Coordination Mechanisms for Self-Organized Work in an Emergency Communication Center

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We describe an observational study of work coordination in an emergency communication center, where a collocated team of communication specialists engages in complex activities of communicating with pre-hospital medical teams, and coordinating patient care and transport. Unlike teams with clearly defined work roles and team structures that were introduced to increase work efficiency and minimize redundancy, the team we studied lacks the role differentiation. To better understand how complex work is accomplished under these conditions, we conducted in-situ observations in the center's control room and interviewed communication specialists. We found that communication specialists self-organized by using a mix of material and immaterial coordination mechanisms, including work schedules, computer systems, and tacit agreements to coordinate tasks. Using these findings, we then identified three features of self-organized, collocated and time-critical teamwork that require technology support: awareness of task ownership, task self-assignment, and informal team hierarchy. We conclude by discussing technology requirements to support these teamwork features.

CCS Concepts: **Human-centered computing → Collaborative and social computing → Collaborative and social computing theory, concepts and paradigms → Computer supported cooperative work**

KEYWORDS
Articulation work; awareness; centers of coordination; coordination mechanisms; division of labor; emergency medical communication; emergency medical services; role differentiation; team hierarchy.

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1 INTRODUCTION

Work roles have been a prime topic of research in CSCW. Dourish and Bellotti [15] described a role as an individual's relationship to the shared objects of work and to other participants, typically linked to a set of operations which can be performed. Recognizing the importance of roles in teamwork, CSCW researchers have studied the impact of roles on team communication and collaboration in a range of contexts, including office work [60], critical care settings [16,30,35], centers of coordination [20,23], distributed software development [41], and R&D teams [24]. These studies have shown that role differentiation—a clear distinction between workers in terms of what they do—serves as an important mechanism by which teams organize their work and divide labor [58]. Awareness of who does what, when, and how, has made teams

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more efficient in completing tasks and addressing emergent problems [61]. It is not surprising then that work roles featured prominently in early CSCW systems, such as collaborative authoring tools [17,42,44], with succeeding tools and collaborative online environments continuing to support them [7,21,22,55].

While many CSCW studies have been focusing on teams with clearly defined role- and team structures, fewer have examined work coordination in teams that lack role differentiation. In this paper, we examine one such team—a group of communication specialists in an emergency communication and information center (ECIC) in a pediatric teaching hospital. All communication specialists carry the same job title with identical responsibilities: (1) responding to emergency and referral calls requesting urgent patient care or transfer between hospitals, (2) dispatching transport teams, and (3) summoning medical teams to treat critically injured patients. This shared set of responsibilities was not common in the past, when specialists who were taking all referral calls had the primary role, and specialists taking all emergency calls had the secondary role. Although this division of labor supported teamwork at the time, it soon became apparent that dividing work along the call types was not sustainable because of their unequal distribution. Facing the problem of managing complex tasks in a timely manner, communication specialists dropped the primary and secondary roles, and started using a set of mechanisms to organize and coordinate their work. These changes in the team structure and workflow have opened up an avenue for exploring the coordination mechanisms in the context of self-organized, collocated and time-critical teamwork.

Our goal here is twofold. First, drawing on the concept of "coordination mechanisms" [54], we aim to understand the kinds of mechanisms that self-organized teams use to coordinate work in the context of emergency medical communication, as well as the challenges associated with those mechanisms. Second, we aim to identify the features of self-organized, collocated and time-critical teamwork that require technology support. To achieve this goal, we conducted a two-week long observational study in the ECIC center using in-situ observations and interviews. We found that communication specialists coordinated complex and high-tempo tasks by using both "material" (e.g., work schedules and computer systems) and "immaterial" mechanisms (e.g., letting the initial call taker follow through the call thread from start to end, surreptitiously overhearing other call discussions, tacitly agreeing to coordinate tasks, and verbally announcing actions). Based on these findings, we identified three features of the ECIC teamwork that would benefit from computerized support: awareness of task ownership, task self-assignment, and informal team hierarchy. Although these features characterize other types of self-organized teamwork (e.g., [29,56]), the work of emergency communication specialists lacks role differentiation and spans much smaller temporal and spatial scales. For these reasons, the means by which ECIC team members accomplish their work differ from those of other self-organized teams. Understanding these features, in turn, allows for the re-examination of challenges in developing technology support for self-organized, high-risk cooperative work.

We contribute to CSCW by (1) identifying coordination mechanisms in the context of self-organized, collocated and time-critical teamwork during emergency medical communication, as well as the challenges associated with those mechanisms; and (2) identifying features of self-organized, collocated and time-critical teamwork, and the challenges in designing technology to support those features.

2 RELATED WORK

In reviewing related work, we first describe CSCW studies of role-based coordination in different contexts, including the emergency and time-critical work settings. We then turn to works that highlighted the importance of work roles in CSCW systems design. Finally, we define the concept of coordination mechanisms and describe its evolution.

2.1 Role-Based Coordination in Emergency and Non-Emergency Contexts

Goffman defined *roles* as the basic units of socialization that provide continuity in organizations [19]. As such, roles and role structures in general, have been of interest to sociologists and organizational scholars, offering insight into how work and social order are organized, enacted, negotiated, and reconstructed in different social contexts [58]. Concerned with similar questions about social organization of work, albeit for different reasons—that is, to inform system design—CSCW researchers have also studied work roles, focusing mostly on their impact on team interaction, communication, and work coordination.

Most relevant to our work are studies of high-reliability teams that require careful coordination of complex, interdependent activities under time pressure, such as those found in London Underground line control rooms [23], air traffic control [6,25], firefighting brigades [33], airport operations rooms [20], ship navigation [26], 9-1-1 call centers [43,51] and emergency medical dispatch [3,40]. Although members of these groups are also collocated, they rely on the relatively stable team and role structures to organize their work and behavior in relation to one another. Role differentiation in these settings results in a differentiated structure of attention, allowing group members to focus on their tasks. At the same time, being engaged in a highly integrated, joint tasks, these groups develop a shared view of the world by overhearing conversations or by monitoring each other's behavior, which in turn allows them to rapidly address emergent problems and avoid error [61]. Role differentiation is also common in the context of distributed and decentralized emergency teamwork, such as emergency response and management [2,34], disaster response and management [36,49,56], emergency medical services [31], and critical care [1,27]. Work of these teams, however, is based on a scale both temporally and spatially larger than that of collocated ECIC teams, with activities being coordinated across different locations over hours, days and months, rather than within minutes.

