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MOBILE & WIRELESS HEALTH

# Evaluative Research of Technologies for Prehospital Communication and Coordination: a Systematic Review

Zhan Zhang[1] · John Brazil[1] · Mustafa Ozkaynak[2] · Kristen Desanto[3]

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## Abstract

Various technologies have been designed and developed to support communication and coordination between the field and hospital during a medical emergency. The usability issues and human factors entailed in these new technologies are important to their application and effectiveness, suggesting the need to examine this information in a systematic review. The systematic review aims to synthesize the user-centered evaluative research of prehospital communication technologies. We conducted a systematic literature search in four databases (Medline, Cochrane, Embase, and Web of Science) for articles published between the years 2000 and 2019. We included articles that evaluated the technologies developed for supporting prehospital communication and collaboration, and were published in English. A total of 918 articles were retrieved and screened, with 17 articles included for in-depth analysis. Two authors conducted independent screens and reviews of the articles using a list of inclusion/exclusion criteria and defined factors. The types of technology of reviewed articles included ambulance-based telemedicine, wearable, handheld, and Internet of Things (IoT) devices. Even though these technologies have demonstrated high levels of user acceptance, the reviewed studies noted a variety of challenges faced by emergency care providers, which were grouped into three categories—technical, usability, and organizational challenges. Our review also highlighted the paucity of evaluative research of prehospital communication technologies and the lack of user engagement throughout system design process. Based on the results, we discuss the importance of adopting user-centered design approaches and accounting for three social-technical factors in designing technologies for time-critical medical settings, including cognitive and physical stressor, workflow, and context. This systematic review presents an overview of key evaluative research of prehospital communication technologies. The paucity of evaluative research in prehospital communication technology and challenges faced in adopting advanced technological solutions in emergency care highlight the need to adopt user-centered design and take into account socio-technical issues at the point of system design.

**Keywords** Technologies · User evaluation · Emergency care · Prehospital communication · Systematic review

## Introduction

Emergency care is a high-risk, time-sensitive medical event, involving geographically dispersed and multidisciplinary emergency care professionals [1]. During a medical emergency, the emergency medical services (EMS) team provides initial medical care in the field and transports patients to the hospital. They also collect patient information and communicate this information to the emergency department (ED) team at the receiving facility. The information is then used to prepare for the patient's arrival with appropriate materials, treatment plan, and anticipated initial diagnoses [2]. Effective communication and coordination between prehospital EMS and hospital ED teams is crucial for rapid and effective patient care [3]. Despite its importance, prehospital communication and collaboration remains inefficient, requiring further studies [4–6].

With the rapid advancement in information and communication technologies, there has been increasing research to design and develop novel technology solutions to support prehospital communication and coordination [7, 8]. However, adopting these technologies to the prehospital setting is a complex process. The

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✉ Zhan Zhang
zzhang@pace.edu

[1] School of Computer Science and Information Systems, Pace University, New York, NY 10038, USA

[2] College of Nursing, University of Colorado, Denver, Colorado, USA

[3] Health Science Library, University of Colorado, Denver, Colorado, USA

development of technology solutions should not only take advantage of technological advances, but also pay close attention to the usability issues and human factors entailed in these new technologies [9–11]. Prior work has linked usability issues of healthcare technology to problems relating to efficiency and intuitiveness of use [12, 13], integration into the workflow [14, 15], and patient safety [16]. Given the time-sensitive nature of emergency care, the technologies developed for capturing and sharing real-time prehospital information, must be thoroughly designed and evaluated by the users, such as emergency medical technicians (EMTs) and ED physicians [17] (throughout this paper, we use the term EMTs to refer to EMS personnel or paramedics dispatched to the field for patient transportation).

There have been few studies evaluating technological solutions designed for prehospital communication and coordination. To the best of our knowledge, a systematic review of the literature on user evaluations of these technologies, has not been published. To this end, we conducted a systematic review to examine the state of current research in the design and evaluation of technologies in the prehospital setting. Such a synthesis can provide guidance on strategies for the successful design and development of technologies to better support communication and collaboration between the field and hospital. The specific research questions of this review include 1) what types of technology solutions have been designed, developed, and evaluated for prehospital communication and coordination; 2) what types of methodologies are used for designing and evaluating these technologies; and 3) what are the user's perceptions and facing challenges associated with using and adopting systems in the prehospital context.

## Methods

### Search Strategy

A literature search was performed by a health librarian for articles published between the years 2000 and 2019. This search timeframe was chosen because it documents the development of the current generation of prehospital communication technology, such as telemedicine and electronic patient care reports [17, 18]. Relevant publications were identified by searching the following databases: Ovid MEDLINE, Cochrane Library, Excerpta Medica Database (Embase.com), and Web of Science. The search strategy included three types of keywords: emergency medical services (EMS), emergency departments (ED), and technologies. For example, search terms for technologies included: "mobile health", "telehealth", "telemedicine", "communication technology", and "information technology". The full list of keywords used and a sample search strategy from Medline are illustrated in Appendix 1 and Appendix 2 (Table 5), respectively. The retrieved citations were managed using Endnote bibliographic management software (Version X9, Clarivate Analytics, Philadelphia, PA).

### Inclusion and Exclusion Criteria

We included studies published in peer-reviewed journals and conference proceedings in English. The technologies reported in the studies were required to be directly related to prehospital communication and collaboration, and based on empirical user evaluations. Studies that did not conduct user evaluation were excluded. Literature reviews, dissertation, theses, posters, and extended abstracts were also excluded.

### Article Screening

The search process returned 918 articles (Table 1). We used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology to search and screen articles [19]. Figure 1 outlines the number of records that were identified, included, and excluded through different phases. The list was further reduced by removing duplicates, resulting in 552 articles eligible for further review. Two authors independently screened and selected papers for inclusion by applying the inclusion/exclusion criteria as described in the above section. Any conflicts in selection decisions were resolved through discussion between the authors.

Screening of article titles and abstracts excluded 425 and 84 studies, respectively. With this screening process, 43 articles were chosen for full text analysis. Finally, 17 articles were selected for this systematic literature review.

