TEAM COGNITION IN CONTEXT:
Application of Novel Methods and Metrics To Characterize Team Performance in Pediatric Emergency Simulations

By

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Abstract

Emergency Medical Service (EMS) providers work in teams and their teamwork can affect patient safety and outcomes. Teamwork represents a mixture of collaborative behaviors that have been operationalized in different ways: describing types of communication, subjectively rating behaviors, assessing attitudes, and measuring shared situational awareness. Current methods attempt to distill the quality of teamwork into a single summative value, and consequently provide limited insight into the ongoing process of teamwork. The purpose of this dissertation was to develop a holistic and objective method to analyze the dynamics of EMS teamwork. This was pursued in three aims:

1) Compare communication behaviors
2) Model task processes
3) Describe behaviors associated with variations from process model

EMS teams were recruited to participate in prehospital pediatric trauma simulations. Teams were presented with a child, SimNewB from Laerdal, exhibiting signs of increased intercranial pressure (ICP) caused by head trauma. Teams were expected to initiate airway management, protect cervical spine, monitor vitals, initiate cardiopulmonary resuscitation (CPR), establish intraosseous (IO) or intravenous (IV) access, and transport the patient. Simulations were video recorded and Subject matter experts (SMEs) used the Clinical Teamwork Scale (CTS) to rate team performance *in situ*. Teams were partitioned into high (≥ 8) and low (≤ 4) performing groups based on the overall CTS score, and these groupings were used to evaluate if the applied methods could distinguish performance levels.

The first aim described communication in terms of the communication rate $\left(\frac{\#utterances}{\#minute}\right)$, anticipation ratio $\left(\frac{\#inform\ utterances}{\#request\ information}\right)$, and explicit coordination ratio $\left(\frac{\#announce\ self-directions}{\#directions}\right)$; as well as the use of orienting statements over time. High performing teams were found to have a greater

explicit coordination ratio and leaders that periodically uttered orienting statements throughout the simulation.

The second aim used computational methods, sequence alignment and process mining, to construct process models from logs of patient centric tasks. In terms of methods, sequence alignment provided a more accurate but noisy representation of EMS processes. Task sequences were highly varied across teams, but a few highly conserved tasks suggested that there was an underlying structure of activity. High performing teams initiated airway management early to treat ICP, while low performing teams initiated CPR early in reaction to the low heart rate caused by ICP.

The third aim describes behaviors associated with variations from a model of care. Process sequences from a pair of high and low performing teams were compared to the model process sequence of high performing teams from aim 2. Variations were identified as mismatches and insertions in the candidate sequences. Variations that were not explicitly verbalized, deletions and a set of noisy tasks, were excluded from analysis. Probes investigated who requested and who performed the variations. The high performing team had centralized leadership and hierarchical organization, in which the Person in Charge (PIC) issued directions that were carried out by team members. The low performing team had distributed leadership with independent/federated organization, in which different team members announced and carried out their own directions.

This dissertation develops a method to describe behaviors associated with process variations, which revealed a broader, emergent pattern of the teams' decision-making tendencies. This approach provides a domain-independent method for evaluating team cognition. It also helps connect interactions amongst team members to the resulting consequences and performance outcomes. The implication for EMS care is that specific behaviors can be identified and targeted for improvement. For example, leadership training might be recommended for teams with federated organization. There were limitations. First, the analysis did not analyze behaviors associated with matching tasks. Teams may act similarly or differently under matching contexts. Second, sequence alignment was not designed for team activities in which multiple tasks are performed concurrently, resulting in noisy models. Future directions include applying this method for teams in other activity systems, examining behaviors associated with matching tasks, and designing a new algorithm to align activities in teams over time.

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To friends and family

I am extremely grateful.

Thank you very much.

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Acronyms

Acronym	Definition
ACLS	Advanced Cardiac Life Support
BLS	Basic Life Support
BVM	Bag Valve Mask
CPR	Cardiopulmonary Resuscitation
CTS™	Clinical Teamwork Scale
ITC	Interactive Team Cognition
IO	Interosseous
IV	Intravenous
EKG	Electrocardiogram
EMS	Emergency Medical Service
EMSC	Emergency Medical Services for Children
EMT	Emergency Medical Technician
MSA	Multiple Sequence Alignment
MVC	Motor-vehicle crash
NAT	Non-accidental trauma
NRP	Neonatal resuscitation program
PALS	Pediatric Advanced Life Support
PM	Process Mining
ProM	Process Miner

Definitions

Term	Definition
Cognition	An internal thought process responsible for perception, comprehension, memory, decision-making, and action-execution.
Communication	A verbal or non-verbal exchange of information between two or more people.
Coordination	The act of managing interdependencies between activities performed to achieve a goal.
Team Cognition	The cognitive structures and processes that occur at the team level.
Team	A group of two or more people working towards a common goal.
Teamwork	The activity that occurs between two or more people working towards a common goal.

Chapter 1

Introduction

Paramedics and Emergency Medical Technicians (EMTs) work as a team to treat patients in out-of-hospital situations. The effectiveness of their teamwork has a direct impact on patient safety and can influence outcomes. There are factors at different levels of organization that contribute to the quality of care. Individuals apply their knowledge, skills, and attitudes towards performing a task well. Interactions, such as communication and coordination, choreograph multiple tasks amongst team members. The healthcare community has embraced simulations as a means of practicing and improving the delivery of care. These efforts have largely been focused on improving technical skills, though there is an interest in improving the joint performance of the team.

An important prerequisite for improving a skill is having the capacity to describe and measure it. It is arguably easier to develop objective criteria for technical skills because their execution is directly tied to results; e.g. CPR practice improves compression depth and rhythm, which in turn, normalizes a patient’s pulse and circulation. Behaviors associated with non-technical skills occur based on the perceived needs of a situation. For example, a paramedic may respond to a cardiac arrest by orienting team members and delegating tasks. The quality of non-technical skills is not necessarily determined by their quantity but by how they guide a situation towards accomplishing a goal and the occurrence of a behavior depends on emergent context.

1.1 Problem Statement

The predominant paradigm for studying teamwork has been to use observational-qualitative techniques to identify behaviors associated with effective teams and count or rate their occurrence over time. The quantitative values are then placed in a logistic regression model to measure the effect of various behaviors on performance. The problem with such an approach is that it assumes that the performance of a behavior is equivalent in all situations and such models tend to emphasize quantity over quality. For example, directions may be given but they may not always correspond to a task being performed. Context and time are not typically included to analyze teamwork but may nevertheless provide insight into the impact of related behaviors. The responsive nature of non-technical behaviors calls for a holistic methods of analysis.

1.2 Research Objectives

The objective of this research was to develop a holistic, objective method of analysis that could distinguish between performance levels of EMS teams participating in prehospital pediatric simulations. Teamwork is represented by the interactions that occur between members over time in a given situation. Interactions include acts of communication and coordination while the situation refers to the activities that teams participate in. There is a tendency to analyze these two aspects of teamwork in isolation, but their combined representation could offer insight into certain behaviors affect process and performance.

1.3 Methods

A method was developed in three phases to analyze videos of EMS teams participating in non-accidental trauma (NAT) and motor-vehicle crash (MVC) simulation, as outlined in Figure 1. Teams were expected to treat a baby suffering increased-intracranial pressure due to trauma. The Clinical Teamwork Scale (CTS™), is a behavioral rating instrument that was used to evaluate teamwork and partition teams into high and low performing groups.[1]

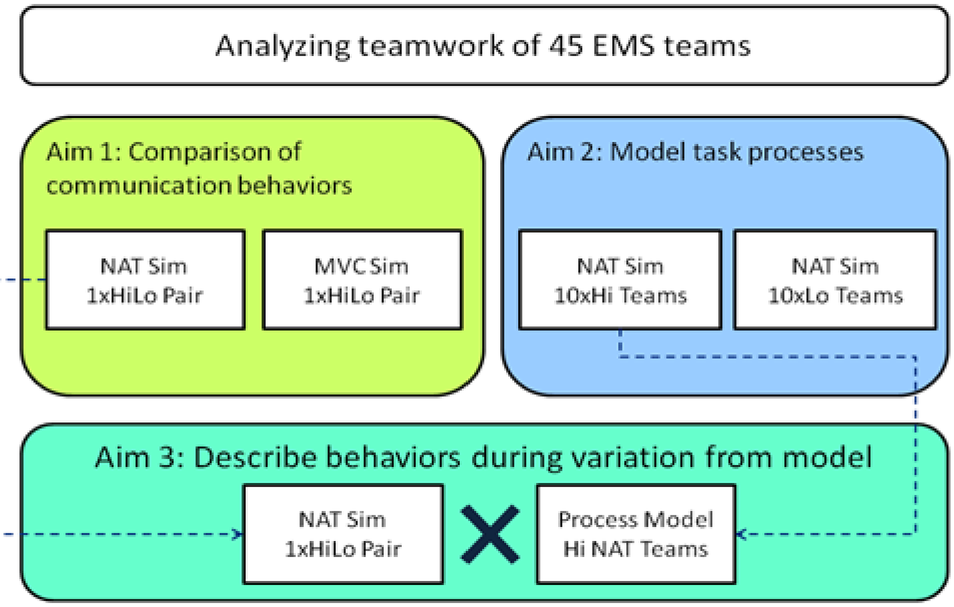


Figure 1: An overview of aims used to develop a holistic, objective method of team analysis.

The first phase of analysis involved describing communication behaviors associated with high and low performance. The behaviors included utterances used to exchange information, coordinate action, and orient team members. This analysis would help identify behaviors that potentially affect performance.