Roles are also critical in understanding how work is coordinated and achieved in less stable, temporary organizations, such as project-based groups or dynamically, *ad-hoc* formed teams. Examples include emergency department (ED) medical and trauma teams [16,35,46,50], film crews [5], and software development teams [41]. Unlike organizations with stable team and role structures, temporary groups rely on short-term workers who are unfamiliar with one another's roles and skills, and may not know *a priori* with whom to collaborate [5]. This lack of knowledge about each other's roles and skills requires coordination mechanisms that make those roles and skills explicit. For example, Faraj and Xiao [16] identified four expertise coordination processes used by trauma resuscitation teams to manage distributed expertise among various roles: reliance on protocols, plug-and-play teaming, community of practice, and knowledge sharing. McChesney and Gallagher [41] found that clear separation of responsibilities across project roles represented a significant coordination feature in software development teams, while Bechky [5] suggested the importance of interplay between the structural context and the negotiated enactment of roles in order to coordinate activity on film sets.

As a whole, these studies have looked into coordination among workers with clearly defined roles and associated set of responsibilities. A common theme is that roles have an important function in organizations because they affect how work is organized and coordinated; they are either a catalyst for smooth coordination or the actual coordination mechanism. We contribute to this body of work by studying coordination among team members in an emergency communication center—an organization with a stable team structure (i.e., long-term workers) but without role differentiation. Because members of this group cannot rely on role differentiation to divide labor, they self-organized, using several material and immaterial coordination mechanisms to complete high tempo tasks. Identifying these mechanisms and features of teamwork is a critical first step towards the design of computerized support for self-organized teamwork in highly dynamic and collocated work environments.

2.2 Computer Support for Role-Based Collaboration

Explicit computer support for work roles started with early CSCW systems, such as collaborative authoring tools Quilt [17], PREP [44], and ShrEdit [42]. Recognizing roles as an important mechanism for coordinating work and sharing awareness information [15], CSCW researchers have built role-based features that allowed users to either control the degree of access to the document based on individual pre-determined roles, or to negotiate and re-assign roles based on the changing demands of the activity. Later CSCW systems and online environments for both synchronous and asynchronous, small- and large-group collaboration have continued embedding solutions and features to meet the needs of different work and play roles (e.g., [7,21,22,55]).

Support for work roles is especially important in systems and tools that aid multi-role teams in emergency and time-critical situations, including emergency planning and management teams [12], emergency medical dispatch teams [8,62], firefighters [29,63], and emergency medical teams [31,64]. A common need for these teams is to have tools that allow explicit role identification, as well as efficient and unbiased access to and sharing of information for flexible coordination across different roles. Systems that support such teams have therefore included both role-defining and role-supporting features.

Although these studies highlighted the importance of work roles, proposing various system features to support them, little is known about the kinds of features that support awareness and coordination in teams engaged in time-critical work that lack role differentiation. Our work fills this gap by showing how technology use supported (or failed to support) activity coordination in a team of communication specialists, all of which occupy equivalent work roles and positions. Drawing on this insight, we then identify features of this self-organized teamwork and discuss challenges and implications in developing technology to support those features.

2.3 Coordination Mechanisms: Definition and Evolution

In this paper, we drew on the concept of coordination mechanisms to study how communication specialists self-organize and coordinate their work in a timely manner. Early CSCW work in coordination theory recognized the role of coordination mechanisms in managing dependencies among tasks, resources (e.g., tools, equipment) and people [39]. Schmidt and Simone [54] were the first to explicitly define coordination mechanisms as the different temporal artifacts used for coordinative purposes (e.g., timetables, schedules, checklists, routing schemes, catalogues, and classification systems in large repositories) based on early empirical investigations of the use of artifacts in different work domains. These artifacts can be used to lessen the amount of articulation work [58] and to represent the state of work [53]. Bossen [9] refined the concept of coordination mechanisms by suggesting the distinction between *material* and *immaterial* mechanisms: material mechanisms focus on artifacts, while the immaterial mechanisms refer to different aspects of work, such as organizational structures, division of labor, procedures, routines, peripheral awareness, and knowledge about team members' experience. As Bossen argued, the immaterial mechanisms are equally important as material ones in coordinating work because "they explicate who does what and when" [9]. Bardram and Bossen [4] showed that an in-depth understanding of the relationship between material and immaterial mechanisms can lead to important implications for how work is achieved and how awareness can be produced or not produced through those mechanisms.

To date, only a few studies used the notion of material and immaterial mechanisms to examine collaborative work in particular settings. Our prior work [64], for example, identified the material (e.g., personal artifacts) and immaterial mechanisms (e.g., division of labor and overhearing) for supporting collaboration between emergency medical teams in the field and those in the receiving hospital. In this paper, we use this distinction to define coordination mechanisms as a combination of material artifacts [54] and immaterial mechanisms of interaction [9].

3 EMERGENCY COMMUNICATION CENTER OVERVIEW

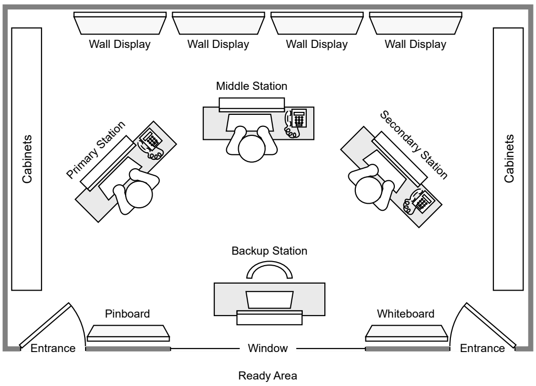
The setting for our study is the Emergency Communication and Information Center (ECIC) located in a pediatric teaching hospital. This is a high technology, state-of-the-art facility in which a team of communication specialists engages in complex activities of coordinating patient care and transport. The center is the first point of contact for anyone who is bringing or sending patients to the hospital by any means (air or ground), including emergency medical services (EMS), other hospitals, primary care physicians, and even school nurses. The ECIC team is therefore responsible for (1) coordinating patient transfers between hospitals; (2) coordinating the dispatch of ground and air medic crews and monitoring their movement; (3) coordinating consults between referring and hospital's physicians and nurses; and (4) coordinating arrivals for critically injured patients and activating trauma teams. The center is also a part of a larger hospital network, serving as the coordination hub for about forty hospitals in the region in an event of massive casualty or disaster. We next describe the ECIC team and its organizational structure, as well as the center's control room layout and technology.