### Data Extraction and Synthesis

A table consisting of author name, year of publication, study objectives, methods, and a summary of findings was constructed in an MS Excel spread sheet to systematically document relevant information from these 17 articles. Two authors independently used the spread sheet to extract data from the included studies. The third author reviewed all the articles and coded results as a verification step. The research team met regularly to discuss the results and merge extracted data. A meta-analysis of

**Table 1** Database Search Results

| Database | # Results |
|---|---|
| Ovid MEDLINE | 298 |
| Cochrane Library | 51 |
| Excerpta Medica Database | 319 |
| Web of Science | 250 |
| Total | **918** |

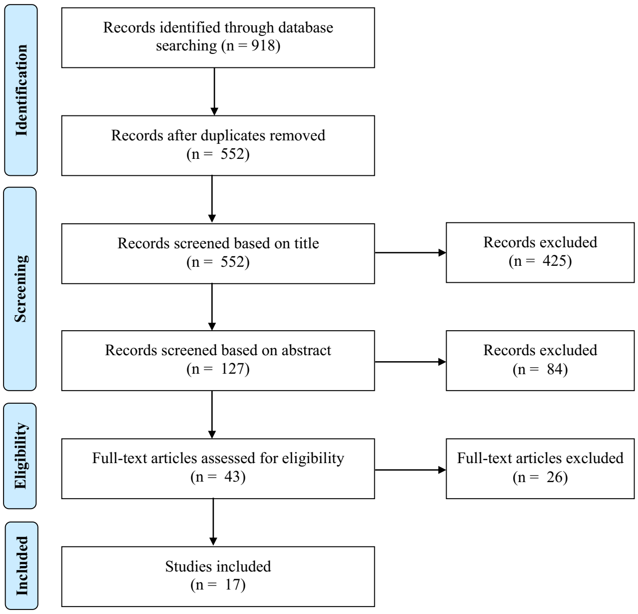


**Fig. 1** Information Source and Search Strategy

study results was not considered in these analyses due to the heterogeneity of the study design and results.

In the following section, we will report information that was synthesized from the reviewed articles, including characteristics of selected studies (e.g., country, clinical focus), technology types, study objectives, user evaluation methods, user perceptions and opinions, and challenges in using and adopting prehospital communication technologies.

## Results

### Characteristics of the Reviewed Studies

Of the 17 studies included in this review, seven were conducted in the United States [20–26], three in Germany [27–29], three in South Korea [30–32], two in Belgium [18, 33], and one each in Ireland [34] and Sweden [35]. The articles included in this review have different clinical foci: eight focused on general emergency care [18, 21, 24, 25, 27, 30–32], six on applying technologies to stroke condition [20, 26, 28, 29, 33, 35], two addressed technology utilization in the treatment of trauma patients [22, 23], and one examined the application of telemedicine in multiple clinical fields, including stroke, trauma, and myocardial infarction (MI) [34].

### Technology Types and Transmission of Content

The technologies used in prehospital communication varied among the studies (Table 2). They consisted of ambulance-based telemedicine systems, handheld devices, Internet of Things (IoT) devices and sensors, and wearable devices. The most widely used technology was telemedicine ($n = 12$) [18, 20, 22, 23, 26–29, 31, 33–35]. By ambulance-based telemedicine, we refer to the systems that are being integrated into ambulances and use mobile networks to enable real-time, audio-video communication between care providers in dispatching ambulances and those at the receiving hospital [18]. A typical ambulance-based telemedicine system consists of two major components: a mobile unit installed in the ambulance and a receiving station for medical professionals at the hospital. The mobile unit is equipped with a laptop or tablet computer with an integrated digital camera, sometimes paired with video cameras mounted inside the ambulance that could capture the view of a designated area (e.g., patient body). A vital signs monitor was also connected to the mobile unit to transfer patients' real-time vital signs (e.g., respiratory rate, heart rate, blood oxygen saturation). In three studies [23, 27, 28], the telemedicine system also allowed for capturing and sharing images.

Handheld devices, such as mobile- or tablet-based applications, were reported in three studies for EMTs to share information with the receiving hospital. For example, an early study built a menu-driven mobile application to document field information (e.g., vital signs, demographics, medical history, nature of injury, etc.) [21]. The information was then uploaded to a central database for hospital personnel to instantaneously access and track the status of the patient. Another study [25] discussed the design and evaluation of an Android-based smartphone application for communicating emergency information related to an incident. The application enabled EMTs to collect data in relation to mechanism of injury (e.g. leg trapped in dashboard of car), photograph the patient and/or scene, record digital audio notes, and capture video for the incident. Such features are beneficial as they capture and relay information that is often difficult to express in words and allow EMTs to record a description of an incident in more detail when time allows. The collected patient information can be viewed by ED physicians via a web application.

Wearable devices were also used to share information between the field and hospital. This type of device was only reported in one study [30]; the system consists of a portal computer and a portable camera attached to goggles. In this instance, EMTs wear goggles to capture their visual field. The captured audio and video information is then sent to the portal computer, which leverages on a messenger program (Windows Live Messenger) to enable real-time information sharing between EMS and ED providers.

Lastly, in one study [32], a smart EMS system is implemented using Internet of Things (IoT) technology, which integrate personal lifelogs, electronic medical record, and patient monitoring in ambulances, and then delivers them directly to the receiving hospital. It uses health information standards to ensure interoperability between different devices and the smart EMS system. This system has a great potential to

**Table 2** Transmission of Content and Technology Used

| AUTHORS | TECHNOLOG | | | | TRANMISSION OF CONTENT | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ambulance Telemedicine | Handheld Devices | IoT & Sensors | Wearable Devices | Video & Audio | Audio Recording | Picture | Vital Signs | Lifelog & EMR | Free-form text |
| Bergrath et al. [27] | X | | | | X | | X | X | | |
| Cho et al. [31] | X | | | | X | | | X | | |
| Kwak et al. [30] | | | | X | X | | | | | |
| Reddy et al. [24] | | X | | | X | | | | | |
| Schooley et al. [25] | | X | | | X | X | X | | | |
| Tang et al. [22] | X | | | | | | | | | |
| Tollefsen et al. [21] | | X | | | | | | X | | X |
| Espinoza et al. [33] | X | | | | | | | | | |
| Yperzeele et al. [18] | X | | | | X | | | X | | |
| Sibert et al. [23] | X | | | | X | | X | | | |
| Felzen et al. [28] | X | | | | X | | X | X | | |
| Xiao et al. [20] | X | | | | X | | | X | | |
| Gilligan et al. [34] | X | | | | X | | | | | |
| Park et al. [32] | | | X | | | | | X | X | |
| Smith et al. [26] | X | | | | X | | | | | |
| Johansson et al. [35] | X | | | | X | | | | | |
| Geisler et al. [29] | X | | | | X | | | | | |

address the inaccuracy in collecting and reporting information during EMS activities and patient handoff.

