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# Making sense: Sensor-based investigation of clinician activities in complex critical care environments

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ABSTRACT

In many respects, the critical care workplace resembles a paradigmatic complex system: on account of the dynamic and interactive nature of collaborative clinical work, these settings are characterized by non-linear, inter-dependent and emergent activities. Developing a comprehensive understanding of the work activities in critical care settings enables the development of streamlined work practices, better clinician workflow and most importantly, helps in the avoidance of and recovery from potential errors. Sensor-based technology provides a flexible and viable way to complement human observations by providing a mechanism to capture the nuances of certain activities with greater precision and timing. In this paper, we use sensor-based technology to capture the movement and interactions of clinicians in the Trauma Center of an Emergency Department (ED). Remarkable consistency was found between sensor data and human observations in terms of clinician locations and interactions. With this validation and greater precision with sensors, ED environment was characterized in terms of (a) the degree of randomness or entropy in the environment, (b) the movement patterns of clinicians, (c) interactions with other clinicians and finally, (d) patterns of collaborative organization with team aggregation and dispersion. Based on our results, we propose three opportunities for the use of sensor technologies in critical care settings: as a mechanism for real-time monitoring and analysis for ED activities, education and training of clinicians, and perhaps most importantly, investigating the root-causes, origins and progression of errors in the ED. Lessons learned and the challenges encountered in designing and implementing the sensor technology sensor data are discussed.



## 1. Introduction

Critical care environments are characterized by distributed, inter-dependent, episodic and non-linear work activities. The dynamic nature of the care process in critical care environment affects the nature and timing of work activities of clinicians, and often increases the possibility of errors. Studying the work activities of clinicians in such environments can help us understand the care delivery process, workflow, and interruptions that affect clinical work. Exploratory investigations of clinician activities are often performed using observational methods. While these methods provide a descriptive depth that cannot be matched by automated methods, use of participant observation methods [1,8,10,13,14,16] in a critical care setting is often challenging, as capturing the work activities of multiple clinicians requires several observers who must be closely synchronized during their data capture sessions. In this paper, we propose the use of multi-sensor technology as an approach to complement human observation in critical care settings, to capture highly detailed and precise information regarding certain work-related activities of clinicians. We believe that such a hybrid approach that combines human observation and sensor-based data capture facilitates a holistic mechanism for understanding and evaluating a complex critical care environment.

Two of the easily discernable clinician activities in the ED are movement of the clinician across various locations and their interactions with other clinicians. The mobility and interactions of the clinicians are an inherent part of the work activities as they go through the patient care process. The complex nature of the work activities in the ED is likely to result in fairly complex mobility and interaction patterns. Studying the nuances of these patterns can provide insights into how the complexity of the environment affects the clinician work activities. Our approach for this study

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was predicated on prior research [24,27,28], where it was found that sensor-based technologies could be used to reliably capture mobility and interaction of clinicians. One of the challenges of studying an environment such as the ED is that the complexity is often caused by several contributing factors. If the randomness in the mobility or interaction patterns among the clinicians in the ED environment is very high, then it is unlikely that there are trends or patterns within such activities. In contrast, if the randomness falls within certain established boundaries, it provides an opportunity to investigate the underlying patterns within such activities. We use entropy to measure of the degree of randomness in the environment. Based on a detailed entropy analysis of the movements of physicians within the ED (considered as a system), we found that there was a high likelihood of underlying patterns in the clinician movement and clinician interactions. We also established the significant correlation between human observation and sensor data, which provides validity for using the sensor data as a measure for capturing clinician activities.

The entropy computation and the strong correlation between observed and sensor data provided a basis for using sensor data for "piecing together" ED work activities. By tracking clinician movement and their interactions with co-workers (i.e., other clinicians), we developed a trace of their workflow along the following dimensions: location, time spent at a location, transitions across different locations in the ED, and finally, their collaboration with other clinicians in the ED. In other words, we created a workflow of the clinician activities that provided significant insights into the work patterns, resource utilization, overheads and potential for the occurrence of errors. We also describe the implications of the use of sensor technology in critical care settings in terms of its use for monitoring and management of resources, as resource for training in virtual environments such as Second Life, and most importantly, as a useful source of highly precise data for investigating the origin, causes and progression of errors in the ED.