3.1 ECIC Team and Organizational Structure

The ECIC team consists of ten full-time and two part-time communication specialists. Their job title was recently changed to Transport Coordination Specialist to avoid any confusion with a similar job title in the hospital's Telecommunications department. From now on, we will use the acronym "TC" and "TCn" when referring to particular ECIC team members, e.g., TC1.

To qualify for this position, all TCs must be EMT-B (Emergency Medical Technician-Basic) trained and must complete a 3-month, on-the-job training to familiarize with tasks and duties of a transport coordination specialist and the hospital system. The TCs work in 12-hour shifts, with day shifts starting at 7am and night shifts starting at 7pm. At least two TCs are available during each shift, listening to over dozen radio frequencies and responding to calls. A third TC may take a 12pm-12am shift to partially cover both day and night shifts and assist with task load. A typical shift may see 15-20 inter-hospital transfers, about ten EMS transports, and several flight arrangements that involve pre-flight, landing, and post-flight operations, making the helipad operation the most complex activity.

Unlike teams with clearly defined work roles and team structures, the ECIC team lacks role differentiation—all team members share the same job title (or role) and have identical responsibilities. Another evidence that role differentiation is lacking in this environment is the same, on-the-job training that each TC undergoes after hiring, i.e., they are all being trained for the same role of a transport coordination specialist. In addition, all TCs occupy equivalent positions within the ECIC team, which makes their intra-team hierarchy flat. As a team, however, they are led by the ECIC manager, a role with mostly operational and administrative responsibilities that interfaces with other hospital units and the outside world. Located on a separate floor, the ECIC manager rarely interferes with the activities of TCs, and only visits the control room when needed (e.g., to assist with system troubleshooting).



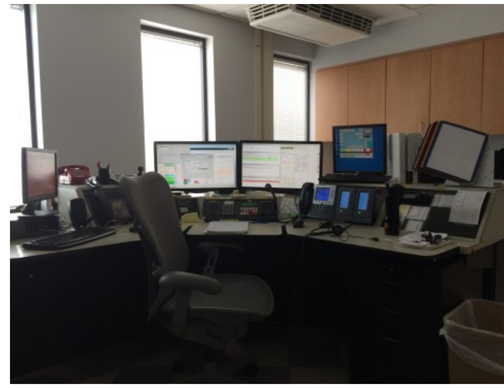


Figure 1. The ECIC control room layout (left). Tools and technology available at the transport coordination specialist's workstation (right).

3.2 ECIC Control Room Layout and Technology

The center is located at the top level of the hospital building and is adjacent to the helipad. The space includes the control room, a large area for air transport preparation and access to the helipad, and a flight mechanic's workshop. We focused our observations on TCs activities occurring in the control room (Figure 1).

Each TC sits at his or her own workstation. There are three workstations placed in the middle of the room following a U-shape, with TCs facing out. Storage space and cabinets can be found on both sides of the room. The left workstation is considered the primary station and the right station is considered the secondary station, a leftover from earlier times when the primary TC managed most of the referral calls and patient transfers (Figure 1, left). The primary and secondary stations are occupied at all times. A third TC, who works the 12pm-12am shifts, usually takes the middle workstation. Currently, seat assignment has no effects on TCs' workload and is done on the first-come, first-served basis through an online scheduling system. The TCs' schedule is usually determined a month in advance, with each TC selecting the shifts based on their preferences.

3.2.1 Technology and Artifacts in the ECIC Control Room. The ECIC control room is a high-technology environment equipped with both state-of-the-art communication systems and traditional low-tech artifacts.

The primary and secondary workstations are fully equipped with a desktop computer and two monitors, a radio communication system, a landline phone, and a panel for controlling wall-mounted displays (Figure 1, right). A back-up landline phone (or the "red phone," in the event that the current phone system goes down) is also available, along with a back-up computer monitor, which is used for both entertainment (e.g., web browsing) and work-related activities. Each TC has a notepad and pencil handy to scribble notes while receiving phone and radio calls. TCs working at the middle station have the same equipment setup, except for the radio communication system, which prevents them from answering any radio calls. Across the middle workstation is a smaller, backup desk with a desktop computer and phone (Figure 1, left). This desk is sometimes used by the flight crews for updating paperwork.

Four large, wall-mounted displays are facing the primary, secondary and middle workstations (Figure 1, left). These wall displays provide live video feeds from the cameras installed at the helipad, entrance to the ED and ground dispatch area, main resuscitation room, and hallway toward the ED entrance. A view of the regional map with weather information overlaid on top is available as well. Each TC can easily zoom into any of the scene views or switch between multiple views using a control panel. Feeds from several cameras can also be tiled into a single monitor view.

On the opposite wall, there is a large glass window, which allows TCs to visually check ongoing activities in the helipad-ready area where flight crews assemble and prepare for departures (Figure 1, left). A pinboard with work announcements, schedules, and protocol guides is placed on the left side of the window. On the right side are a whiteboard showing on-call personnel information for massive event coordination, and ECIC team weekly schedule. Next to the whiteboard, covering the right door, is a wall chart showing the algorithm for configuring transport teams. A regional map covers the other door.

To accomplish their work, TCs use three computer systems: FirstNet, Star Navigation, and Golden Hour Dispatch System. FirstNet, an emergency information system for managing patients admitted to the emergency department, is used by TCs for initial charting of the incoming patients. This system has a spreadsheet-like layout, with each row representing a patient, and columns showing different patient parameters. This same system and view are also available to physicians and charge nurses in the ED to track the admitted patients. As each TC takes calls from sending facilities or patient transport crews, they record the initial patient information into the FirstNet, including the patient's age, gender, chief complaint, sending facility, and call-back number. They can also enter additional information using free-text fields. Next is Star Navigator, a hospital-wide system for registering patients. TCs will first search for the patient in this system using information they have gathered through the radio or phone call (in case the patient has already been in the hospital). If they are admitting an existing patient, they will re-activate their record and add new information. If the patient is new, they will register the patient and start their record from scratch. If the hospital physician agrees to admit the patient, TCs will move onto the next step—arrange for the patient transfer using the Golden Hour Dispatch System. This system allows TCs to summon transport team members, dispatch a transport team, track all messages sent from the ECIC control room, monitor the availability and movement of medic units, monitor ongoing calls, summon emergency medical and trauma teams to the ED using pager notifications, and document the call- and patient-related information. Patient data are manually copied from the FirstNet to Golden Hour because the two systems are not integrated and do not share information.

4 METHODS

We conducted an observational study in the Emergency Communication and Information Center (ECIC) of a large pediatric teaching hospital to understand how workers self-organize in a collocated, dynamic, and high-stakes work environment.