## Study Objectives and User Evaluation Methods

The 17 studies used a combination of qualitative and quantitative methods to evaluate technologies from the user's perspective (Table 3). The user evaluation focused on user needs [32], user satisfaction and acceptance [18, 23, 27, 28, 30, 31, 33–35], system usability [20–22, 25, 26], technical feasibility and reliability [18, 29, 35], and inter-team collaboration [24, 27].

The primary qualitative method used was interview ($n = 5$). In one study, both EMS and ED providers were interviewed jointly to understand their perceived challenges in communication and collaboration between the field and hospital [24]. In another study, interviews with practitioners from different disciplines (e.g., EMTs, ED providers, and administrators) were conducted to understand their perceptions about the usability, utilization, and challenges of a multimedia system developed to support prehospital care [25]. Observation was another commonly used qualitative method. Tollefsen et al. [21] observed the use of a mobile application throughout the field test. The observation data was further augmented by interviews with EMTs to obtain feedback on system usability.

Eleven studies solely relied on quantitative methods for user evaluation [20, 23, 27–35]. These studies used questionnaires, sometimes in combination with a Likert scale, to evaluate the reliability and performance of the technology (e.g., quality of videos and photos, severities of background noise, voice communication), and to understand needs, opinions and perceptions of the users on the use of the applications. For example, the study conducted by Xiao et al. [20] used a questionnaire with a 5-point Likert scale to gather data on the opinions of the telemedicine users in four areas: privacy of video transmission, interference of regular tasks on ambulances, efficacy in providing valuable information, and usability. The study conducted by Espinoza et al. [33], on the other hand, used a 10-item questionnaire to elicit the general public's opinions about telemedicine for emergency treatment during ambulance transportation.

Three studies used both qualitative and quantitative methods [18, 22, 26]. In the study conducted by Yperzeele et al. [18], the quality of the audio-video connection and the usability of the system were assessed using a Likert scale and interviews. Another study used both heuristic evaluation and ethnographic methods (e.g., observation and analysis of video recordings) to identify usability problems of telemedicine prototypes [22]. Lastly, Chapman Smith et al. [26] used different approaches to evaluate a mobile telestroke platform. More specifically, they asked participants to complete the System Usability Scale (SUS), NASA Task Load Index (NASA TLX), audio/video quality scale, and a modified Acceptance of Technology survey to assess system usability. In addition, interviews along with observations and video review were conducted to evaluate user's experience and aspects that need to be improved.

## Users' Perceptions and Opinions

Ten studies reported that the users indicated high levels of satisfaction and acceptance [18, 20, 23, 25, 27–29, 33–35], whereas three studies documented high ratings of usability [18, 20, 26] (Table 3). The transmitted data, such as photos and videos, were considered to be useful for patient diagnosis. A few studies, however, raised concerns about the system's reliability and usability [21, 25, 26, 28, 30, 31, 35]. For example, the advantage of telemedicine over voice calls in delivering medical consultation was found to be not significant [31] and EMTs were unclear about the efficacy of telemedicine technology in the care of stroke [35]. Tollefsen et al. [21] also expressed concerns about EMT's willingness to use a new technology because technologies may slow them down and the benefit of using technologies may not be immediately obvious. In the user study conducted by Gilligan et al. [34], both ED staff and EMTs expressed concerns regarding the use of telemedicine technology, including patient confidentiality, technological limitation, staff liability, financial cost, added distraction, and so forth.

The issue of privacy was also examined by three studies [20, 33, 34]. Overall, patients didn't perceive privacy issues as significant and were willing to use telemedicine technology to contact a provider in the ED so they could be assessed before arriving at hospital [34]. Lastly, inter-team collaboration and organizational feasibility were examined in two studies [24, 27]. Bergrath et al. [27] concluded that using telemedicine in a prehospital context was organizationally feasible, based on the observation of structured cooperation and joint decision making between distributed healthcare practitioners.

## Challenges Reported in Reviewed Studies

The studies identified a set of challenges in using and adopting technologies to support communication and coordination between the field and receiving facility. We categorized these challenges into three areas: technical, usability, and organizational challenges (Table 4).

These studies reported a variety of technical problems such as: unstable connections to mobile network [18, 24, 26, 27, 30, 31], software or hardware malfunctions [18, 27], lack of interoperability between systems [24], and

**Table 3** Summary of Studies. (Note: "EMTs" for EMS personnel dispatched to the field, "ED" for emergency care professionals at the receiving hospital, and "teleconsultants" for healthcare professionals at a remote consultation center (not a hospital). If identifiable, the number of participants is also specified inside the parenthesis following the category of participants)