The second phase involved building a model of context. In this case, context is defined as the processes or patient-centric tasks that teams perform to deliver care. In qualitative research, models tend to be constructed manually. This phase explores two automated approaches to model activity: multiple sequence alignment (MSA) and process mining (PM). MSA is a visual-analytical technique that involves lining-up similar elements and inserting gaps or mismatches for dissimilar elements between two or more sequences. The aligned elements represent conserved features that can serve as the basis for a model. PM was developed to extract meaningful information from electronic logs of human activity. PM discovers models by constructing graphical models based on the inferred relations between pairs of consecutive tasks. For example, if a task B always follows task A, A is a prerequisite of B; if A occurs before B and B occurs before A, they are independent. These techniques produced normative models that were used to identify performance variations across teams. For example, a model might say that most teams check pulse in 30 seconds but team X checks pulse after 1 minute into the simulation.

The third phase involved describing coordination patterns associated with process variations relative to the model from aim 2. A process variation is defined as a difference in activity between the selected samples and the reference model. It was hypothesized that team members interact in an explicit or implicit manner to cause these variations to occur. The following probes are used to explore teamwork involved in the variation: who requested the variation, who performed the variation, when was it requested, and when was it performed? The first two questions describe the leader/follower dynamics by which activity is executed. The next two questions describe the speed at which actions are executed.

1.4 Overview

This section provides a brief overview of each chapter.

Chapter 1 Introduction– Outlines the structure of the dissertation.

Chapter 2: Background – Provides the rationale and theoretical basis for adopting Interactive Team Cognition to study EMS teams. ITC states that interactions reflect a team's cognition, i.e. their ability to think and process environmental cues to accomplish a goal. EMS teams use communication and coordination to rapidly treat patients in hazardous situations. The effectiveness of these interactions amongst team members directly contributes to patient safety and outcomes.

Chapter 2: EMS Simulations –Describes the experimental setup in which this research took place. The Emergency Medical Service for Children (EMSC) group, recruited EMS members from public fire and private transport crews to participate in a series of prehospital pediatric simulations. Teams responded to trauma and cardiac arrest codes under different conditions. This work studied teamwork in the trauma simulations.

Chapter 3: Specific Aims – Presents research aims designed to pursue the objective of developing a holistic, objective analysis of EMS teamwork. The aims cover three phases: 1) describe communication patterns that reflect team cognition in an EMS activity system; 2) create a normative model of activity; and 3) describe communication patterns with respect to variations from the normative model. Events and interactions are often studied in isolation. Integrating the two dimensions allows for the analysis of behaviors under similar or contrasting contexts.

Chapter 4: Comparative Case Study – Describes interactions associated with high and low performing EMS team. Interactions are described in terms of communication and coordination throughput, and use of orienting statements. Performance levels are based on scores assigned by Subject Matter Experts using the Clinical Teamwork Scale.

Chapter 5: Modeling Variation of EMS Activity with Multiple Sequence Alignment – Uses ClustalG to performance multiple sequence alignment on task sequences within and between high and low performing teams. ClustalG is software that was designed to perform MSA on sociological data. Tasks that were aligned and conserved across >50% of the teams represented a “backbone” of activity that served as the basis for a normative model.

Chapter 6: Modeling Variation of EMS Activity with Process Mining – Uses Process Miner (ProM) to construct graphical process models based on task logs. ProM is an extensible software framework that provides tools to extract knowledge from electronic logs of activity. This software presented an alternative method for exploring the conformance and performance of a team’s process trace to the model.

Chapter 7: EMS Teamwork Involved in Process Variations – Describes communications used to coordinate activity for a pair of high and low performing teams that varied from a normative process model of high performing teams. The process model, created in chapter 5, provides situational context of how a given team behaved relative to other teams. This analysis provides evidence of how interactions contribute to the trajectory of care and performance outcomes.

Chapter 8: Discussion – Implications for Research and EMS Care – Discusses the implication this work in regards to clinicians, researchers, and methodologists. For clinicians, the findings suggest that: 1) orientation statements are used to maintain team awareness and 2) the organizational structure of the team, hierarchical versus federated, may influence how tasks are coordinated. For researchers, sequence alignment and process mining are useful for performing time-motion analyses in a systematic manner. For methodologists, the integration of activity and behavior offers a new approach for understanding team cognition in context.

Chapter 2

Background

In EMS, and other healthcare domains, teamwork is considered critical to patient safety.[2] Poor teamwork has been associated with delays in testing and treatment, and medical errors.[3,4] Various training programs, such as Crew Resource Management (CRM) and Team Strategies and Tools to Enhance Performance and Patient Safety (TeamSTEPPS), have been created to improve team performance in healthcare. CRM and TeamSTEPPS are curricula that are designed to improve communication, leadership, situational monitoring, mutual support, and decision making through facilitated classrom training, which tend to include lectures that review theory, case reviews, and group discussion.[5,6] Their efficacy, however, is still being determined. Evidence supporting the link between teamwork and outcomes is mostly based on descriptions, observations, case studies, and expert opinions.[7] Studies that do measure clinical teamwork often use subjective assessments and behavioral rating instruments to quantify related non-technical skills such as leadership, communication, decision-making, and situation awareness.[1,8–10] Existing methods attempt to distill the quality of teamwork down to a single summative value, which provides limited insight on how team interactions affect outcomes. Improvements are still needed for evaluating and optimizing teamwork in healthcare.[11]

This research develops a method to analyze EMS team dynamics using the theoretical perspective of Interactive Team Cognition (ITC). The objective is to systematically identify interactions that distinguish high and low performance. ITC states that a team's cognition, or how it thinks and functions in the work environment, is reflected in the interactions between team members.[12] ITC is grounded in a rich and diverse history of psychology and human factors research, which influences the development of methods. This introduction will provide an overview on 1) the theoretical basis of ITC, 2) existing methods, and 3) application in EMS teams going forward.

2.1 Theoretical basis of Interactive Team Cognition

ITC is an extension of cognition and a counterpoint to Team Cognition. Cognition refers to the mental processes and structures of individuals who are involved in thinking and understanding. For example, a paramedic *perceives* and becomes *aware* of a patient with no pulse. The paramedic *comprehends* the patient's situation, recalls *memory* of care procedures, and makes the *decision* to perform CPR. The italicized words refer to constructs that psychologists have identified as being part of human cognition.[13] Researchers have sought to extend these theories into teams so as to explain, predict, and improve their performance.

The concept of cognition in a system emerged from separate but convergent lines of inquiry. Hutchins developed the theory of Distributed Cognition, which treats cognition as a metaphor of computation and describes it as the propagation of information across different representational states in an activity system.[14] He conducted a cognitive ethnography on a US Naval Frigate, in which he observed that members and artifacts performed computations for navigation. For example, several instruments are used to fix a ship's position on a chart. Navigators then use this information to track the ship's trajectory and destination. The navigators and instruments did not have equivalent capabilities, rather their combined contributions as a system led to navigation.

Around the same time as Hutchin's work, Endsley developed a theory of situational awareness (SA)[15] as a part of individual cognition.[14] This theory stated that SA was composed of an individual's perception, comprehension and projection of environmental stimuli. Endsley also suggested that awareness could be shared between teams via communication. Team SA was then defined as "the degree to which every team member possessed the SA required for their task."[16] Team SA has been used interchangeably with Team Cognition to refer to the team's state of knowledge at a given point in time.[17–20] The intuition behind Team SA is that members with overlapping and complementary awareness will be able to anticipate each other's needs and work together more effectively.

Another perspective has been to define Team Cognition in terms of communication and coordination processes.[18,20,21] Cooke et al conducted a series of experiments in which they measured structural and process based measures of individual and team cognition relative to performance in UAV-STE simulations (Uninhabited Aerial Vehicle-Synthetic Task Environment) in the context of military reconnaissance missions.[22–24] They found that interaction-based measures better explained performance variation, which led to the proposal of ITC[12] with the following premises:

1. Team cognition is an activity, not a property or product.

2. Team cognition should be measured and studied at the team level.

3. Team cognition is inextricably tied to context.

In the first premise, ITC draws on functionalist psychology to view properties, such as shared mental models of awareness, as being dependent on "its context within the stream."[12,25] In teams, the stream represents interactions between team members, such as acts of communication and coordination. The second premise argues that interactions are emergent phenomena of the team and cannot be adequately represented through aggregate measures of individual behavior. Rather, it is the sequential interplay between team members that leads to meaningful patterns. The third premise states that variation in process is driven by "co-adaptation" of the individual's "internal" state and "contextual environment". In activity theory, an individual's culture, history, environment, and tools mediate their perception, understanding, and activity.[26–28] For example, in United States, vehicles are driven on the right-hand side of the road, while in the United Kingdom vehicles are driven on the left-hand side. Cognitive work analysis presents complementary views in stating that constraints in the work environment shape behavior.[29,30] For instance, a bag valve mask offers the affordance of pushing a specific amount of air into the patient's lungs. According to ITC,[12] team interactions unfold dynamically in a context, and corresponding measures need to account for these factors accordingly.

The aforementioned theories reinterpret cognition from information processing in the head to information processing that occurs across multiple individuals situated in a broader sociotechnical system. Team cognition has been defined as a product and process, and each perspective has influenced identification and measurement of constituent parts. This work adopts the theory of ITC, because it appears to provide the best representation of how EMS teams react to evolving emergency situation in simulation.