4.1 Participants

Our participants included ten Transport Coordination Specialists (TCs), with years of experience ranging from three to 22 years, and the ECIC manager. Prior to joining the ECIC team, most TCs worked as firefighters, ambulance drivers, 9-1-1 dispatchers, or paramedics. All TCs had Emergency Medical Technician-Basic (EMT-B) training completed. Three TCs came in with additional skills acquired as part of their previous occupations, such as comprehensive EMT and special medical training. While the levels of training and years of experience varied across the participants, all possessed basic medical knowledge and were experienced in high-risk, time-critical patient care.

4.2 Data Collection

We spent two weeks observing the work of TCs in the ECIC control room, for a total of 86 hours of fieldwork. The first week-long field visit occurred in December 2014 and the second in February 2015. By the time the first round of observations took place, the first author accrued four years of experience in conducting field studies in the emergency medical settings, while the second author had spent more than ten years studying this domain. This prior exposure to time- and safety-critical teamwork and the knowledge we gained through it allowed us to (1) quickly build rapport with our participants, (2) easily follow their work practices and communications within and outside the ECIC, and (3) better understand the collected data. In addition, at the end of each week of observations, we performed member-checking with TCs to ensure the validity of our findings. The study was approved by the hospital's Institutional Review Board (IRB). Data were collected using observations and interviews.

4.2.1 In-Situ Observations. On average, we spent eight hours a day in the ECIC center, with observations ranging from four to 20 hours. Each week, we also observed one entire day shift (7am-7pm) and one entire night shift (7pm-7am), as well as shift handovers. The observer mostly sat at the supplemental desk along the wall in the middle of the room, which allowed for an overview of the entire control room and all three workstations (Figure 1). Observations of TCs work practices, therefore, took place in the natural environment and within the context of actual work. Observations focused on different aspects of the environment and work, including the room layout, placement of artifacts, types of activities, procedural steps during call taking and transport arrangement, types of information gathered during calls, and interactions between TCs. We collected a variety of materials: field and interview notes; transcripts of 48 calls, four ground team dispatches, and 11 flight arrangements; transcripts of conversations between TCs; transcripts of pager notifications sent out to summon trauma teams; and, photos of the artifacts and room. After each observation session, field notes were transferred to an electronic observation log that included detailed descriptions and reflections on what was observed, generating more than 90 pages of notes and conversation transcripts. Patient information and any other data that would allow linkage to patient transport cases were removed from notes and transcripts. The second researcher had access to the electronic log and used it to review field notes each day and discuss them with the observer. Based on this preliminary data review, we concluded that data saturation was reached at the end of the second week of observations.

4.2.2 Semi-Structured and Contextual Interviews. Our goal was to interview all 12 TCs during the observation periods. Due to the scheduling conflicts, however, we could not interview four TCs, two of which were part-time. We therefore conducted both formal and informal interviews with a total of eight TCs and one ECIC manager. We first conducted formal, 15 to 45 minutes long semi-structured interviews to learn about TC work practices and job responsibilities, their background and experience, and any concerns about their work. Most interviews occurred in early morning, when the call volume was lower. Starting the fieldwork early also allowed us to observe shift handovers, meet incoming TCs that were new to us, and familiarize them with our study goals and data collection techniques [18]. In addition to formal interviews, we conducted multiple, brief contextual interviews to gather additional data about the observed patient cases, TCs' conversations with callers, and tools and technologies they used. These interviews were conducted opportunistically, but only after TCs completed their work to avoid disruptions. We also asked three TCs to walk us through the computer systems they use for work—FirstNet, Star Navigation and Golden Hour—and describe how they document call-related information. All interviews were audio recorded and transcribed into the electronic observation log.

4.3 Data Analysis

We used an open coding technique to identify themes and patterns related to TCs' work coordination and articulation. We first performed a detailed review of the observation log containing field notes and transcripts to gain an overview of the findings and context. In the subsequent stage, we transferred the data into Atlas.ti, a program for organizing, storing, and manipulating qualitative data. Our analysis focused on work practices, communication behaviors, interactions between TCs, and technology use. Major themes describing how TCs self-organize, i.e., coordinate with each other to accomplish the tasks emerged after the second round of coding. This step was followed by identifying representative quotes and vignettes to support the claims. We also performed content analysis of the photographs taken during fieldwork. This analysis provided additional contextual information. For example, the photograph of the algorithm for configuring transport teams helped us better understand our notes about this task.

We next describe our first set of findings—the call-taking workflow and associated procedures—that emerged based on our analysis of observed calls, and ground and flight team dispatches. This description will help contextualize our subsequent findings about the coordination mechanisms and work articulation in the ECIC control room.

5 ECIC CALL-TAKING WORKFLOW

Each patient transport case starts with a call. We observed three types of calls: (1) Emergency Medical Services (EMS) calls, (2) referral calls, and (3) follow-up calls. EMS calls come from the EMS crews in the field via radio or landline phone. Their purpose is to announce the arrival of a critically injured patient and to relay known information about the patient's injuries. EMS calls take priority over all other calls. Referral calls are made by physicians and care providers in other hospitals, primary care offices, or care institutions to refer a patient (e.g., a school nurse could call to report that a child has been fevering all day and needs an ED visit). Follow-up calls occur after either EMS or referral calls to relay additional information and provide updates about the patient's status. Because the middle workstation lacks the radio channel, EMS calls can only be answered by TCs sitting at the primary and secondary workstations. All TCs can take referral calls. EMS and follow-up calls are relatively short, whereas referral calls take about 5 minutes, on average, depending on the case complexity. Because their work environment is high-stakes and unpredictable, TCs are prepared to address a range of calls. A TC described:

> "We are always, 24/7, ideally at least two of us, listening to all 14 of these radio frequencies, and at any moment, we could be awarded the next Sandy Hook, or the next Metro train crash. Every time the phone rings, it could be one of those. More often, it is a stable kid with respiratory illness coming in by a car. From one minute to the next, we don't know what it is going to be like." [TC1]

Call taking procedures and subsequent actions depend on the call type. For EMS calls, TCs would first inquire if the EMS crews need a physician or destination decision. ED physicians are added to the call if EMS crews need to consult about the patient or pre-hospital procedures. Destination questions are discussed if the patient needs to go to another hospital. TCs would then write down on their notepads initial information about the caller, patient status, estimated time of arrival (ETA), and any other relevant information. After completing the call, TCs would notify the ED about the incoming patient. As they are relaying patient information to the ED physician or charge nurse, they would also start entering it into the FirstNet and Golden Hour systems, as well as composing pager notifications to summon the trauma team.