| AUTHORS | METHODS | PARTICIPANTS | STUDY OBJECTIVE | MAJOR FINDINGS |
|---|---|---|---|---|
| Bergrath et al. [27] | Questionnaire | EMTs and teleconsultants (10) | Evaluate the technical and organizational feasibility of a telemedicine system from the user's perspective. | • Quality of the photos and videos were satisfactory<br>• Ambient and technical noise were the most frequently reported disturbing factors<br>• Teleconsultation was organizationally feasible with joint medical decisions made and structured cooperation observed<br>• Technical reliability and availability need to be improved |
| Cho et al. [31] | Likert-scales | EMTs and ED physicians | Evaluate the feasibility and usefulness of telemedicine. | • Participants rated the video and bio-signal transmission quality with a satisfaction score of 4 (very satisfied) on a 5-point scale<br>• Consultation from the scene of the accident was impractical because of the size and weight of the telemedicine equipment |
| Kwak et al. [30] | Questionnaire | EMTs (11) and ED physicians (8) | Investigate the feasibility of using a hands-free portable device to support communication between physicians and EMS practitioners. | • Quality of audio and video transmission were intermediate<br>• Participants considered the device was useful for diagnosing trauma patients, but disagreed on the ease of use of the device |
| Reddy et al. [24] | Interview (focus group) | EMTs (8), communication specialists (2), and ED physicians (11) | Identify major challenges to coordination between EMTs and ED physicians. | • Three major challenges exist in coordinating tasks between EMTs and ED physicians: ineffectiveness of current telecommunication technologies, lack of common understanding, and breakdowns in information flow |
| Schooley et al. [25] | Interview (focus group) | EMTs (22), ED nurses (17) and physicians (2), administrators (5), and IT representatives | Design and evaluate a mobile multimedia information system for collecting and visualizing prehospital information. | • EMTs and ED physicians have positive attitudes regarding the mobile application and the multimedia<br>• Multimedia information is perceived by users to positively augment decision making<br>• The evaluation also found significant challenges to address: sending video file, varying work flows across hospitals, and inter-organizational collaboration |
| Tang et al. [22] | Heuristic evaluation, observation, and video analysis | Usability experts (3) | Examine the utility of heuristic evaluation in improving the usability of telemedicine. | • Usability should be given high priority in the development of a telemedicine system<br>• Heuristic evaluation can be effective in identifying usability problems and improving user interface design |
| Tollefsen et al. [21] | Observation, interview | EMTs | Report about design and usability evaluation of a handheld device for EMTs. | • Data entry should follow more normal entry of paper work that EMTs follow<br>• EMS providers might need a while to start to use technology |
| Espinoza et al. [33] | Questionnaire | Professional caregivers (123), visitors (234), general public (250) | Evaluate the opinions of the public, patients, and professional caregivers about telemedicine for ambulance transportation. | • People are positive about the use of telemedicine in the ambulance<br>• People had confidence that their privacy and identity would be protected during telemedicine consultations |
| Yperzeele et al. [18] | Likert-scales, interview | EMTs and teleconsultants | Evaluate the feasibility and reliability of in-ambulance teleconsultation using a telemedicine system. | • The quality of the audio-video connection and user friendliness of the system was rated as "Good" by the teleconsultants and the nurses |

**Table 3** (continued)

| AUTHORS | METHODS | PARTICIPANTS | STUDY OBJECTIVE | MAJOR FINDINGS |
|---|---|---|---|---|
| | | | | • The general acceptance of the system was high, which was reflected by the high rates of the system activation (75.4%) |
| Sibert et al. [23] | Questionnaire | Trauma surgeons (2), ED physicians (2), and ultrasound technologists (3) | Evaluate the satisfaction and feasibility of using ultrasound and video laryngoscopy in a mobile telemedicine consult. | • Lower ratings for video than for still pictures, with no respondent giving a high rating for quality and focus of video<br>• Video laryngoscope has higher mean satisfaction than ultrasound imaging |
| Felzen et al. [28] | Questionnaire | Teleconsultants | Evaluate technical performance of a telemedicine system in routine use. | • Multifunctional teleconsultation was successful in routine use<br>• The quality of videos and pictures were rated as high |
| Xiao et al. [20] | Questionnaire | EMTs (2) and stroke specialists (2) | Report on design, implementation, and testing of a mobile telemedicine system. | • Participants agreed that the telemedicine system was easy to use, conveyed critical clinical information, and did not intrude into the privacy of the patient or the paramedics |
| Gilligan et al. [34] | Questionnaire | ED doctors (12), ED nurses (19), ambulance personnel (46), and patients (56) | Examine if the stakeholders (patients, paramedics, doctors and nurses in the ED) want and accept telemedicine in prehospital emergency care. | • Both ED staff and paramedics expressed positive attitudes regarding the use and implementation of telemedicine in the prehospital environment<br>• Concerns of using such a system include patient confidentiality, technological limitations, financial cost, staff liability, and added distraction<br>• Patients would like the ambulance service to use video link telemedicine technology to contact a doctor in the ED so they could be assessed before arriving at hospital |
| Park et al. [32] | Survey | EMTs (113) in 5 fire-stations | Examine the utility of heuristic evaluation in improving the usability of telemedicine. | • Perceived challenges in efficient EMS work include accurate reporting in EMS activities, referencing reliable medical records, real-time data communication from scenes to hospitals and control centers, triaging and patient tracking, and life monitoring in EMS<br>• Implemented a smart EMS system with several brokers to enable information sharing between EMS and hospital |
| Smith et al. [26] | Evaluation of NIHSS scores, questionnaire, interview, and observation | EMTs (3), neurologists (13), and patients (23) | Assess the usability of an ambulance-based tele-stroke platform and identify strengths and limitations of the system from the user's perspective. | • Human factors and workflow play a significant role in the overall success of facilitating mobile evaluations in the prehospital setting<br>• The common usability issues include poor audibility, unreliable connection, shifting of equipment during transport, and poor visibility during the assessment.<br>• Unintended organizational issues need to be addressed before implementation |
| Johansson et al. [35] | Questionnaire | Ambulance nurses (6) and neurological specialist (1) | Evaluate technical feasibility of a telemedicine system in the prehospital assessment of patients with suspected | • The tele-stroke platform is reliable to use and the digital stroke assessment is believed to increase uniform assessment. The image quality is perceived suitable in the assessment situation |

**Table 3** (continued)

| AUTHORS | METHODS | PARTICIPANTS | STUDY OBJECTIVE | MAJOR FINDINGS |
|---|---|---|---|---|
| | | | stroke, and elicit ambulance nurses' experiences with the use of the tele-stroke technology. | • Several issues with digital stroke assessment are highlighted, including minor operating interference, physician's competence crucial (physicians' skills and personality are important factors), and unclear efficacy |
| Geisler et al. [29] | Questionnaire | Remote and onboard neurologists | Evaluate the technical feasibility and audiovisual quality of a telemedicine system for prehospital stroke treatment. | • Remote assessment and treatment decisions of emergency patients are technically feasible with satisfactory audiovisual quality<br>• The interrater reliabilities between the onboard and remote neurologist were high for diagnoses and treatment decisions |

difficulties in system maintenance [30] and transmitting multimedia information (e.g., audio and video) [25, 26, 35]. In particular, unstable connections to the mobile network was commonly seen. This issue could lead to breakdowns in information flow, causing potential loss of patient information, misrepresentation of patient issues, and transporting patients to the wrong location [24]. In addition, three studies documented the difficulties in the transmission of multimedia information [25, 26, 35]. For example, Schooley et al. [25] noted that the video file was often not received by the ED prior to patient arrival because encrypting a video file on the mobile device and then sending it through a network was troublesome and time-consuming. Johansson et al. [35] and Chapman Smith et al. [26] reported poor audibility and visibility of telemedicine systems during medical consultation.