## 2. Background

The study of complex systems draws together emerging approaches from several diverse fields including economics, physics, biology, mathematics and computer science on the common ground of complexity. This interdisciplinary effort seeks to formulate unifying principles of complexity. Several authors have proposed that the healthcare system or elements thereof can be characterized as a complex system [3,17–19,21,25]. For example, Smith and Feied [21] argue that an emergency department is a *paradigmatic complex system*. This argument rests on the unpredictability of both patients' clinical conditions and clinicians' work patterns, the vast decision space and incomplete evidence that complicate clinical decision-making and the inherent unpredictability of the system as a whole.

Several concepts drawn from the complex systems literature are pertinent to the study of a critical care unit as a complex cognitive system. A cogent and readable account of the ways in which concepts from the complexity literature might be applied to social systems has been developed by the Complexity in Social Science (COSI) project [9]. Complex systems are by their nature nondeterministic and dynamically structured. That is to say, it is not possible to predict the behavior of a complex system by studying the function of its components in isolation, and furthermore the study of the behavior of any such component reveals little about the system as a whole. Likewise, the process of clinical care emerges from a series of dynamic and flexible interactions between patients, health-care providers and outside influences [4]. While this argument applies readily to workflow, it also relates to the cognitive processes that underlie critical care decision making, as the cognitive processes in critical care settings are distributed across the minds of the clinical team and a range of physical media [7]. Given the complex nature of system behavior, it is not possible to predict the knowledge, expertise and information that will be available at the point in time at which clinical decisions are made. Similarly, for transfer of information, it has been observed that within complex social systems the flow of information is determined somewhat serendipitously by the geographical location of team members [6], which is influenced in turn by the complex dynamics of the system as a whole.

These aspects of the critical care workplace present challenges for the human-intensive ethnographic methods we have employed in our previous research [7,14,16], as these have tended to focus on the shadowing of individual clinicians. However, complex systems theory suggests that only limited insight into system behavior can be obtained through the study of component parts. Consequently, in our recent work we have explored the use of automated sensors through which we aim to complement the human-intensive focused data collection we have employed previously [24]. While not able to capture the depth and richness of representation that are possible through ethnographic methods, these sensors offer certain advantages in that it is possible to collect data concerning a geographically mobile clinical team over an entire shift. This is desirable, as even an exceptionally well-funded research program that may be able to employ multiple well-trained human observers is likely to experience problems integrating a team of observers into a busy clinical environment without obstructing patient care.

In this paper, we present an overview of our work in which we use sensors in a real-world clinical environment to try to characterize the movements of, and interactions and collaboration among members of a clinical team in the ED setting. Data captured from these sensors are interpreted in the light of human-intensive observations of key team members captured contemporaneously. We present a series of analyses of these data, and discuss their significance for the study of complex social systems. In addition, we share some lessons learned with respect to the use of automated sensors in a complex clinical context.

## 3. Methods

In this section we describe the study setting, data capture using the sensors and human observers, data synchronization and analysis. Detailed description of the sensor setup, physician shadowing, and data analysis are also provided.

### *3.1. Study setting*

The study was conducted in a certified Level 1 Trauma Center in the Emergency Department of a large teaching hospital located in the United States. The hospital provides 24/7 emergency and trauma care to approximately 52,000 patients a year. The ED is separated into distinct units caring for pediatric patients, general medicine patients and those requiring trauma care. The physical setup of the trauma side of the ED includes eight trauma patient beds and five urgent care beds. In times of high patient volume, additional chairs and beds are placed in the open spaces as needed. The care team for trauma ED typically includes one attending physician, two resident physicians and two trauma nurses, an urgent care nurse, a charge nurse, one technician, and a respiratory therapist shared by the entire ED. The trauma center is also supported by a dedicated trauma team, consulting physicians and the staff from other units of the ED (including off-service providers) as needed.