For referral calls, TCs would follow a similar procedure—they would start by taking patient information (e.g., name, weight, chief complaint) and documenting it directly into the FirstNet system, followed by connecting the caller to the ED for a consult. If the hospital agrees to admit the patient, TCs would then proceed to arrange the patient transfer using either the hospital's transport crews or third party providers. To save time, TCs listen in during the caller-physician consults for transport decisions and then start making transport arrangements, filling in the forms and notifying transport team members. A paper sheet listing contact information and availability for all transport team members is printed each day to facilitate transport arrangements. The hospital has five ground medic teams (numbered Medic 1 through Medic 5) and one flight medic team available for patient transport. In the event all medic teams are busy transporting patients, TCs can contact a third-party ambulance or helicopter vendor. To select the appropriate transport team, TCs use an algorithm that configures the team based on patient acuity. Transport teams range from the least critical, Delta team (with only one EMT on board) to most critical, Alpha team (with a medical doctor, nurse, EMT and respiratory therapist on board). While all TCs have sufficient medical knowledge to select the appropriate transport team, they still rely on physicians' input in determining the best way to transport the patient. During transport, TCs will keep an eye on each team and monitor their movement, occasionally receiving calls from the units with their status updates.

The call-taking workflow, including the patient transport arrangement, requires work articulation and coordination among TCs, as well as between TCs and other teams and workers involved in patient care. In the next section, we describe the observed coordination mechanisms at different steps during the call-taking process.

6 WORK COORDINATION & ARTICULATION IN THE ECIC

We identified four steps during the call-taking process that required coordination and articulation work. These included (1) call answering, (2) documenting call information, (3) decision making during calls, and (4) configuring and dispatching transport teams. The coordination mechanisms ranged from material (e.g., schedules, telephone, and computer systems) to immaterial (e.g., letting the initial call taker follow through the call thread from start to end, surreptitious overhearing of call discussions, or verbal announcements about actions). We next describe how these mechanisms were used and their relationship during the call-taking process.

6.1 Call Answering

Typically, call answering tasks in the emergency medical dispatch centers are distributed between different roles [8]. This type of work arrangement reduces the amount of articulation work and facilitates collaboration [52]. For example, call operators take calls from outside callers (e.g., witnesses, first responders), radio operators maintain radio contact with ambulance crews in the field, and telephone dispatchers communicate with ambulance crews that are yet to be dispatched, or with other facilities, like police or fire service control centers. Given the absence of role differentiation in our setting, call answering occurs on the "first comes first" basis. For example, we frequently observed more than one TC simultaneously reaching for or picking up the phone, or responding to a radio call. Because only one TC could get connected to the caller, others who answered at the same time would hang up and let the first TC continue with the call. This simultaneous call answering was further complicated by TCs' current positioning (Figure 1), which affects their ability to tacitly monitor each other's work—a widely used mechanism for coordinating tasks and maintaining awareness in dynamic teamwork settings [23]. This inability to leverage coordination mechanisms used in other coordination centers, like tacit monitoring or labor division along roles, led to using a set of mechanisms to coordinate call answering.

For example, once the "call owner" emerged, TCs did their best to follow an implicit mechanism to coordinate the remaining work related to that call. That is, a TC who owned the call continued answering all calls from that same sending facility or sender, assuming that those were follow-up calls related to the same patient. TCs are able to organize in this way by checking the caller name and phone number being displayed when their phones ring. As one of the TCs explained, whoever takes the call first should follow this call through (i.e., own this activity thread) from start to end because he or she already has the knowledge of the case:

> "First comes first. If he [TC10] is doing Hospital X, he is the person who took all the information. So every time I see Hospital X pop-up on my call ID, and if he [TC10] is not on the phone, I will check if he wants to grab it first because he knows the patient and what's going on." [TC3]

Despite this implicit agreement about maintaining call-taking consistency, we still observed follow-up calls being answered by a different TC. Several reasons may explain why this occurs. First, TCs may be in charge of more than one call at the same time, which may prevent them from following-up on their original call. Second, the large call volume makes it difficult for TCs to maintain awareness of who is responsible for which call, especially if calls are coming from the same caller (e.g., ED). Finally, original call takers may be out of the room (e.g., taking a break). As far as we could observe, the only explicit mechanism for maintaining call-taking consistency was to verbally announce, "I got this" when TCs saw a call from the caller they previously talked to. When a different TC answered the follow-up call, he or she did not have sufficient background information to address additional concerns or requests made by the caller. To work around this challenge, TCs asked others in the room for the information, or they put the phone on speaker so that others could hear and answer the questions. As we describe next, more than one TC working on the same patient case also required explicit negotiation about the use of computer systems for documenting information.

6.2 Documenting Call Information

To document information about an incoming patient, TCs mostly relied on the FirstNet computer system. When multiple TCs responded to calls about the same patient, they all contributed to the patient record by documenting information obtained during the calls. Although all TCs shared the same access and view of the FirstNet system, they still needed explicit negotiation of activities to accomplish their work [52]. For example, the system design restricts the number of users who can simultaneously edit the record to only one user. Although welcoming, this safety feature required TCs to engage in the articulation work to coordinate their documenting activities. Because TCs could see in the system who was "locking" (editing) the patient record, they coordinated their updates by asking each other to either close or exit the record. This explicit negotiation was most visible when different TCs answered the calls about the same case, as shown below:

> An EMS call came in to announce the arrival of a critically injured patient. TC3 took this radio call and recorded all the information into the system. Shortly after, the same ambulance unit called twice with updates. Both TC3 and TC5 answered these follow-up calls. When TC5 attempted to add the newly obtained information to the patient record, she could not open it. She then asked TC3 to exit the patient record so she can update it.

6.3 Decision Making during Calls

When EMS calls arrived through the radio channel, other TCs could overhear conversations between the TC taking the call, the EMS crew and the ED physician. This ability to listen in to EMS calls helped TCs maintain awareness of not only what was going on around them, but also which ED physician was available for consults. If a new referral call came during an EMS call requesting a consult with the same ED physician, the TC answering the referral call would put the caller on hold, wait for the EMS call to end, and then connect the caller to the ED.