Several usability challenges were also reported. Usability is an important measurement of the extent to which a device or application is easy to use, and can be used by particular users to achieve specified goals with effectiveness, efficiency and satisfaction [36]. The reviewed studies reported that the system devices were hard to use and inconvenient to carry around, and usually became a hindrance to the user [21, 25, 26, 30, 31, 34]. For example, Cho et al. [31] highlighted the difficulties in using telemedicine outside of the ambulance given the size and weight of the telemedicine unit. In addition, as Gilligan et al. [34] and Schooley et al. [25] reported, using video communication technology in prehospital care to share multimedia information (e.g., pictures) may have been a distraction to both paramedics and hospital staff (e.g., ED physicians). As such, they called for the development of protocols on the types and quantity of information to share. Lastly, as Tollefsen et al. [21] discussed, while systems were developed to cope with a wide variety of emergency situations and patient cases, they may not cover all possibilities and there may be information that cannot be captured by these systems. This is particularly relevant to the emergency environment, where many medical events are not predictable. As such, systems should be "designed in such a way as to provide flexibility for unique situations" [21].

With regard to organizational challenges, studies have highlighted the difficulties in integrating technologies into workflow [21, 25, 26] and building common understanding between geographically dispersed prehospital and hospital teams [24, 26]. Two studies reported that adopting new technologies, such as an ambulance telemedicine system, could potentially add more workload and new tasks to emergency care providers [20, 28]. More extensive user training is therefore needed to increase efficiency and reduce human errors in system operation [28]. Other reported organizational issues that need to be addressed before implementation include the need for adequate equipment/software training, staff liability, patient safety and privacy, and financial cost [26, 34].

## Discussion

In this section, we discuss the implications of our results, focusing on the emerging need of adopting user-centered design approaches and taking into account sociotechnical perspectives (e.g., cognitive and physical stressors, workflow, and context) when designing and developing prehospital communication technology.

### Applying User-Centered Approaches to Designing Prehospital Communication and Collaboration Technologies

This systematic review focused on user evaluations of information technologies for prehospital communication and coordination, including user satisfaction and acceptance, system usability, and inter-team collaboration. Out of 918 retrieved papers pertaining to prehospital communication technology, only 17 studies conducted user evaluations, highlighting the paucity of evaluative research in the prehospital technology domain. Prior work has suggested that user evaluation plays an important role in the successful implementation of technologies as it provides valuable feedback about potential users' perceptions and assessment about certain qualities of a system [37, 38]. Additionally, it is important to involve users in the early phase of system development to identify and address usability issues (i.e., via usability testing of prototypes), because design changes made late in working systems will cause higher expenditure than if identified earlier [11, 39]. However, the majority of reviewed studies conducted user evaluation either at the end of the system design or after implementing the system. Only three studies worked with potential users to examine challenges in prehospital communication and collaboration and investigate system requirements to address these challenges in the initial system design process [24, 32, 34]. Without a medical background and field experience, it is very challenging for technology designers and developers to independently design and build successful communication system for prehospital emergency care. Therefore, in order to implement a user-friendly system in a time-critical medical environment, there is a need to adopt a user-centered design approach in their development [40]—placing users at the center of the design process from the phases of inception to implementing and testing the system [39]. That is, the major stakeholders of prehospital communication technologies, such as patients, EMS and ED providers, should be highly involved throughout the system design process [17].

Choosing the right method to evaluate user's perceptions is also important [11]. Each method has its advantages and disadvantages. For example, analyzing logs of system use can objectively measure user's interaction with a system, whereas interviews and questionnaires can be performed to give users more flexibility to express their opinion after interacting with the system. We found that the reviewed studies mainly used two types of methods (interview and questionnaire), with each study tended to rely on one methodology, such as questionnaire, to elicit user's perceptions [e.g., 27,30,23]. Even though questionnaires are a commonly used method for user evaluation, other methods can provide more in-depth insights into user's needs and perspectives on technological systems. For example, observation can be used to better understand the context of user behavior, such as when, how, and why the system is used, and what kinds of usability challenges exist that cannot be identified otherwise. Future work should consider using multiple methods to gain a holistic view of user's perspectives on using technologies in the prehospital context.

### Design Implications: A Social-Technical Perspective

The reviewed studies reported technical, usability, and organizational issues that hindered the adoption and use of technologies in the context of prehospital communication. In particular, many reviewed studies reported unstable connections to the mobile network as a major technical challenge, causing communication drop-outs during teleconsultation. Given the rapid development of telecommunication technology (e.g., 5G network), this technical challenge is likely to be addressed, along with significantly improved stability and quality of communication between the field and hospital. Additionally, our systematic review highlighted and synthesized the usability and organizational issues that affect the efficient use of technologies in the prehospital setting. These usability and organizational issues should receive equal attention as technical challenges in order to ensure successful implementation and adoption of health technologies. Along this line, prior work has called for a *social-technical* perspective to designing and developing health technologies [41, 42]. Based on the reported challenges, we believe three socio-technical issues (cognitive and physical stressors, workflow, and context) must be taken into account when developing the technologies to support communication and collaboration between prehospital and hospital teams.

#### Cognitive and Physical Stressors

Designing user-centered healthcare information technologies should account for an individual's cognitive and physical limitations. Emergency care is a complex, fast-paced, and a mentally demanding activity. Emergency care professionals may experience high levels of uncertainty, deal with vast amounts of

**Table 4** Challenges to Adopting Technology Support for Prehospital Communication

| | |
|---|---|
| Technical Challenges | Unstable connections to mobile network [18, 24, 26, 27, 30, 31] |
| | Software/hardware malfunctions [18, 27, 35] |
| | Lack of interoperability between systems [24] |
| | Difficulties in system maintenance [30] |
| | Issues in transmitting multimedia information [25, 26, 35] |
| Usability Challenges | Devices are inconvenient to use [21, 25, 26, 30, 31, 34] |
| | Added distractions to medical professionals [25, 34] |
| | Not adaptable to unique situations and every patient case [21] |
| Organizational Challenges | Difficulties in integrating technologies into existing workflow [21, 25, 26] |
| | Lack of common understanding between distributed emergency medical teams [24, 26] |
| | Extra tasks and added workload to users [20, 28] |
| | Issues with patient privacy and safety [26, 34] |
| | Inadequate equipment and software training [26] |

information, and perform multiple tasks simultaneously. All of these factors and activities contribute to cognitive overload. It has been reported that poor usability of clinical information systems may increase the cognitive burden of clinicians and lead to errors [43, 44]. This burden was also found in this study—navigating through a number of screens to enter data can be a hindrance and slow down the user during an emergency situation [21]. Technologies should be carefully designed to help emergency care professionals make decisions and complete tasks with little cognitive demand [45].