2.2 Existing methods

Team cognition has been defined as both a product and a process.[20] Product-based theories operationalize team cognition as the team members' mental models. A mental model is an externalized representation of an individual's internal thoughts. Researchers have measured the correspondence of mental models with the environment,[16] as well as the overlap[31] and compatability[32,33] between team members. Interaction-based theories view exchanges that occur between team members, such as communication and coordination, as team cognition. This perspective includes a variety of methods based on type. Cooke outlines four types of interactions that have been explored in teams: events, communication, coordination, and shared situation awareness.[24]

Events are observable phenomena that occur at a given point in time and include tasks, body movement, physiological signs, and talk-aloud verbal protocols.[24] The term "case" refers to a set of related events and "trace" the specific sequence of events. Logs are paper or electronic files that contain temporally ordered information about events, including case identifier, event name, start time, end time, location, and participants.

Researchers in the human factors community have used procedural networks (ProNet) on communication logs to model the flow of communication in teams.[34–37] The geographic information science community used sequence analysis, a technique used to measure the similarity between strings of letters,[38–40] to identify patterns in the activity sequences of individuals.[41,42] The business process management community developed process mining algorithms to transform event logs into graphical models, which represent the flow of activity in a system.[43–45] Diagnostic algorithms have been created to evaluate the quality of a model in terms of completeness and behavioral appropriateness,[46,47] as well as the conformance of a trace to a model.[48] These techniques are useful for identifying variation in event sequences across multiple teams or systems.

Communication is a popular phenomenon to study because it is an observable approximation of a person's thoughts and can be investigated at multiple levels of abstraction. Communication refers to verbal, written, and behavioral exchange of information between two or more people and has the following properties: content, intent, sender, receiver, time sent, and time received.

A variety of methods have been used to explore the properties of communications. Parush et al. explored the content and intent of communications in the operating room.[49,50] They used the theory of shared situational awareness to identify overlapping content and design a shared display of the patient's vitals.[51] Entin and Entin proposed a number of communication measures based on intent and timing, such as the anticipation ratio (number of information transfers divided by information requests).[52] Network analysis techniques have been used to describe the flow of information across individuals.[35,53–56] The healthcare community has focused on training specific patterns of communication to improve team performance, such as closed-loop communication[57] and Situation Background Assessment Recommendation (SBAR) orientation statements.[58]

Coordination has been defined as a process in which individuals work together in harmony to achieve effective results.[59] This process involves "orchestrating the sequence and timing of interdependent actions"[60] and making "mutual adjustments to meet goals".[61] The concept is generally understood, but there are nuances in its application. There are two modes of coordination: explicit and implicit.[62] Explicit coordination involves the use of communication to organize activity, while implicit coordination depends on shared mental models. Explicit coordination can be further divided into communications about actions or information[63] and whether it is on a group or peer-to-peer basis.[4] Communication is deeply intertwined with coordinative acts because it can incite action. Furthermore, coordination occurs and fluctuates over time, which has implications for the design of measures.[64]

There are a variety of methods to match the various interpretations of coordination. Certain types of communications have been counted due to their tight coupling[65,66] with explicit coordinative acts, such as giving direction and offering assistance. Implicit coordination has been quantified based on observable actions, such as synchronized execution of a plan,[67] sharing resources,[68] and physical proximity.[69] A more recent technique has been to measure coordination based on the temporal order of specific, reoccurring speech acts, e.g., the difference in time between receiving information and giving feedback.[64] A reoccurring theme is that measures are based on a structured activity in which subtasks are performed by different team members managing shared resources. Information about the activity could provide a framework for specifying coordination requirements or constraints.

Shared situational awareness has largely been treated as a static product of team knowledge. The interactionist perspective views awareness as an evolving construct. Gorman et al developed the Coordinated Awareness of Situation by Teams (CAST) method, in which they traced the propagation of team awareness regarding a "roadblock" or communication glitch.[70] The setup involved having three-man teams photograph targets as part of an unmanned aerial vehicle (UAV) simulation. Team members communicated through radio headsets, and a line of communication was disrupted as part of the roadblock conditions. The method quantified who first perceived the roadblock, who coordinated perception of the roadblock, who coordinated action, and if the roadblock was overcome. The score reflected the team's evolving awareness over time.

2.3 Analysis of Teamwork healthcare

Teamwork in EMS and other clinical settings involves a significant amount of physical and verbal interaction. Computer simulations have been used to study teamwork in other domains because they streamline the process of analyzing communication and coordination data.[16,61,70] In the healthcare field, *in situ* observations and simulations have been used to study teamwork.[71,72] Simulations are used because they allow for the repeated observation of teamwork during rare events with no risk to actual patients, e.g. cardiac arrests.[73] Teamwork is commonly evaluated using behavioral rating scales, which presents tradeoffs relative to the aforementioned techniques.[74]

Behavioral rating scales involve having a subject matter expert (SME) rate teamwork based on types of behaviors associated with effective teams. For example, *leadership and management* is a factor in the Non-Technical Skills (NOTECHS) instrument.[9] SMEs rate surgical teams on this factor using a scale of 1 (below standard) to 4 (excellent). The scoring system is guided by prototypical examples, such as *raising team morale* and *taking control when required* for the *leadership and management* factor.

Behavioral rating scales have limitations in that they are reductive, subjective, and domain specific. Scales are reductive when they attempt to distill the quality of teamwork down into a single-point summative value. Such metrics do not describe temporal variations in performance and fail to provide insight into the dynamics of teamwork.[64] Subjective scales involve having a SME assign numerical values to dimensions of teamwork based on the perceived level of performance. For example, if team A had 8 closed-loop utterances and team B had 10, an SME might rate their communication as 4 (good) out of 5 (excellent). Alternatively, if 2 utterances were excellent in quality, the reviewer may be unsure of whether to rate the communication based on the existence, mode, count, or average of excellent communications. Values are indirectly tied to behaviors and their interpretation is not completely transparent. Lastly, SMEs are trained to rate teams based on prototypical exemplars that are domain specific. In NOTECHS, a positive modifier for cooperation is when the senior nurse covers for the junior nurse[9]. This limits the generalizability of the scale but demonstrates how domain-specific criteria are important in rating levels of performance.

2.4 Implications for Research

A variety of methods have been applied to quantify the team's cognitive factors in order to evaluate baseline performance and develop interventions for improvement. It has been noted that context and team cognition are deeply connected;[56] however, existing methods tend to aggregate performance over time without accounting for how context affects team interactions. ITC provides a guiding framework in identifying factors and criteria for studying teamwork. The factors include communication, coordination, and context. Modality means the analysis should study the team holistically over time. The intent of this dissertation is to develop a method of analysis to describe differences in teamwork with respect to situational variation. The implication is that a more holistic method of analysis would provide greater insight into team dynamics.

Chapter 3

EMS Simulations

This research was conducted in partnership with the EMSC group at Oregon Health & Science University (OHSU). The EMSC group is focused on improving the quality of care and outcomes for children in prehospital emergencies. As part of a large NIH-funded study (NICHD R01 HD062478), investigators recruited 47 EMS teams from local public fire and private transport agencies to participate in a series of 4 prehospital pediatric simulations:

1. Non-accidental trauma (NAT)
2. Motor-vehicle crash (MVC)
3. Neonatal cardiac arrest (NRP)
4. Pediatric cardiac arrest (PALS)

Their objective was to characterize the sequence of events that lead to adverse safety events (ASEs) during the prehospital care of children's emergencies.

These simulations provided an ideal setup for studying teamwork because they allowed for the observation of repeated samples over an observable time-frame with structured activity. The samples are repeated in that teams performed the same set of simulations. The sequence of simulations each team would respond to was randomized to account for potential bias introduced by familiarity with simulation and equipment alone. The time-frame was observable because the simulations were designed to last approximately 10 minutes. In other settings, such as inpatient care, treatment may span days or weeks. The simulations involved structured activity, where teams were expected to perform a set of tasks at key points in time. For example, the paramedics were expected to check vitals within the first 30 seconds of the encounter. Teams were free to assign roles, so the timing and execution of tasks varied across teams.

3.1 Subjects

Forty-seven EMS providers were recruited from public fire and private transport crews in a major metropolitan city (700,000 residents). Two teams were excluded from analysis due to clerical errors on the consent forms. This research complied with the American Psychological Association Code of Ethics and was approved by the OHSU Institutional Review Board IRB00006942. Participants signed both study and video consents and were given permission to opt out at any time. Participants wore colored tape to allow anonymous tracking of individuals by role.

There were two types of teams: fire-only crews and mixed crews, made up of members from fire or transport. Participants had training that ranged from EMT to paramedic. The fire-only crews had approximately 5 members, with 2 paramedics and 3 EMTs. The mixed crew had approximately 4 members from fire (1 paramedic and 3 EMTs) and 2 from transport (either 2 paramedics or 1 paramedic and 1 EMT). The teams had some variation in quantity (± 1 members) and composition (± 1 EMT or paramedic).

3.2 Simulator

The simulations used high fidelity mannequins as stand-ins for patients: Laerdal's® SimNewB® for NAT and MVC, Guamard's® Newborn HAL® for NRP, and Laerdal's® SimJunior® for PALS. The mannequins could be programmed; controlled remotely; emit vitals to simulate pulse and breathing; be attached to the agencies usual patient monitors; and receive treatment such as CPR, ventilation, and administration of epinephrine. The mannequins could not show signs of broken bones, change in overall skin color, or produce eye movement. Moulage was applied in a standard way to indicate bruising for the trauma simulations and recent birth for the NRP simulation. Participants watched videos outlining features of the mannequins prior to participating in the simulations and were permitted to ask questions about non-supported findings during the simulations.

3.3 Scenario

The research involved in this dissertation primarily focused on the NAT and MVC trauma simulations. These simulations took place at local training centers in areas mocked-up to look like real-world settings. Professional actors were hired to act as family members and bystanders, and provide information, such as how the situation occurred and patient history.