Overhearing other calls also served as an opportunity for TCs to collaborate and make joint decisions. Here, we observed how more experienced TCs sometimes used this opportunity to guide less experienced TCs, or even take over the call. Although all TCs occupy equivalent positions, this observation suggests that there may be an informal hierarchy characterizing the work of the ECIC team. Compared to formal (or authority) hierarchy, informal hierarchy refers to an organic, non-bureaucratic, informal structure among team members who occupy equivalent positions in the formal hierarchy, with an informal leader who emerges and sets up a team dynamic [24]. Prior work has argued that this structure is a more effective way of organizing, especially in dynamic environments, because it allows workers to better coordinate based on the changing demands of the task [11]. The following vignette illustrates a case that revealed the presence of informal hierarchy in the ECIC team:

> TC4 (3 years of experience) answered an EMS radio call. The EMS crew greeted the TC and stated: "This is [unit number], I want to consult with you guys about destination decision. I have two kids, a 13-year old and a 15-year old, both with gunshot wounds." Immediately after hearing the number 15, TC1 (7 years of experience) told TC4 without turning his head: "We can take the 13-year old, but the 15-year old should go to the adult medical facility." TC4 waited until the EMS crew completed the report and responded: "Copy. We can take the 13-year old, but the 15-year old should go to the adult trauma center." As TC4 continued gathering other information from EMS, TC1 called the ED and started talking to the charge nurse. After completing the EMS call, TC4 asked TC1: "Are you talking to the ED?" TC1 nodded and said, "I got this."

In this vignette, TC1, who is more experienced, overheard the conversation between the less experienced colleague (TC4) and the EMS crew, and emerged as an informal leader, making decisions about the patient destination and calling the ED to relay the information. Normally, the TC who takes the EMS call is responsible for relaying the obtained information to the ED. Here, however, we observed a takeover by a more experienced worker. According to TC4, these situations are rare:

> "[TC1] just wanted to give ED a quick heads-up. In here, we are trying to help each other. But this kind of help does not happen very often, because you know, this makes people feel uncomfortable [...] You want to relay the information that you get from the EMS crews, not let other people do this job for you."

Although this particular takeover episode created some tension, we observed how other TCs considered TC1 an informal leader because of his experience and seniority. Comments from other TCs during interviews, such as "[TC1] is extremely brilliant and knows everything," confirmed these observations. The ECIC manager also highlighted the importance of experience and how influential it can be in the control room:

> "Years of experience and confidence factor into their work performance. More experienced workers are likely leading the shift. And we would like to see a more experienced worker sitting with a less experienced worker."

Even when TC1 was not on call, newer, less experienced TCs would turn to other, more experienced TCs in the room for help or advice when dealing with unknowns. In one episode, for example, TC6, who is part-time, was documenting information about an EMS call into the Golden Hour system. TC6 turned to TC2, who is full-time with five years of experience, and inquired about the difference between "paramedics" and "ambulance." TC2 explained that the difference lies in the ways in which the ambulance is staffed. These examples show how, in the absence of formal hierarchy and role differentiation, TCs used this experience-based, informal hierarchy as an implicit mechanism to organize their work; it was not only helping their efficiency but also ensuring they all had the information they needed in a timely manner.

6.4 Configuring and Dispatching Transport Teams

Although ECIC team members possess basic medical knowledge, they rarely made medical decisions; their decisions were purely operational. For example, when recommending the means of transport (ground or air), they would factor in the distance between the sending facility and the hospital, weather conditions, and road and traffic conditions. For decisions on team configuration, TCs would primarily rely on medical experts on the call. For instance, if the patient with a breathing problem requires an urgent endotracheal intubation during transport, ED physician would ask that a respiratory therapist be added to the transport team. A TC explained:

> "Sometimes the physician may not have all of the information, they are thinking medically, and may not be aware of, say, the distance to go. Today we have snow, so you got to take that into consideration. Getting there may get delayed even though you have lights and sirens. We have things to say that they may not be thinking about, so they respect us. All of us have to be at least at the EMT level. And we have to have practical experience in the field so we can bring some expertise to the table." [TC6]

To coordinate their work while arranging both flight and ground transportation teams, TCs relied on several artifacts. First, they used a set of paper artifacts, such as the sheet listing transport medicine team members who were on call for the day or the chart showing the algorithm for configuring transport teams. These simple artifacts increased TCs' work efficiency by eliminating the need for repeated questions about who is on call or who should be summoned for the next transport team. These artifacts also showed the extent to which TCs' work was already prescribed based on established rules. A TC commented:

> "We are not a decision-making component of the system. We are collecting information from physicians and then looking at our staffing situation, other calls pending, the time of the day, the urgency of the call. But all these factors plug into standard operation procedures, a set of written algorithms that specify solutions for us." [TC1]

Second, TCs relied on the Golden Hour system to not only document patient transfers, but to also track medic crews' availability and movement. Similar to the FirstNet system, the Golden Hour system offers shared access and view to all TCs. The system allows TCs to see which medic team is in the field and which team is still available. This information, however, was not up to date at all times. For example, when TCs started arranging a medic team, the status of that team remained "available," despite the fact that it would be dispatched shortly. To work around this issue and help maintain team awareness, TCs kept announcing out loud the medic teams they were going to deploy. Finally, wall-mounted displays showing live video feeds of the helipad and ground dispatch areas served as another set of artifacts for coordinating dispatch efforts. Even though these monitors provided at-a-glance information about available ground units for dispatching, TCs still resorted to verbal announcements of their plans.

While much of the work around configuring and dispatching ground teams appears prescribed, configuring and dispatching the flight medic team poses more challenges, as there are more unpredictable factors that may affect decisions. The following vignette illustrates some of the complexities involved in configuring a flight crew:

> Right after the ED physician decided to transfer the patient by air, TC6 started summoning the flight crew. As the crewmembers assembled in the helipad ready area, a few problems emerged. First, because the patient was in a critical condition, the ED physician asked TC6 to get a respiratory therapist on board to perform intubation. TC6

> invited the flight nurse into the control room for consultation. The flight nurse commented that adding respiratory did not leave any room for the patient's parent, which was a problem. After insisting on a respiratory therapist for another few minutes, the physician left the call to attend to ED patients. Soon after, the pilot entered the control room, announcing that he was about to end his shift because he reached the maximum hours he was allowed to fly. TC6 inquired about the new pilot, who was on his way, but needed at least 10 more minutes. Considering the case complexity, the flight nurse called back the ED physician and also added the air ambulance services team manager to the call. They first discussed the necessity of having a respiratory on board. The physician repeated his request, but the flight nurse convinced him that the paramedic on board had sufficient training to perform intubation. The flight crew was then downgraded from Bravo to Charlie. They next considered whether to contact the third-party helicopter vendor. TC6 commented that by the time the third-party helicopter arrived, the new pilot would also have arrived, so they decided to wait for the new pilot. The second TC (TC2) did not participate in these discussions. She was focused on taking other calls so that TC6 could fully participate in this flight arrangement. When TC2 received a phone call pertinent to this flight, she relayed the information to TC6. For example, a call from the air ambulance services came in to provide an update about the incoming pilot.