Designers should also pay close attention to user's physical stressors. Both EMTs and ED providers deal with severely ill patients and critical injuries, with limited abilities to interact with computing devices. For example, one reviewed study reported several challenges in using ambulance telemedicine systems due to placement of the equipment, such as maneuvering the camera, and using the speaker/microphone to relay communication [26]. Another study highlighted the difficulties in using telemedicine outside of the ambulance given the size and weight of the telemedicine unit [31]. In order to reduce the constraints of bulky equipment, Kwak et al. [30] developed wearable technology to facilitate data collection and communication outside of the ambulance environment. However, such wearable devices also have limitations in its use in the field. For instance, sudden head movements by EMTs made it impossible to generate stable visualization for remote teleconsultants [30]. Future work needs to examine how cognitive and physical constraints affect the interaction with systems in ambulances and the field, and how to eliminate these stressors.

## Workflow

The literature suggests that developing systems to support emergency medical care should account for the workflow of care providers [24]. A previous study on a clinical documentation system has shown that the computerized systems could have unintended consequences (e.g., result in higher workload, be time-consuming) if workflow is not considered at the point of system design and implementation [46]. Several commercial electronic systems, such as emsCharts [47], have been developed for EMTs to structure data collection in the field. These systems, however, are rarely used at the point of an accident or during transport [1]. One possible explanation is that EMTs are busy with patient care, with limited time to work on the system and detailed data collection.

Our review revealed several challenges related to workflow, such as difficulties in integrating technologies into existing workflow [21, 25, 26] and increased workload as a result of the technology [20, 28]. Integrating technology into an existing workflow can change the job requirements of EMS and ED providers. For example, mobility is an integral part of emergency care, with both EMTs in the field and ED doctors at the receiving facility moving from one location to another [6, 48]. They may not have easy and timely access to equipment and computer devices in a fixed position. The prehospital communication technology should be designed in a way to support such great mobility of medical work. More specifically, future work should investigate the temporal organization of the tasks performed by EMS and ED providers in a technology-mediated environment when designing technology support [17] and embedding workflow protocols and procedures into the system [24].

## Context

Communicating context in which patient information is generated is crucial [6]. When the information moves from one context (e.g., accident scene) to another context (e.g., hospital), it may lose its original meaning. To address this challenge, the technology solutions reviewed in this article, such as telemedicine and wearable technologies, provide means for sharing pictures or videos from the incident scene to help ED physicians better anticipate the severity of the patient's injury. However, these technology solutions have their own limitations. For example, the telemedicine unit is not accessible outside of the ambulance. Future work needs to address these technology limitations and develop easy-to-use approaches for capturing and sharing contextual information.

On the other hand, contextual information could be overwhelming [6, 25]. For example, EMTs may provide contextual information relevant to the prehospital setting that may not be relevant to the receiving hospital. It is, therefore, important to establish common understanding between prehospital and hospital teams as to what types of contextual information are needed [6]. Furthermore, different healthcare professionals at the receiving hospital (e.g., ED physician, nurse, trauma surgeon) may need different types of contextual information. For example, ED physicians and trauma surgeons need details about patient injuries to anticipate patient needs, whereas nurses need information about en route treatments to prepare for the types of needed medications and fluid [6]. As such, it is important to communicate the right level of detailed information to the right people (e.g., who should receive the information). One possible solution is to provide different representations of the same context so that healthcare professionals can "see the information in a manner that is most relevant to their work while the information still retains its original meaning" [24].

## Limitations

This review has several limitations. Only publications from 2000 to 2019 were reviewed. It is possible that some articles published prior to 2000 were relevant. However, the time period selected represents the beginning of the development of the current generation of prehospital technologies [17]. Defining the search keywords was difficult, posing another limitation. To cope with this challenge, keywords were iteratively selected based on review of current systematic review articles and group discussion among researchers.

## Conclusion

This article reviewed the literature conducted user evaluations on technologies for communication and collaboration between the field and hospital. Telemedicine is the primary technology used in the majority of studies. In addition, wearable, handheld, and IoT devices were also used to bridge the communication gap between EMS and ED teams. Even though the user acceptance and satisfaction of these systems were rated as high, the reviewed studies reported a variety of technical, usability, and organizational challenges in the use and adoption of these systems. With only 17 studies out of 918 retrieved articles conducted user evaluations, our study highlights the paucity of evaluative research in the prehospital technology domain. Furthermore, major stakeholders of the technologies designed for prehospital communication, such as EMTs and ED physicians, were rarely involved in the system design process. Our results align with those from previous studies of prehospital work [1, 6, 17], suggesting that there is a need to adopt a user-centered design approach to address the identified challenges and implement easy-to-use technologies in a time-critical medical environment. More importantly, future work should take into account socio-technical issues (e.g., cognitive and physical stressors, workflow, and context) at the point of system design.

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## Compliance with Ethical Standards

**Conflict of Interest** All authors declare that he/she has no conflict of interest.

**Ethical Approval** This article does not contain any studies with human participants performed by any of the authors.

## Appendix 1: Keywords for literature search

*Technology* terms: Mobile health, telehealth, telemedicine, telenursing, tele-pathology, tele-radiology, tele-rehabilitation, information technology, communication technology.

*Emergency Medical Services (EMS)* terms: Ambulance, emergency fire dispatch, emergency medical dispatch, emergency medical service, emergency medical technician, emergency police dispatch, emergency dispatch, EMS communication system, paramedic, patient transport, prehospital emergency care, prehospital emergency service, prehospital triage.