The NAT simulation involved a baby that "fell" from the couch in an environment and context that had risk for abuse. Trash, in the form of pizza boxes, beer cans, cigarette packs, and diapers, was scattered about the scene. An actor, playing an apathetic boyfriend, provided dubious information about how the baby fell, while the mother was away at work. The baby mannequin was moulaged to have patterns of bruising on the torso that would be consistent with shaking the baby suggesting possible abuse and presented with signs of increased intracranial pressure: decreased heart rate, increased blood pressure, and irregular breathing.

The MVC simulation took place in the street, where a car struck a baby in a stroller. A car was running idle with the actor-driver nearby. The mother cradled the baby as she cried for help. The baby presented with increased intracranial pressure due to trauma from the motor-vehicle accident.

Both simulations had different causes but the same problem of increased intracranial pressure due to trauma. The causes varied to see if providers' anxiety, evoked by an abusive environment, caused more errors. The teams were expected to provide the same treatment: initiate airway management, protect cervical spine, initiate CPR, establish an IO or IV access, and transport the patient.

3.4 Data Collection

Simulations were recorded by an overhead GoPro® and a Subject Matter Expert (SME) rated teams *in situ* using the Clinical Teamwork Scale (CTS™),[1] a behavioral rating scale that scores team performance along five dimensions: communication, situational awareness, decision making, role responsibility, and patient friendliness. The teams had an average overall CTS™ score of 6 ± 2, with a range of 0 (unacceptable) to 10 (perfect). Teams were split into high (CTS™ ≥ 8) and low (CTS™ ≤ 4) performing groups to see if methods distinguished performance levels.

Chapter 4

Comparative Case Study of Team Cognition in Trauma Simulations

4.1 Abstract

Background: EMS providers work in teams, to deliver care. The effectiveness of teamwork in healthcare is thought to be related to patient safety and outcomes. Little is known about the patterns of behavior that predict good and bad teamwork in the out-of-hospital setting.

Objective: To describe behaviors occurring in EMS teams during the simulated delivery of care that are observed at different performance levels.

Methods: Forty seven EMS teams were recruited from a major metropolitan city in the US to participate in pediatric trauma simulations. Subject Matter Experts (SMEs) rated team performance using the Clinical Teamwork Scale (CTS™). Participants reported their perceived workload using the NASA Task Load Index (NASTA-TLX). The simulations were video recorded and two pairs of low/high performing cases were selected for transcription, coding of communications, and analysis. Communication codes were used to measure the communication rate, anticipation ratio, and explicit coordination in teams, and explore if these aspects of team cognition were associated with performance. Cohen's kappa was computed to measure the inter-rater reliability of the communication codes.

Results: The coding dictionary defined 12 communication codes. The two coders had very good agreement in labeling communication acts, with a Cohen's Kappa of 0.68 (95% CI: 0.65-0.71). Coding disagreements were largely based on whether utterances were used to orient or inform team members. There was no significant difference in the communication rate and anticipation ratio between teams. However, the explicit coordination was higher in high performing teams and leaders in high performing teams oriented team members more frequently to the current situation and shared goals.

Conclusion: Findings of this study suggest that good teamwork relies on effective leadership and information sharing. Fluctuations in the communication rate over time and periodic orientation by PICs suggest that, in addition to summative scores, teamwork should be studied holistically over an events duration. These findings are based on a small but rich set of data and work is needed to validate the findings.

4.2 Introduction

In prehospital pediatric care, EMTs and paramedics work as a team to treat and transport critically ill patients. The patient's safety depends on their ability to work as a coordinated unit. In 1999, the Institute of Medicine (IOM) published a report attributing systemic failures to patient deaths.[2] For the past three years, the Joint Commission has listed human factors, leadership, and communication as the top three root causes of sentinel events in patients.[75] Many of these failures manifest as delayed treatment, misdiagnosis, use of incorrect equipment, and administering the incorrect drug dose. Prehospital care is particularly susceptible to these failures, because care providers in this specialty must treat rapidly deteriorating patients in a hazardous environment[76] with limited equipment,[77] support,[78] and training.[79] Effective teamwork can be used to manage environmental hazards and provide cognitive redundancies that protect against erroneous decisions.

4.3 Background

Teams are defined as a group of people working towards a common goal.[80] They can be evaluated from different perspectives, which guide the evaluation of teamwork in this study: structural organization, social interaction, process, and outcomes.[7] Structural organization describes team composition in terms of member competencies (paramedic or EMT training), organizational membership (fire or transport), task assignments (CPR, ventilation, scribe, etc.), role assignments (leader or follower), and location (distributed or co-located). These are factors that influence how team members take on tasks and interact with one another. For example, members with paramedic training are typically assigned the role of team leader and given the authority to direct other team members.

The social interaction perspective views teams as information-processing units and focuses on constructs related to the flow of information, such as communication, coordination, shared mental models, and the distribution of work.[68] For example, when the leader (a.k.a. person in charge or PIC) tells their teammate to start compressions because the patient is bradycardic, this is a communication that establishes a shared mental model and coordinates the execution of a task. These constructs are based on observations of interactions between team members in a naturalistic setting. Teams are not deconstructed into their constituent members for study because the interactions between members are considered the essence of teamwork.[32,81]

The process perspective evaluates teams with respect to task criteria, such as throughput, efficiency, speed, completeness, and correctness. Checklists are frequently used to verify that teams are performing the expected series of tasks in a timely manner, otherwise known as protocol compliance.[82,83] In prehospital situations arrival time,[84] hands-on-time for compression,[85] and correct calculation of drug dosages[86] are used as indicators of performance. This method is a more direct form of evaluation, but makes it difficult to compare teams across different types of situations.

The outcomes perspective evaluates if the team achieved good or bad results. In the domain of healthcare, this evaluation corresponds to the patient's successful treatment and wellbeing. In the context of simulation, it means performing to expected, practice-based guidelines in a timely manner with no errors. Human evaluators are often employed to rate team performance along these criteria.

4.3.1 Simulations in healthcare

Simulations are used to study clinical teams because they allow for the observation of rare events with no risk to actual patients.[73] Most simulation-based studies have been focused on the development of particular skills, such as intubation, trauma care, CPR, ventilation, and triage while using mannequins to mimic a patient's response to treatment.[87] In practice, tasks are distributed across multiple team members. For example, EMS providers are taught to swap resuscitation roles to maintain high quality compressions.[88] It has been noted that leadership and communication can impact patient outcomes, but that more work is needed to understand how these behaviors affect delivery of care.[89] This study uses simulation to describe patterns of activity observed in low and high performing EMS teams.

4.4 Methods and Materials

EMS teams were recruited to participate in a series of four video-recorded simulations: non-accidental trauma (NAT), motor vehicle crash (MVC) or accidental trauma, pediatric cardiac arrest (PALS), and neonatal cardiac arrest (NRP). Teams were recruited from public fire departments and private EMS transport agencies in a major US metropolitan city. Participants had professional training ranging from EMT to paramedic, and each team had at least one paramedic. The underlying research was approved by the Institutional Review Board of Oregon Health & Science University IRB00006942. Participants signed study and video consents, were given permission to opt out at any time, and were assigned a color-coded ID to allow anonymous tracking. A comparative analysis was performed on 1 pair of high- and low-performing NAT simulations and 1 pair of high- and low-performing MVC simulations. The purpose was to describe patterns of communication and behavior associated with a given performance level.

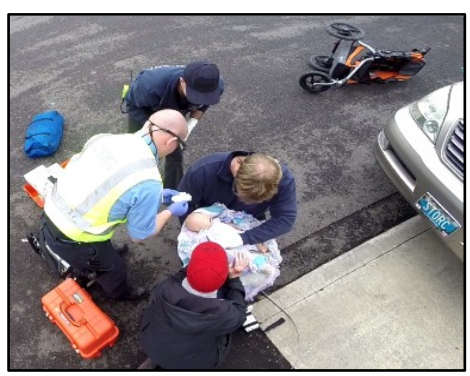
Simulations took place at local training centers and were mocked up to look like the scene of an event. The SimNewB™ patient simulator from Laerdal™ was used as a stand-in for child patients. The mannequin was moulaged in a standard way prior to the scenario to simulate bruises consistent with abusive injuries. It was anticipated that participants might check for signs that were not available in the mannequin: for example, the patient simulator cannot blink, dilate pupils, change its skin color, or simulate broken bones. Participants were instructed to explicitly ask for anything that they did not see or was delaying them. Simulations were limited to approximately 10 minutes to standardize evaluations and because EMS teams are expected to transport trauma patients within 10 minutes according to local protocols. If a procedure was started, such as administering epinephrine, the simulation was allowed to continue to complete observation of task process.

SMEs (JMG and MH) used the CTS™ instrument to evaluate team behaviors with regards to communication, leadership, and decision making. CTS™ is a validated instrument that measures teamwork skills in clinical and simulated settings, whereby SMEs rate teams based on five dimensions of behavior: communication, situational awareness, decision making, role responsibility, and patient friendliness.[1]

Non-accidental Trauma (NAT)

The patient presented as a 1-year-old who “fell” from the couch in an environment that suggested abuse (disheveled “boyfriend” played by a professional actor, empty beer cans, wine bottles, pizza boxes etc all over the floor, moulage of bruising on baby in pattern consistent with a man’s hands). The expected treatment was to Initiate airway management, protect the cervical spine, monitor vital signs, initiate CPR, establish IV/IO access, and transport the patient to the hospital.