In this vignette, we could see how complex scenarios require the involvement of other teams and workers, and not just TCs. Several specialists from different disciplines worked together to reach an optimal solution, each bringing different expertise and sets of skills. The physician approached the problem from a medical perspective, preferring a respiratory therapist to paramedic; the flight nurse was more concerned about the presence of the patient's parent; and, the TC provided input about the third-party helicopter vendor. Even though the process required inter-team coordination and involvement of other actors, we also saw how the two TCs tacitly agreed on how best to coordinate their work so it supports decision making without hindering it: TC2 took over call-answering and documentation tasks, while TC6 focused on the flight arrangement. In other words, the two TCs tacitly coordinated their work without explicit communication or negotiation.

In addition to arranging and dispatching transport teams, TCs are also responsible for monitoring the departure and landing of the helicopter. This activity involves a series of tasks performed right before the flight takes off or lands, such as calling security and closing the vents. A security staff member is called to monitor takeoffs and landings so they can activate the fire distinguisher and alert the hospital in case of an emergency. TCs usually call the security to come up to the helipad about five minutes before the helicopter takes off or lands. TCs also need to close the vents at this time so that exhausts and fumes from the aircraft do not enter the hospital. These takeoff and landing tasks are the responsibility of the TC who arranges the flight. We observed, however, that TCs sometimes divided these tasks between them. For example, when the TC who arranged the flight got busy with other calls, he or she explicitly asked the other TC to help. We also observed several cases when both TCs realized the helicopter was about to land and preparation tasks were not performed; they got occupied with call taking, losing the sense of time and awareness of the flight status. To make up for the lost time in these situations, they would divide the work, sometimes even without any verbal communication, with one TC calling the security and the other closing the vents.

7 DISCUSSION

Our study showed that emergency communication specialists in the ECIC center self-organized to coordinate work and balance the workload. This arrangement is in contrast to many other work domains that have been the subject of CSCW inquiry, where work is divided either along the roles [16,23,25,35] or along the tasks [6]. For example, work division among air traffic controllers is accomplished by partitioning the airspace into equal size sectors—as an aircraft moves from one sector to another, the responsibility for controlling the aircraft also moves from one controller to another [6]. The work of TCs, however, revolves around call taking, with each call being sub-divided into smaller tasks, like relaying information to other hospital units, and arranging and dispatching transport teams. As such, TCs work cannot be easily partitioned because call types and the amount of work associated with each type are unequally distributed. Similarly, the absence of role differentiation means that TCs cannot split or organize their work along roles. To coordinate, TCs used a set of mechanisms that ranged from material (e.g., paper printout of team members who are on call, charts showing the algorithms for configuring transport teams, and computer systems) to immaterial (e.g., letting the initial call-taker follow through the call thread from start to end, surreptitious overhearing of call discussions, or verbal announcements about actions). We next discuss the three features of self-organized, collocated and time-critical teamwork that emerged from our analysis of how these coordination mechanisms were used, and then re-examine the challenges in developing technology for supporting this type of teamwork.

7.1 Features of Self-Organized, Collocated and Time-Critical Teamwork

An important characteristic of the ECIC team is that all team members have the same type of training and share the same work title and responsibilities. This team structure has allowed for a single worker to manage the entire call-answering process, from taking the call, to documenting and relaying information, to arranging the patient transport. Our study, however, showed how specific tasks that may seem to be an individual's work are in practice accomplished through collaboration among the workers. The use of different material coordination mechanisms, such as on-call schedules and algorithms for configuring transport teams, allowed TCs to tacitly coordinate patient care and transport. For instance, when the telephone rang, TCs used the basic phone features such as displayed caller IDs and phone numbers to verbally coordinate who should take the call, thus maintaining call-taking consistency and allowing the initial call-taker to follow through the call thread from start to end. We saw here how the material and immaterial coordination mechanisms interacted, whereby the collaborative features of material mechanisms helped the construction of immaterial mechanisms and facilitated work.

We also observed TCs using different immaterial mechanisms to "lessen the amount of articulation work needed to achieve an alignment" of their actions [4]. TCs took advantage of working side-by-side to overhear each other's call discussions, which in turn triggered their own actions. As we saw above, one TC tacitly agreed to take over call answering while the other TC was busy with arranging for the patient transport. Overhearing and tacit agreements are common mechanisms for maintaining awareness in many other collocated and time-critical settings (e.g., [6,23,26]). What differed in the ECIC case is that TCs' current positioning (Figure 1) as a product of flat hierarchy (i.e., TCs could take any of the workstations) affected their ability to tacitly monitor each other's work, posing several challenges along the way. For instance, because they could not see actions and intensions of each other when answering phone calls, they had to rely on verbal communication by explicitly stating "I got this" to coordinate call-answering.

Like many other work domains, emergency communication centers have a tendency to address the workflow challenges by implementing new technologies to integrate tasks, functions and existing systems [62]. Given the interdependencies between material and immaterial coordination mechanisms, it is important to ensure that the prominent, sometimes invisible, collaborative features embedded in the current artifacts and practices are also supported with new technologies. Our findings revealed three such features of ECIC teamwork: (1) awareness of task ownership, (2) task self-assignment, and (3) informal team hierarchy.

7.1.1 Awareness of Task Ownership. Shared responsibilities and tasks, like answering calls, relaying information, and arranging patient transportation, allow the workers to assist each other, and even take over each other's work, if necessary. However, they also create challenges in maintaining awareness of task ownership. We saw, for example, how TCs in the ECIC control room simultaneously reached for the phone to answer calls, creating confusion about who owned the call. Also, a lack of procedures and policies about who does what sometimes led to tasks becoming "no-ones-tasks" [48], further blurring the boundaries of task ownership. To circumvent those problems, TCs used several immaterial coordination mechanisms to ensure that the same worker completed an action they initiated. Despite using different mechanisms to maintain awareness of task ownership, challenges in teamwork persist, including competition among workers and blurred task sharing.