*Emergency Departments (ED)* terms: Emergency department, emergency hospital service, emergency room, emergency unit, emergency ward, emergency psychiatric service, hospital emergency service, psychiatric emergency service, trauma center, trauma unit

## Appendix 2

**Table 5** A sample search strategy from Medline

| | | |
|---|---|---|
| MEDLINE (via Ovid MEDLINE® and Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Daily and Versions®, 1946 to present) | | |
| Search date = 8/13/2019 | | |
| 1 | exp Telemedicine/ or exp Telenursing/ or (communication technolog* or information technolog* or mobile health* or telecardiolog* or tele-cardiolog* or teleconsult* or tele-consult* or teledermatolog* or tele-dermatolog* or telediagnos* or tele-diagnos* or telehealth* or tele-health* or telemedic* or tele-medic* or telemonitor* or tele-monitor* or telenursing or tele-nursing or telepatholog* or tele-patholog* or telepractic* or tele-practic* or telepsychiatr* or tele-psychiatr* or teleradiolog* or tele-radiolog* or teleradiotherap* or tele-radiotherap* or telerehabilitat* or tele-rehabilitat* or telesurger* or tele-surger* or teletherap* or tele-therap*).tw,kf. | 50566 |
| 2 | exp Emergency Medical Dispatch/ or exp Emergency Medical Dispatcher/ or exp Emergency Medical Service Communication Systems/ or exp Emergency Medical Technicians/ or exp Emergency Police Dispatcher/ or exp Transportation of Patients/ or (ambulance* or (emergency adj3 (dispatch* or technician* or responder*)) or emergency medical service* or paramedic* or (patient* adj4 transport*) or ((prehospital or pre-hospital) adj3 (emergenc* or triag*))).tw,kf. | 43540 |
| 3 | exp Emergency Service, Hospital/ or exp Emergency Services, Psychiatric/ or ((emergency or trauma) adj3 (care or center or centers or centre or centres or department* or healthcare or health-care or room* or service* or unit* or ward*)).tw,kf. | 173096 |
| 4 | 1 and 2 and 3 | 355 |
| 5 | limit 4 to (english language and yr="2000 - current") | 298 |

## References


1. Sarcevic, A., and Burd, R. S., Information handover in time-critical work. In: Proceedings of the ACM 2009 International Conference on Supporting Group Work, 2009. ACM, 301–310.
2. Aase, K., Soeyland, E., and Hansen, B., A standardized patient handover process: Perceptions and functioning. Safety Science Monitor 15(2):1–9, 2011.
3. Faraj, S., and Xiao, Y., Coordination in fast-response organizations. Management Science 52(8):1155–1169, 2006.
4. Meisel, Z. F., Shea, J. A., Peacock, N. J., Dickinson, E. T., Paciotti, B., Bhatia, R., Buharin, E., and Cannuscio, C. C., Optimizing the patient handoff between emergency medical services and the emergency department. Annals of emergency medicine 65(3):310–317, 2015 e311.
5. Rowlands, A., An evaluation of pre-hospital communication between ambulances and an accident and emergency department. London: SAGE Publications Sage UK, 2003.
6. Zhang, Z., Sarcevic, A., and Bossen, C., Constructing common information spaces across distributed emergency medical teams. In: Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing, 2017. ACM, 934–947.
7. Xiao, Y., Kim, Y. J., Gardner, S. D., Faraj, S., and MacKenzie, C. F., Communication technology in trauma centers: A national survey. Journal of Emergency Medicine 30(1):21–28, 2006.
8. Chan, T. C., Killeen, J., Griswold, W., and Lenert, L., Information technology and emergency medical care during disasters. Academic Emergency Medicine 11(11):1229–1236, 2004.
9. Salvemini, A. V., Challenges for user-interface designers of telemedicine systems. Telemedicine and e-Health 5(2):163–168, 1999.
10. Buck, S., Nine human factors contributing to the user acceptance of telemedicine applications: A cognitive-emotional approach. Journal of Telemedicine and Telecare 15(2):55–58, 2009.
11. Klaassen, B., van Beijnum, B. J., and Hermens, H. J., Usability in telemedicine systems—A literature survey. International Journal of Medical Informatics 93:57–69, 2016.
12. Viitanen, J., Hyppönen, H., Lääveri, T., Vänskä, J., Reponen, J., and Winblad, I., National questionnaire study on clinical ICT systems proofs: Physicians suffer from poor usability. International Journal of Medical Informatics 80(10):708–725, 2011.
13. Viitanen, J., and Kuusisto, A., Nykänen P usability of electronic nursing record systems: Definition and results from an evaluation study in Finland. Studies in Health Technology and Informatics, 2011, 333–338.
14. Militello, L., Patterson, E. S., Tripp-Reimer, T., Asch, S. M., Fung, C. H., Glassman, P., and Anders, S., Doebbeling B clinical reminders: Why don't they use them? In: Proceedings of the human factors and ergonomics society annual meeting, 2004. Vol. 15. Los Angeles: SAGE Publications Sage CA, 1651–1655.
15. Sarcevic, A., and Ferraro, N., On the use of electronic documentation systems in fast-paced, time-critical medical settings. Interacting with Computers 29(2):203–219, 2017.
16. Middleton, B., Bloomrosen, M., Dente, M. A., Hashmat, B., Koppel, R., Overhage, J. M., Payne, T. H., Rosenbloom, S. T., Weaver, C., and Zhang, J., Enhancing patient safety and quality of care by improving the usability of electronic health record systems: Recommendations from AMIA. Journal of the American Medical Informatics Association 20(e1):e2–e8, 2013.
17. Rogers, H., Madathil, K. C., Agnisarman, S., Narasimha, S., Ashok, A., Nair, A., Welch, B. M., and McElligott, J. T., A systematic review of the implementation challenges of telemedicine systems in ambulances. Telemedicine and e-Health 23(9):707–717, 2017.
18. Yperzeele, L., Van Hooff, R. J., De Smedt, A., Espinoza, A. V., Van Dyck, R., Van de Casseye, R., Convents, A., Hubloue, I., Lauwaert, D., and De Keyser, J., Feasibility of AmbulanCe-based telemedicine (FACT) study: Safety, feasibility and reliability of third generation in-ambulance telemedicine. PloS one 9(10):e110043, 2014.
19. Moher, D., Liberati, A., Tetzlaff, J., and Altman, D. G., Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. Annals of Internal Medicine 151(4):264–269, 2009.
20. Xiao, Y., Gagliano, D., LaMonte, M., Hu, P., Gaasch, W., Gunawadane, R., and Mackenzie, C., Design and evaluation of a real-time mobile telemedicine system for ambulance transport. Journal of High Speed Networks 9(1):47–56, 2000.
21. Tollefsen, W. W., Gaynor, M., Pepe, M., Myung, D., Welsh, M., and Moulton, S., iRevive: A pre-hospital database system for emergency medical services. International Journal of Healthcare Technology and Management 6(4–6):454–469, 2005.
22. Tang, Z., Johnson, T. R., Tindall, R. D., and Zhang, J., Applying heuristic evaluation to improve the usability of a telemedicine system. Telemedicine and e-Health 12(1):24–34, 2006.
23. Sibert, K., Ricci, M. A., Caputo, M., Callas, P. W., Rogers, F. B., Charash, W., Malone, P., Leffler, S. M., Clark, H., and Salinas, J., The feasibility of using ultrasound and video laryngoscopy in a mobile telemedicine consult. Telemedicine and e-Health 14(3): 266–272, 2008.
24. Reddy, M., Paul, S. A., Abraham, J., McNeese, M., DeFlitch, C., and Yen, J., Challenges to effective crisis management: Using information and communication technologies to coordinate emergency medical services and emergency department teams. International Journal of Medical Informatics 78(4):259–269, 2009.
25. Schooley, B., Abed, Y., Murad, A., Horan, T. A., and Roberts, J., Design and field test of an mHealth system for emergency medical services. Health and Technology 3(4):327–340, 2013.
26. Chapman Smith, S. N., Brown, P. C., Waits, K. H., Wong, J. S., Bhatti, M. S., Toqeer, Q., Ricks, J. V., Stockner, M. L., Habtamu, T., and Seelam, J., Development and evaluation of a user-centered Mobile Telestroke platform. Telemedicine and e-Health 25(7): 638–648, 2019.
27. Bergrath, S., Rörtgen, D., Rossaint, R., Beckers, S. K., Fischermann, H., Brokmann, J. C., Czaplik, M., Felzen, M., Schneiders, M. T., and Skorning, M., Technical and organisational feasibility of a multifunctional telemedicine system in an emergency medical service – An observational study. Journal of Telemedicine and Telecare 17(7):371–377, 2011. https://doi.org/10.1258/jtt.2011.110203.
28. Felzen, M., Brokmann, J. C., Beckers, S. K., Czaplik, M., Hirsch, F., Tamm, M., Rossaint, R., and Bergrath, S., Improved technical performance of a multifunctional prehospital telemedicine system between the research phase and the routine use phase–an observational study. Journal of Telemedicine and Telecare 23(3):402–409, 2017.
29. Geisler, F., Kunz, A., Winter, B., Rozanski, M., Waldschmidt, C., Weber, J. E., Wendt, M., Zieschang, K., Ebinger, M., and Audebert, H. J., Telemedicine in Prehospital acute stroke care. Journal of the American Heart Association 8(6):e011729, 2019.
30. Kwak, M. J., Kim, J. M., Shin, I. H., Shin, S. D., Song, K. J., Suh, G. J., and Kim, H. C., Real-time medical control using a wireless audio-video transmission device in a pre-hospital emergency service in Korea. Journal of Telemedicine and Telecare 15(8):404–408, 2009. https://doi.org/10.1258/jtt.2009.090504.
31. Cho, S. J., Kwon, I. H., and Jeong, J., Application of telemedicine system to prehospital medical control. Healthcare Informatics Research 21(3):196–200, 2015.
32. Park, E., Kim, J. H., Nam, H. S., and Chang, H. J., Requirement analysis and implementation of smart emergency medical services. IEEE Access 6:42022–42029, 2018.