Motor-Vehicle Crash (MVC)



In the simulation of a motor vehicle versus stroller accident, a mother was walking with her 1-year-old baby and was struck by a car. The stroller fell over and baby was initially crying in the mother's arms and had head bruising. The baby became unconscious as the EMS team arrived at the patient. The expected treatment was to initiate airway management, protect the cervical spine, and monitor vital signs.

4.4.1 Qualitative Coding

Simulations videos were transcribed and coding frameworks were developed to label EMS team utterances and tasks. Theories on team cognition view utterances as explicit interactions that represent how the team thinks and solves problems.[12,20] Team members can provide information, request information, and acknowledge that information was received.[51,90] Utterances are also used to prompt action by directing others or describing self-direction.[85] These speech acts can support coordination. In addition, the clinical community is expected to use the SBAR framework[58] for goal orientation in patient care. In this framework, care providers describe the patient's state (Situation), identify underlying cause (Background), specify a course of action (Assessment), and invite input from other team members (Recommendation). These types of statements help create a shared mental model and plan for coordinated activity. Table 1 provides a list of codes, definitions and examples corresponding to team cognition and SBAR communications.

Verbal Behavior	**Definition**	**Example**
Inform	Providing information about the patient, task, rationale of behavior, or clarification.	*Heart rate still eighty four.*
Request information	Requesting information about the patient, task, rationale of behavior, or clarification.	*Did you give me a depth on that tube?*
Direction	Direct a specific individual to perform a task.	*And make sure we bring uh [Green] bring the guide with us too.*
Self-direction	The speaker tells others what they are doing or will do.	*I'm gonna slide this board out.*
Acknowledge	Indicate that an utterance was heard.	*Ok.*

Situation	State what has happened to the patient.	*The kid fell from there onto the ground.*
Background	The patient's medical history and synopsis of treatment to date.	*So we've given one dose of epi so far.*
Assessment	The patient's status and most recent vital signs.	*So sating at a hundred percent. Etco2 is forty eight.*
Recommend	State what should be done next.	*So, we'll get some vitals going and some airways out.*
Invite Help	Request input from other team members.	*Does anybody have any thoughts of what we could do?*
Irrelevant	Statements that are not audible, incomplete, orirrelevant to the task.	*And um …*

Table 1: Types of communications that are used to evaluate interactions between team members.

Utterances were double-coded by two researchers, NB and SH, according to the speaker's verbal behavior and intent. A contingency table was created to highlight disagreements and measure inter-rater agreement using Cohen's kappa. Disagreements were resolved through consensus for subsequent analysis.

4.4.2 Measurement of Interactions

The communication acts were used to measure aspects of the team's information processing activity in terms of communication rate and efficiency, and coordination. The communication rate can be measured as the average number of utterances per minute. Lower rates implied that there was less need for coordination and was associated with better team performance. MacMillan et al.[68] view communication as emerging from a need for coordination.

$$Communication\ Rate = \frac{\#\ Utterances}{minute}$$

Communication is considered efficient when team members anticipate information needs without being asked.[68] The anticipation ratio is measured as number of inform utterances divided by the number of requests for information.[52]

$$Anticipation\ Ratio = \frac{\#\,Inform}{\#Request\ information}$$

Coordination is defined as team members combining resources to achieve a shared goal.[68] This concept is difficult to measure in a clinical setting, where information in the environment is spontaneously used to mediate activity. For example, EKG monitors display a patient's heart rate to the entire team. If the heart rate is low, this will prompt one member to start chest compressions and another to prepare epinephrine in an effort to increase it. The use of many information resources is implicit and cannot be easily identified. It was observed in pilot simulations that leaders would give directions or members would describe their own directions to coordinate the distribution of work. Given this insight, explicit coordination can be measured as the ratio of self-directions divided by directions. Coordination is hypothesized to be more efficient when team members take the initiative in performing tasks and inform other members about their behavior.

$$Explicit\ Coordination\ Ratio = \frac{\#Self\ directions}{\#Directions}$$

4.4.3 Visualization of Activity

These measures summarize interactions between participants into a single value. Teamwork, however, occurs over time, and there is a choreographed rhythm by which it emerges. For example, teams try to keep their on-scene time to ≤ 10 minutes and swap compression roles every two minutes or less to maintain stamina.[88] The orientation statements, represented by SBAR utterances, were placed on timelines to visualize temporal patterns of activity. Timelines are represented by a line on the X-axis, divided into intervals. The intervals specify minutes in the simulation. Orientation statements are represented by triangular icons, colored according to speaker, and labeled according to the type SBAR statement. The icons and their labels are positioned along the X-axis according to when they were uttered.

4.5 Results

Forty-seven teams participated in the prehospital pediatric simulations. Two pairs of high and low performing teams were selected based on their CTS™ scores. The high performing team in both pairs was the same but used different PICs. Their compositions and scores are presented in Table 2. According to SME notes, the low performing NAT team received its score because they had poor leadership and administered a 10x overdose. In the low performing MVC team, members were scolded due to miscommunication and they used the wrong-sized equipment for intubation.

Sim (Group id)	CTS	Sim Duration (min:sec)	# Fire Paramedics	# Fire EMTs	# Transport Paramedics	# Transport EMTs
High Perf. NAT (8)	9	10:05	3	3	N/A	N/A
Low Perf. NAT (25)	4.5	11:00	1	2	2	0
High Perf. MVC (8)	9	13:08	3	3	N/A	N/A
Low Perf. MVC (9)	4	11:36	3	3	N/A	N/A

Table 2: Team characteristics.

4.5.1 Qualitative Coding

The coders had very good agreement labeling verbal behaviors, with a Cohen's Kappa of 0.69 (95% CI: 0.66, 0.72). Coders disagreed most often when coding inform statements because there were several similar but semantically distinct subtypes. For example, self-*direction* conveys information about what the speaker has done or will do. SBAR statements convey situational information, including *recommendations* about what the team should do. The distinctions between these types of statements were sometimes ambiguous and could only be distinguished by the speaker's gaze and vocal projection.

Lastly, incomplete utterances were sometimes labeled as irrelevant because they conveyed partial information that had limited use, for example, *"Baby's not ..."*. Disagreements were resolved by discussing them and arriving at a consensus.

Coders NB \ SH	Inform	Request inform	Direction	Self-direction	Acknowledge	Situation	Background	Assessment	Recommend	Invite help	Irrelevant
Inform	367	8	28	11	11	17	2	4	3	0	53
Request Information	2	194	4	0	2	0	0	0	0	0	10
Direction	6	16	149	3	2	1	0	0	2	1	9
Self-direction	17	1	6	66	0	2	0	0	0	0	9
Acknowledge	24	3	4	1	218	1	0	0	0	0	8
Situation	8	0	0	0	0	4	0	2	0	0	0
Background	3	0	0	0	0	2	1	0	0	0	0
Assessment	11	0	0	0	0	3	1	1	0	0	0
Recommend	8	0	6	1	0	0	0	0	10	0	2
Invite help	1	2	0	0	0	0	0	0	0	0	0
Irrelevant	19	6	3	3	13	2	0	0	1	0	104

Table 3: Contingency table of communication codes.

4.5.2 Measurement of Interactions

CTS performance does not appear to be associated with subjective workload measures or communication rate. High-performing teams do appear to have larger values for anticipation and explicit coordination. In other words, information is provided more frequently than requested and team members take the initiative in performing tasks.

Sim (Group id)	CTS	NASA-TLX Team Avg	Comm. Rate (utterance / min)	Anticipation Ratio (inform / request info)	Explicit Coordination (self-direction / direction)
High Perf. NAT (8)	9	9± 2	32 (321 / 10)	2.07 (93 / 45)	0.66 (31/47)
Low Perf. NAT (25)	4.5	12± 2	39 (426/11)	2.06 (140 / 68)	0.49 (24 / 49)

High Perf. MVC (8)	9	9 ± 3	29 (376 / 13)	2.14 (109 / 51)	0.76 (30 / 41)
Low Perf. MVC (9)	4	7 ± 2	25 (277 / 11)	2.02 (85 / 42)	0.17 (10 / 58)

Table 4: Measurements of team performance and interactions.

Teams have similar communication rates. Figure 2 plots the communication rates over simulation duration. This figure indicates that communication rates fluctuate over time. There is a rise and peak in the first half of activity, when teams first encounter the patient. Communication levels out and drops once a care plan is being implemented.

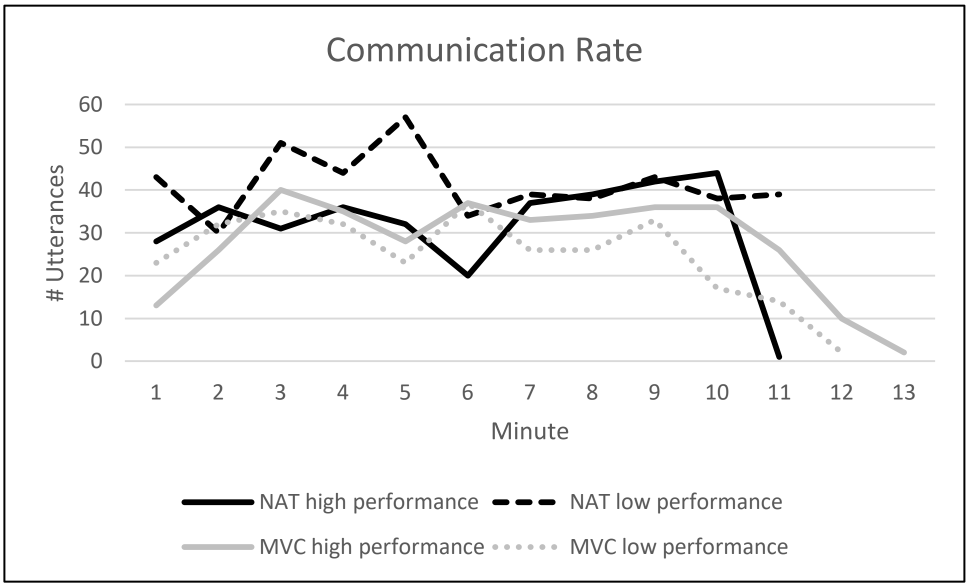


Figure 2: Communication rates.