One common approach to supporting situation awareness among collocated, high-reliability teams is the use of large wall displays (e.g., [32,47]). Awareness displays have been also shown to support the work of distributed teams through communicating current activities, the status of those activities, and the workload of the remote team (e.g., [10,14,28,57]). Designing awareness displays for teams such as ECIC, however, poses several unique challenges. One design challenge, for example, is automating the collection and presentation of task ownership information. While other similar systems integrate data across artifacts, providing one dedicated user interface for all workers to claim and manage task ownership (e.g., [12,15,28]), the use of artifacts in the ECIC setting is highly decentralized (e.g., telephone, pen and paper, FirstNet system, and GoldenHour system). It is therefore challenging for the display system to detect, infer and visualize activity threads for different workers. A related challenge is directing the subsequent tasks of the same activity to the initial owner when tasks can be accomplished over several stages. Other domains have addressed this challenge by using contextual information obtained through sensors and devices to automatically assign tasks and support effective task management [37]. This context-aware task-routing feature, however, heavily relies on distinguishing between workers' roles, which is not available in teamwork that lacks role differentiation. Finally, while the existing awareness systems have greatly improved collaboration in both collocated and distributed work settings, new coordination challenges may emerge as we start assessing the effects of displaying task information on ECIC teamwork. We may, for example, discover that indicating task ownership and responsibilities makes TCs less willing to assist each other, an issue that TCs already faced in their prior, role-based arrangement, when work was divided based on call types.

7.1.2 Task Self-Assignment. In the ECIC case, we observed that TCs sometimes took over each other's tasks and engaged in the activity of their co-workers to coordinate work. We saw this explicit take-over when a team member had a hard time managing his or her workload and the others tried to help. For example, when one TC was busy with configuring and dispatching a transport team on a complex case, the other TC tacitly took over call answering. We refer to this feature as "task self-assignment" because it shows how team members select tasks they are willing to take on and are able to successfully complete.

Prior work has also identified task self-assignment as a useful feature of self-organized teamwork, especially in large peer-production systems and citizen science projects [13,17,30,45,56]. These studies highlighted several factors that motivate task self-assignment, including worker's specialization and expertise, personal interest, and accessibility of resources. For example, Kalliamvakou et al. [30] found that knowledge of one's expertise allows workers to self-organize by selecting tasks that fit their specializations while ensuring optimal task division. In a study of open source software development, Crowston et al. [13] found that active developers stepped forward to work on tasks that caught their interest rather than waiting to be assigned tasks. The accessibility of resources played an important factor in self-organizing virtual volunteers during a crisis situation through the use of Twitter and its features like hashtags [56]. Volunteers took charge of particular tasks based on the resources available to them; some volunteers translated data entries to verify information, while others acted as remote emergency operators because they had connections with the government authorities and contacts on the ground. Unlike environments described in this prior work, where actions can span several days or months (e.g., software development, disaster response, citizen science), the emergency medical communication is a dynamic and time-critical process, demanding rapid team response. Due to these constraints, TCs took tasks not because of their expertise, personal interest, or accessibility to resources, but because of the need to ensure task completions in a timely manner. The challenge in designing efficient task assignment features for fast-response teams that lack clear role differentiation is then not in motivating the workers, or aligning task features with their interests, but in enabling the workers to be aware of the immediate need for assistance so they can take over tasks that require completion. A related design challenge is the rapid filtering of rich task information (e.g., task priorities, pending tasks) into a format that can be quickly absorbed [14]. Even simple, low-tech changes, such as seating or positioning, may help facilitate the use of immaterial mechanisms like overhearing, and accompany a display system.

7.1.3 Informal Team Hierarchy. The ECIC team exhibited informal and flat team hierarchy, which helped team members self-organize and coordinate the work. As we observed, more experienced TCs would take over portions of a task performed and "owned" by less experienced TCs. This occurrence of informal team hierarchy was caused to some extent by differences in team members' years of experience, levels of seniority, and sense of empowerment. That is, a more experienced team member was more likely to emerge as an informal leader. While the feature of informal team hierarchy reinforces on-the-job training for less experienced team members and facilitates faster completion of different task stages between more experienced and less experienced co-workers [11], it can also lead to task takeovers and contention, creating new and different challenges in teamwork. These challenges, however, may be difficult to address using computerized solutions because teams like ECIC usually have developed norms and conventions [9] over time that have defined their social fabric. Any technology that alters these norms may get in the way and be ignored. Rather, computerized systems could be used to augment this feature of informal team hierarchy. The awareness display, for example, could assist the informal team leader in overseeing the activities and pending tasks. More importantly, the display could promote efficient communication, on-the-job training, and collective decision making by serving as a "common material artifact" [9,64], thereby allowing experienced and novice workers to discuss on-going activities and make joint decisions on risky tasks.

8 CONCLUSION AND FUTURE WORK

We examined work coordination and articulation in an emergency communication center, in which a team of communication specialists engages in complex activities of coordinating patient care and transport. Unlike teams with clearly defined work roles and team structures, the ECIC team lacks role specialization. Even so, we found that communication specialists self-organized by using a range of material and immaterial mechanisms to coordinate their work. Based on our findings, we identified three features of self-organized, collocated and time-critical teamwork that require technology support: awareness of task ownership, task self-assignment, and informal team hierarchy. Although these features present opportunities for technological innovation, we recognize that supporting this type of teamwork presents many challenges, such as competition among workers, blurred task sharing, and task takeovers. To address these challenges and to further support self-organized workload balancing, systems should allow team members to rapidly indicate who owns the task or activity thread, which resources are in the process of being allocated, and what tasks were completed, in process, or pending.

Our study has two limitations. First, while our knowledge of the transition from a role-based to role-free work division in the ECIC helped motivate this work, we could not account for these prior relationships and roles because we did not directly observe TCs work at the time. Even so, not observing this prior, role-based arrangement did not affect the richness of our findings because our goal in this study was to identify coordination mechanisms for self-organized work, rather than compare the effectiveness of role-free arrangement with the old, role-based arrangement, or examine the transition between the two arrangements. Our description of the old work arrangement of the ECIC team was solely to provide historic context for our study. In addition, the identical on-the-job training that all TCs undergo and the same set of artifacts that all TCs use have helped minimize the effects of the prior role-based work arrangement on their current work; the workload of answering referral and emergency calls is now equally distributed among TCs. Second, because this study was performed at a single site, the results may not be generalizable to other emergency communication centers. However, the call-answering activity and dispatching of transport teams, as well as the technologies and artifacts used are common across many call centers in the US, making the results about the coordination mechanisms generalizable to other emergency communication centers. Our future research in this area will move in two directions. First, we are extending this work to additional emergency communication and information centers, one of which is a stand-alone site, to assess if our results generalize across different site types. Second, we plan to explore the means by which we can integrate data from current artifacts and systems to automate information gathering, synthesis and presentation.

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