33. Espinoza, A. V., De Smedt, A., Guldolf, K., Vandervorst, F., Van Hooff, R. J., Tellez, H. F., Desmaele, S., Cambron, M., Hubloue, I., and Brouns, R., Opinions and beliefs about telemedicine for emergency treatment during ambulance transportation and for chronic care at home. Interactive Journal of Medical Research 5(1), 2016.
34. Gilligan P, Bennett A, Houlihan A, Padki A, Owens N, Morris D, Chochliouros I, Mohammed A, Mutawa A, Eswararaj M (2018) The doctor can see you now: A key stakeholder study into the acceptability of ambulance based telemedicine.
35. Johansson, A., Esbjörnsson, M., Nordqvist, P., Wiinberg, S., Andersson, R., Ivarsson, B., and Möller, S., Technical feasibility and ambulance nurses' view of a digital telemedicine system in pre-hospital stroke care–a pilot study. International emergency nursing 44:35–40, 2019.
36. Bevan N, Kirakowski J, J M What is usability? In: HJ B (ed) Proceedings of the 4th International Conference on Human Computer Interaction, Stuttgart, 1991 1991. Elsevier,
37. Goodhue, D. L., Understanding user evaluations of information systems. Management science 41(12):1827–1844, 1995.
38. Jiang J. J, Klein G (1999) User evaluation of information systems: By system typology. IEEE transactions on systems, man, cybernetics-part a: systems and humans 29 (1):111–116
39. Kujala, S., User involvement: A review of the benefits and challenges. Behaviour information technology 22(1):1–16, 2003.
40. Norman D. A, Draper S. W (1986) User centered system design: New perspectives on human-computer interaction. CRC Press,
41. Reddy, M., Pratt, W., Dourish, P., and Shabot, M., Sociotechnical requirements analysis for clinical systems. Methods of Information in Medicine 42(04):437–444, 2003.
42. Berg, M., Patient care information systems and health care work: A sociotechnical approach. International Journal of Medical Informatics 55(2):87–101, 1999.
43. Ariza, F., Kalra, D., and Potts, H., How do clinical information systems affect the cognitive demands of general practitioners?: Usability study with a focus on cognitive workload. Journal of Innovation in Health Informatics 22(4):379–390, 2015.
44. Harrison, M. I., Koppel, R., and Bar-Lev, S., Unintended consequences of information technologies in health care—An interactive sociotechnical analysis. Journal of the American Medical Informatics Association 14(5):542–549, 2007.
45. Ahmed, A., Chandra, S., Herasevich, V., Gajic, O., and Pickering, B., The effect of two different electronic health record user interfaces on intensive care provider task load, errors of cognition, and performance. Critical Care Medicine 39(7):1626–1634, 2011.
46. Chen, Y., Documenting transitional information in EMR. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 2010. ACM, 1787–1796.
47. http://www.emscharts.com. Accessed December, 19th 2019
48. Bossen, C., The parameters of common information spaces: the heterogeneity of cooperative work at a hospital ward. In: Proceedings of the 2002 ACM Conference on Computer Supported Cooperative Work, 2002. ACM, 176–185.