4.5.3 Visualization of SBAR communication

The timelines in Figure 3 display the occurrence of orientation statements over time. There were notable differences in communication patterns across performance levels. The PICs in the high performing teams periodically oriented their team using SBAR statements. In the low-performing NAT simulation, these types of statements were distributed across multiple members. The PIC provided situational information, but took on a support role when the transport crew arrived on scene. In the low-performing MVC simulation, the PIC issued directions and did use orienting statements to manage the team.

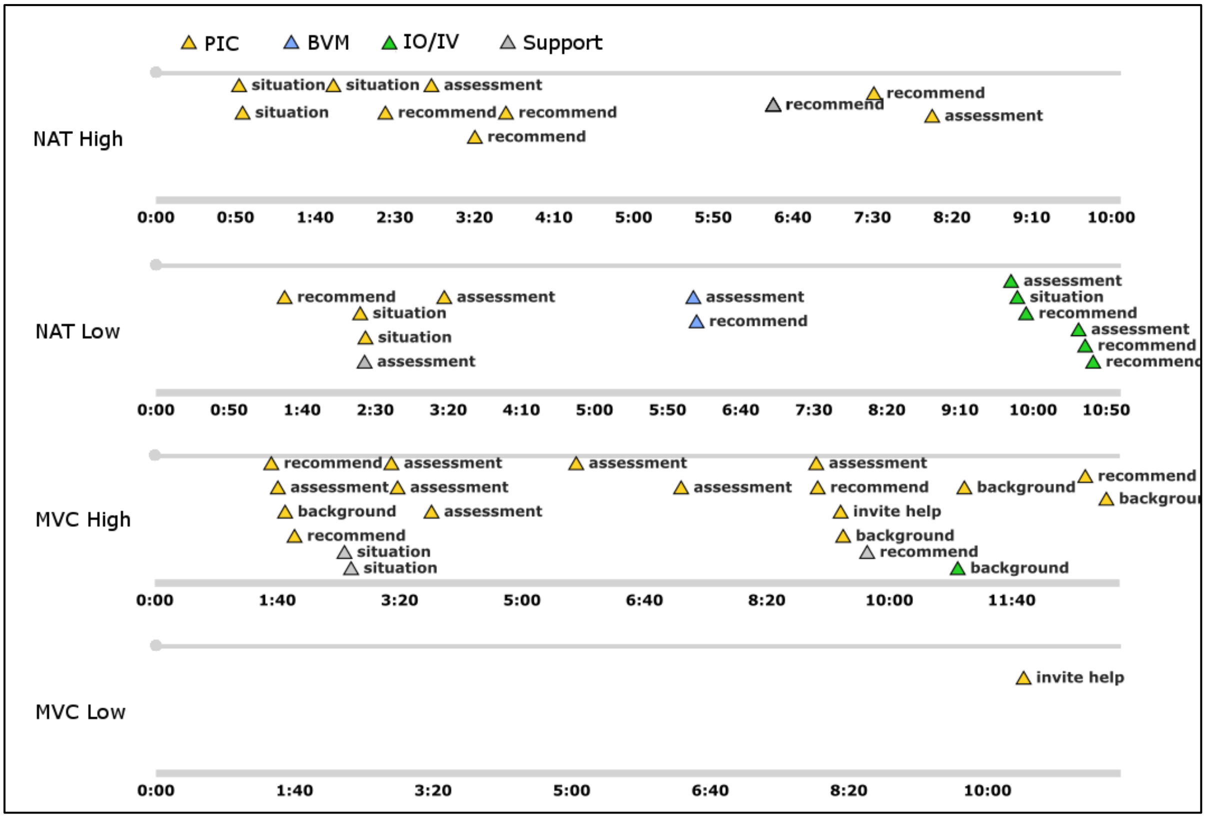


Figure 3: SBAR communications across performance levels and simulation types.

4.6 Discussion

A comparative analysis was performed to compare teamwork in four simulations across performance levels and simulation type. In the clinical setting, performance is often defined in terms of patient safety, e.g. did the patient receive the correct intervention in a timely and safe manner. This study adopts the perspective that teamwork is mediated by leadership, communication, and coordination, and that deficiencies in these areas can lead to delays or errors in the delivery of care. Different types of team interactions were measured or visualized to explore these factors with respect to team performance.

The team's average subjective task load, as measured by the NASA-TLX, was not associated with CTS™ scores. Individual team members experienced stress that was more closely associated with their task than team performance. For example, in the Low performing MVC team, BVM: the member responsible for ventilation reported a high temporal demand while their colleagues reported very low demand. This sense of haste was apparent, as they rushed to transport the patient once arriving at the scene.

RWB	How old is your baby?
Orange	[Get] the backboard out of the truck.
Actor	[Shakes head]
Actor	He's a few months.
RWB	Ok. We're gonna go put him on the back onto the stretcher here ok?
RWB	Ok.
RWB	We're gonna go put him on the back onto the stretcher here ok?
Actor	Ok.
RWB	I'm gonna take it from you ok?
Orange	Hold on to him [RWB]. We still gotta [inaudible].

In this case, the NASA-TLX provides a measure of individual workload, and the average does not completely reflect team workload.

Communication rates did not appear to correlate with performance; rather they appeared to be more strongly associated with simulation type and nature of the work. Figure 2 shows that the communication rates fluctuated throughout the simulations. These fluctuations could be associated with different stages in the delivery of care. The first few minutes of the simulations had increased communication rates, during which teams gathered initial information and oriented one another about the situation. The teams then maintained a steady stream of communication while delivering care. The communication rates decreased in the final minutes of the simulations as the teams completed the tasks they needed to perform.

Teams had anticipation ratios greater than two, indicating that information was provided more frequently than it was requested. This finding is congruent with the nature of EMS teams, where members are trained to frequently vocalize their actions and patient vitals. The high performing teams had slightly greater anticipation ratios, but this may be due to random variation and differences in simulation duration. High performing teams did have greater values for explicit coordination. It was observed that members in high performing teams, took the initiative in performing tasks. For example: *"I'm checking for a pulse."*, "*checking out his pupils*", *"I'm going to do CPR"*. This action is indicative of a self-organizing team and potentially lessens the cognitive burden on the PIC.

The timelines indicated that teams performed a comparable, though slightly varied, sequence of tasks. Also, the timelines showed that PICs in high performing teams used SBAR statements to periodically orient the team. The low performing team in the MVC had some confusion, which could be attributed to lack of goal orientation. For example, in the following excerpt, the *PIC* never verbalized their goals to the team. *Support_2* received instructions *IO/IV* to give the patient fluids. These actions were inconsistent with the *PIC's* implicit care plan, leading to a verbal conflict that appeared to make other team members more tense and silent.

PIC	Didn't I tell you to skip all of that?
Support_2	No one could say they skipped bag fluids while I'm here.
PIC	We don't have to give him fluids. Drop it. Stop it. Stop it [Green] would?
Support_2	[Hehe] you got me in trouble.
IO/IV	[I] got him in trouble.
PIC	Ya.

4.6.1 Application

The results seemed to indicate that high performing teams had PICs who periodically oriented team members and more explicit coordination amongst its members. These findings could be used to inform strategies for improving teamwork. For example, if PICs are trained to provide early goal orientation, this could increase team performance by helping members anticipate needs and explicitly coordinate with one another. The measures are useful because they provide a means to evaluate different characteristics of teamwork.

4.6.2 Limitations and Future Work

The findings are based on a small data set. The data set is small because transcribing team utterances in a noisy, complex environment is labor intensive. Speakers were difficult to identify due to: the video angle; most members being male and speaking in similar tonal ranges; and alarms sounding in the background. These challenges required watching primary videos and backup videos multiple times to ensure transcript quality. Nevertheless, the limited size of dataset is offset by richness of observable activity.

A second limitation is that the same team is represented in both high performing cases, albeit with different PICs. We can say that high performing PICs periodically orient team members, however it is not clear whether this phenomenon might be limited to that specific team and the cultural environment in which it is situated. In other words, members in that particular team may have been trained to orient one another with SBAR communications and that type of behavior may not occur in other high performing teams. The same could be said for team members providing more backup support through explicit coordination.

Lastly, this study only evaluates communication patterns in high and low performing teams. All communications occurred in the context of clinical task work, which could shape it. For example, if teams start with CPR and do not treat the patient's ICP with ventilation, they will observe a decreasing heart rate and troubleshoot it verbally. Certain patterns of activity may only be apparent with respect to the underlying activity and should be studied as such.

4.7 Conclusion

Team performance appears to be influenced by the style and effectiveness of leadership, as indicated by orientation utterances provided by the PIC and explicit coordination provided by the other members. Furthermore, the progression of orienting utterances, fluctuations in communication rates, and variations in tasks, suggest that teamwork should be analyzed over time in addition to summative scores. These findings are based on a limited data set and should be validated in subsequent work.

