al. Work system barriers and facilitators in inpatient care transitions of pediatric trauma patients. Appl Ergon. 2020;85:103059.
11. Durojaiye AB, Levin S, Toerper M, Kharrazi H, Lehmann HP, Gurses AP. Evaluation of multidisciplinary collaboration in pediatric trauma care using EHR data. J Am Med Inform Assoc. 2019;26(6):506-15.
12. Durojaiye A, Fackler J, McGeorge NM, Webster KLW, Gurses AP. Examining diurnal differences in multidisciplinary care teams at a pediatric trauma center using EHR data: Social network analysis. JMIR. Jun 2021 (revise-resubmit).
13. Durojaiye AB, McGerorge N, Kristen W, Oruc C, Fackler JC, Gurses AP. Characterizing the Utilization of the Problem List for Pediatric Trauma Care. AMIA Annu Symp Proc. 2018;2018:404-12.
14. Hose BZ, Hoonakker PLT, Wooldridge AR, Brazelton Iii TB, Dean SM, Eithun B, et al. Physician Perceptions of the Electronic Problem List in Pediatric Trauma Care. Appl Clin Inform. 2019;10(1):113-22.
15. Wooldridge AR, Carayon P, Hoonakker P, Hose B-Z, Brazelton TB, Eithun B, et al., editors. Team Cognition as a Barrier and Facilitator in Care Transitions: Implications for Work System Design. Proceedings of the Human Factors and Ergonomics Society Annual Meeting; 2019: SAGE Publications Sage CA: Los Angeles, CA.
16. Wooldridge AR, Carayon P, Hoonakker PLT, Hose B-Z, Schoroer K, Brazelton T, et al. Care Transitions of Trauma Patients: Processes with Articulation Work Before and After Handoff. Applied Ergonomics. June 2021 (submitted).
17. Hose B-Z, Carayon P, Hoonakker P, Wooldridge A, Brazelton T, Dean S, et al., editors. Challenges of disposition decision making for pediatric trauma patients in the emergency department. Congress of the International Ergonomics Association; 2018: Springer.
18. Coppola S, Webster K, Gurses A, editors. Team trust and performance in pediatric trauma. Proceedings of the International Symposium on Human Factors and Ergonomics in Health Care; 2020: SAGE Publications Sage CA: Los Angeles, CA.
19. Hoonakker PL, Carayon P, Hose B-Z, Ramsey JC, Eithun BL, Kim MK, et al., editors. Proactive Risk Assessment of Team Health IT for Pediatric Trauma Care Transitions (T 3). International Conference on Healthcare Ergonomics and Patient Safety; 2019: Springer.
20. Hose B-Z, Carayon P, Hoonakker PLT, Brazelton TB, Dean SM, Eithun BL, et al. Multiple Perspectives in the Design of a Team Technology. Applied Ergonomics (To be submitted). 2021.
21. Carayon P, Hose B-Z, Wooldridge AR, Brazelton TB, Dean SM, Eithun B, et al. Human-Centered Design of Team Health IT for Pediatric Trauma Care Transitions. International Journal of Medical Informatics (To be submitted). 2021.
22. Coppola SM, editor Remote Usability Testing of a Pediatric Trauma Dashboard. Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021): Volume IV: Healthcare and Healthy Work; 2021: Springer.
23. Hoonakker PLT, Hose B-Z, Carayon P, Eithun BL, Rusy DA, Ross JC, et al. Scenario-based Evaluation of Team Health IT to Support Pediatric Trauma Care Transitions. Applied Clinical Informatics. Jul 2021 (submitted).
24. Wooldridge AR, Carayon P, Hundt AS, Hoonakker PL. SEIPS-based process modeling in primary care. Applied ergonomics. 2017;60:240-54.
25. Martin B, Hanington B, Hanington BM. Universal methods of design: 100 ways to research complex problems. Develop Innovative Ideas, and Design Effective Solutions. 2012:12-3.
26. Albert W, Tullis T. Measuring the user experience: collecting, analyzing, and presenting usability metrics: Newnes; 2013.