Chapter 5

Using Multiple Sequence Alignment to Model Variation of EMS Team Activity

5.1 Abstract

Background: Adverse events can arise from healthcare delivery and can have grave consequences for patients. Prior work has classified types of errors that occur, but has not explored the mechanisms by which they occur.

Objective: We adapted multiple sequence alignment algorithms to model process variation between low and high performing Emergency Medical Service (EMS) teams during prehospital pediatric simulations and explored the suitability of the technique for modeling team interactions.

Methods: We recruited 47 fire department and ambulance EMS teams from a major metropolitan city in the US to participate in prehospital pediatric trauma simulations. Subject Matter Experts (SMEs) scored team performance using the CTS™, a validated tool for measuring team performance. Video recordings for 42 teams were viewed and coded for patient-centric tasks. We used multiple sequence alignment to measure similarity of activities across all teams, and among teams within and between low (CTS ≤ 4) and high (CTS ≥ 8) levels of performance.

Results: Alignments revealed patterns in how teams prioritized treatment. Low performing teams treated individual physiologic findings such as low heart rate, while high performing teams interpreted findings and treated an assumed diagnosis (e.g. increased intracranial pressure). While important patterns were detected, results were noisy due to mapping concurrent activities onto unidimensional sequences. There were also discrepancies between alignment similarity and performance scores. Teams may perform the same sequence of tasks, but at varying degrees of effectiveness.

Conclusion: Sequence alignment can be used to model process variation, but improvements are needed to account for the quality, temporality, and multidimensionality of team activities.

5.2 Introduction

Emergency Medical Service (EMS) providers are faced with the complex task of treating patients in the field with limited resources. Emergency Medical Services (EMS) providers are faced with the complex task of rapidly treating patients in the field with limited resources. Recent studies have found that errors in prehospital pediatric cases are common due to failures in equipment, drug administration, communication, and clinical judgement.[77,91] These errors may be caused by having to perform interventions quickly in stressful situations.[91,92] Guidelines, in the form of clinical algorithms, have been created to support the decision-making process in a natural setting.

Clinical algorithms are intended to improve clinical decision-making and adherence to evidence based practice. The American Heart Association developed advanced cardiac life-support algorithms for cardiac arrest in the 1970s and they have been considered the standard of care for treatment decisions in cardiac arrest.[88,93] An algorithm is simply a set of rules to follow under a given set of conditions. For example, if a patient's heart rate falls below 60 beats per minute (bpm), and there is poor perfusion, one should start cardiopulmonary resuscitation (CPR). The underlying theory is that adherence to evidenced-based guidelines reduces process variation, ambiguity, and failure modes[94] while deviations can result in adverse events that harm the patient.[95]

Even when the evidence for an intervention is indisputable, it is estimated that only 30-40% of patients receive care that is compliant with evidence based recommendations.[96–98] Algorithm nonadherence can occur for a variety of reasons including: unavailability of appropriate equipment or medications, insufficient knowledge, cognitive errors, or poor teamwork (leadership, role assignment, and/or communication).[73,77,99] Existing studies largely focus on quantifying outcomes, but there is a need to understand the underlying mechanisms by which these outcomes occur.[100] In order to address this gap, we adapt and apply sequence alignment to understand how deviations from expected behaviors occur.

5.3 Adaptation of Multiple Sequence Alignment

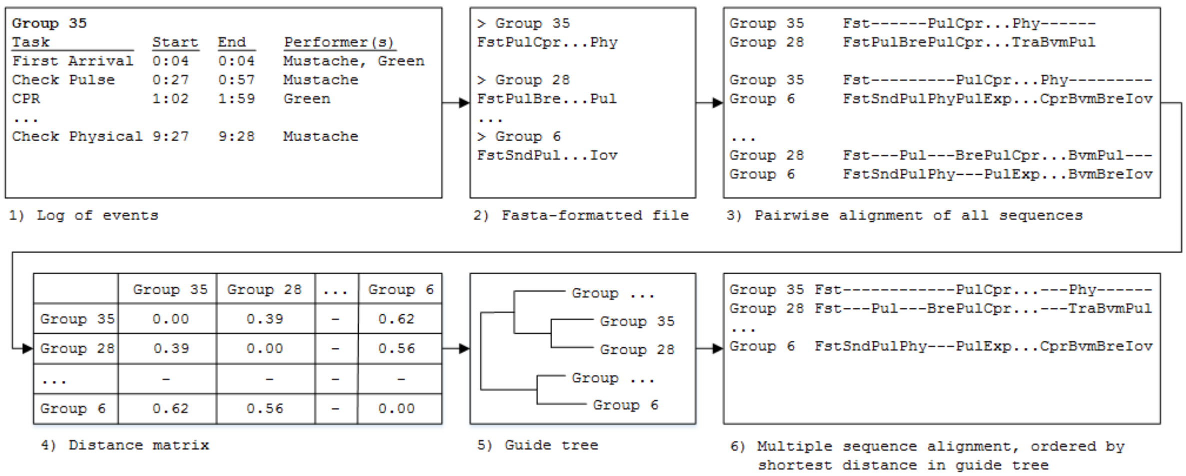


Figure 4: Multiple sequence alignment pipeline.

Sequence alignment refers to a visual-analytical technique of lining up elements in sequences to identify similarities between them.

Figure 4 provides an example of the MSA process for observational data. The observational data is: 1) collected and 2) formatted into fasta-like sequences.[41] The first line of a fasta-like sequence starts with the ">" greater-than symbol and contains descriptive text. Subsequent lines contain the sequence, in which each element is specified by a capitalized word, 1-12 characters in length. In step 3) pairwise alignment uses dynamic programming to match elements across two sequences together.[39,40] MSA uses heuristics to progressively align sets of sequences together, because the pairwise algorithms are too computationally expensive for > 2 sequences.[101] MSA proceeds by: 4) constructing a distance matrix from the pairwise alignment of all sequences; 5) building a guide tree from the distance matrix, and 6) progressively aligning sequences by following the guide tree.

MSA has primarily been used to measure the homology between nucleic acid and amino acid sequences.[101–106] The guide tree describes the hypothetical, evolutionary relationship between sequences[107] and alignments describe the functional conservation of genes across variants. Sequence alignment has been used to describe patterns of activity in the social sciences, where the guide tree and aligned activities describe different strategies of human activity.[41,42,108–110] In the clinical setting, EMS teams are trained to follow practice-based guidelines and deliver a predefined sequence of interventions, e.g. check pulse → if pulse less than 60 bpm → perform CPR. MSA could be used to align these interventions across teams and explicitly describe variations of care. For example, CPR might be delayed if teams establish IO access after checking pulse. We hypothesize that MSA could identify care variations and provide insight of their affect on performance.

Social scientists developed ClustalG, a software application that performs multiple alignments on generic sequences.[41] We used this software in our analysis of team activity because it supported qualitative codes and removed most of the biological assumptions built into existing MSA tools.

5.4 Methods and Materials

Figure 5: The non-accidental trauma took place at local training centers and was mocked up to look like a disheveled room, which was suggestive of abuse

We compared the multiple alignments of low and high performing EMS teams in pediatric simulations to explore the suitability of multiple sequence alignment for modeling team interactions. EMS teams participated in four simulations: cardiac arrest in newborn, cardiac arrest in child, accidental trauma, and non-accidental trauma. The simulations were video recorded using an overhead GoPro™ and supplementary microphone. We then aligned patient-centric activities performed by EMS teams responding to the NAT simulation.

5.4.1 Subjects

EMS teams were recruited from public fire departments and private EMS transport agencies in the greater Portland Oregon metropolitan area. Teams reflected typical response teams in the field, where there is a non-tiered response of Advanced Life Support response from both public fire and private transporting agencies. Fire crews consisted of 3-4 members and the private transport crews had 2 members. Subjects had training that ranged from EMT to paramedic, and each team had at least one paramedic. This research complied with the American Psychological Association Code of Ethics and was approved by the OHSU Institutional Review Board (IRB00006942). Participants signed both study and video consents and were given permission to opt out at any time. Participants wore colored tape to allow anonymous tracking of individuals by role.

The simulations were conducted *in situ* with crews responding in their own vehicles after receiving a radio dispatch. All crews were aware they were participating in simulated emergencies and were oriented to the study and mannequins prior to participation. The fire and transport crews alternated who arrived on scene first order to mimic real-world situations requiring resource management. For the analysis, times are normalized according to when the first crew arrived.

5.4.2 Simulator

The simulation scenarios were conducted at local EMS training centers where rooms were mocked up to look like a disheveled home. We used a SimNewB™ patient simulator from Laerdal™. The mannequin was moulaged in a standard way prior to the scenario to simulate bruises consistent with abusive injuries.

5.4.3 Scenario

The simulation was intended to present nonaccidental trauma (abuse). The patient was a six month old who "fell" from the couch and was unconscious and unresponsive. Vital signs were set to indicate elevated intracranial pressure, consistent with "shaken baby syndrome". A professional actor played the role of the boyfriend to the patient's mother. The actor was instructed to be dismissive towards the EMS teams, act suspicious, and provide minimal information. Based upon SME consensus, the expected treatment sequence and time was: check responsiveness 0:00, check breathing 0:10, check pulse 0:15, begin ventilations 0:40, attach monitors 1:30, and obtain interosseous or intravenous (IO/IV) access 2:30.

The simulations were truncated at approximately 10 minutes because the purpose of measurement was the evaluation of team process, not patient outcome. This limit is congruent with standard EMS trauma guidelines, which recommend transport within 10 minutes. If a procedure was begun, such as calculating and drawing up an epinephrine medication, the simulation was allowed to continue to complete observation of the task in process. If the care protocols proceeded rapidly and the condition of the patient was stable and transport action was begun, the simulation was ended before the 10-minute point.

5.4.4 Data Collection

Two SMEs, JMG and MH, used the CTS™ instrument to evaluate team behaviors with regards to communication, leadership, and decision making. CTS™ is a validated instrument that measures teamwork skills in clinical and simulated settings, whereby SMEs rate teams based on five dimensions of behavior: communication, situational awareness, decision making, role responsibility, and patient friendliness[1]. We used the overall score to compare the alignments of low performing teams to high performing teams.

Task	**Code**	**Task**	**Code**
First arrival	Fst	Attach EKG (pads or leads)	Ekg
Second arrival	Snd	Attach blood pressure cuff	Bpc
Expose	Exp	Maintain cervical spine	Cer
Check physical status	Phy	Intubate	Int
Check mental status	Men	Ventilate with Bag Valve Mask (BVM)	Bvm
Check breathing	Bre	Do cardiopulmonary resuscitation (CPR)	Cpr

Check pulse	Pul	Establish an IO/IV line	Iov
Measure length	Len	Administer drugs	Dru
Attach pulse oximeter	Pox	Transport the patient	Tra
Attach end-tidal CO2 monitor	Ent		

Table 5: Activity codes.

A coding framework (Table 5) for patient-centric tasks was developed through viewing recordings of initial simulations in an iterative process by a single researcher, NB. These codes were validated against tasks listed in pediatric resuscitation guidelines[93] and clinical SMEs. Two researchers, NB and SH, used this framework to code the simulations. One simulation was coded in duplicate to assess the level of agreement between NB and SH. This simulation was selected based on the difficulty it posed for the coding task: team members frequently switched tasks and sometimes occluded view of the patient. We measured percent agreement using the Jaccard coefficient: the intersection of agreed codes divided by the union of codes. Agreement was defined as two codes specifying the same task, same performer, and approximately the same start and stop times.

The sequence of activities for each simulation were then sorted according to start time, transformed into a fasta-formatted sequence, and placed into one of two files based on whether they had a low (CTS ≤ 4) or high (CTS ≥ 8) teamwork score.

5.4.5 Analysis

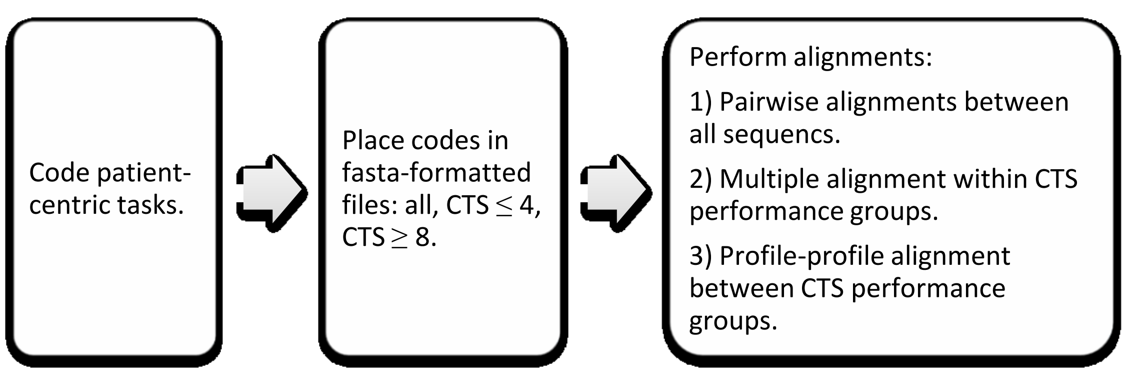


Figure 6: Outline of methods for aligning team activities.

We performed a series of alignments on the activities from the simulations: pairwise alignment between all simulations, multiple alignments within low and high performing teams, and profile-profile alignments between low and high performing teams. See Figure 6 for outline.

5.4.5.1 Pairwise Alignment

We performed pairwise alignments between all sequences. The alignments measure overall similarity and identify potential discrepancies between sequence similarities and expert evaluations. We report the average, standard deviation, and range of similarity, where ClustalG defines similarity as: #matches / minimum sequence length. We also identify sequence pairs that have a high level of similarity, but divergent CTS scores. These discrepant pairs help illustrate the capability and limitations of sequence analysis.

5.4.5.2 Guide Tree

The guide tree contains branches of sequences, which can be cut at different values of similarity to yield clusters of sequences. Selecting the best cutoff value is an open problem, but there are techniques for evaluating cluster quality. In this step, we use the clValid[111] and cluster[112] packages in R to compute the connectivity, Dunn Index, and average silhouette width when creating different numbers of clusters, 2 to 9, from the guide trees. Connectivity measures the extent to which observations are placed in the same cluster as their nearest neighbors, ranges from 0 to ∞, and should be minimized.[113] The Dunn Index measures compactness and separation of the clusters, ranges from 0 to ∞, and should be maximized.[114] The silhouette width measures the degree of confidence in cluster assignment, ranges from -1 to 1, and should be maximized.[115]

5.4.5.3 Multiple Alignment

We performed the multiple alignments within low and high performing teams and the profile-profile alignments between low and high performing teams. The multiple alignments identified activities that were conserved and not conserved at a given level of performance. The profile-profile alignments identified discrepancies between different levels of performance.

ClustalG specifies a column's level of consensus using the following symbols: '#' 80%-100% identical, '*' 60%-79% identical, ':' 40%-59% identical, '.' 20%-39% identical. We abstracted out the highly conserved activities, >40% and displayed them alongside a gold standard, based on the SMEs expectations of what activities should occur when. If an activity was weakly conserved in one set (20%-39%), low or high performance, and strongly conserved in the other set, it was displayed because it appeared to be conserved across groups.

5.5 Results

The results are presented in 5 sections. The first 3 sections: Subjects, Simulator, and Scenario, describe findings related to the setup and implementation of the simulations. The fourth section reports statistics and methodological issues regarding the coding framework. The last section, Analysis, presents results for each stage of the multiple alignments.

5.5.1 Subjects

Fire crew only		
Total number of Teams	# Low Performing Teams	# High Performing Teams
8	2	3
# Members	# EMTs	# Paramedics
5 ± 0	3 ± 0	3 ± 1
Fire & Transport crews		
Total number of Teams	# Low Performing Teams	# High Performing Teams
37	8	7
# Members, Fire	# EMTs, Fire	# Paramedics, Fire
4 ± 1	3 ± 1	1 ± 0

# Members, Transport	# EMTs, Transport	# Paramedics, Transport
2 ± 0	1 ± 1	1 ± 1

Table 6: We recruited teams that were composed of fire crews and fire & transport crews. Here, we report the number of members and their education levels using the median and median average deviation.

We initially recruited 47 EMS teams to participate in prehospital pediatric teams. Two teams were not included in the analysis due to administrative errors on the consent forms used in 2 simulation days. Table 6 provides a summary of the teams. Eight teams consisted of engine and transport fire crews only, while 37 teams consisted of both fire and transport crews. The fire-only crews had a median of 5 members, with about 3 EMTs and 2 paramedics. Teams with both fire and transport crews had a median of 6 members, 4 from fire and 2 from transport. At least one member of the fire crew was a paramedic while the rest were EMTs. The transport crews typically had 2 members: 1 paramedic and 1 EMT.

Wereviewed 45 NAT simulations and excluded three simulators due to poor video quality. In one video, the camera was not angled to view interventions on the patient for the entire simulation. In the second video, the audio cut out midway through, making it difficult to verify the occurrence of certain activities. The third video started recording late, which prevented observation of initial activities.

Low and high performing teams were equally distributed in the fire and fire + transport groups. Teams usually self-assigned the Person in Charge (PIC) before the simulation and assigned other roles during the simulation, e.g., who was setting up equipment, scribing, performing compressions.

5.5.2 Outcomes

We measured inter-observer coding agreement at 58% (22/38 codes). Seven of sixteen disagreements corresponded to differences in the times that cardiopulmonary resuscitation (CPR) and bag valve mask (BVM) ventilation were paused and resumed. Five of the sixteen disagreement corresponded to missing pulse and breath checks. Pulse checks were difficult to detect because team members would occlude view of the patient when performing this task. Breathing was difficult to detect because it could be assessed only by viewing chest rise or listening for breath sounds. The four remaining disagreements occurred due to the ambiguity of whether a task was being performed or not. For example, if the paramedic is gripping the BVM's face-mask on the patient, this could also be counted as stabilizing the patient's cervical spine. Given that each code had four degrees of freedom, we found this level of agreement acceptable, and proceeded with coding.

Low Performing Team (CTS ≤ 4)			High Performing Team (CTS ≥ 8)		
Group	**CTS Score**	**# Activities**	**Group**	**CTS Score**	**# Activities**
3	3	29	2	8	23
6	4	27	4	10	16
13	3	18	7	10	21
16	3	18	8	9	26
18	4	34	10	8	36
28	4	29	17	8	27
30	3	24	19	8	29
35	1	21	20	8	27
36	4	32	27	8	53
47	4	34	46	8	26

Table 7: Summary of individual simulations

The 42 NAT simulations had a median of 29±3 activity codes, with a minimum of 16 and a maximum of 51. The maximum was an extreme outlier in which a participant was overloaded trying to simultaneously use the BVM and apply EKG leads. Table 7 shows the CTS scores and activity count of simulations across levels of performance. The low performing teams had a median of 28±5 activities and the high performing teams had a median of 27±3 activities. The counts of activities are not normally distributed, and the Mann-Whitney U test showed no significant difference across performance levels.

Activity	Freq all teams	Freq LP teams	Freq HP teams
First arrival	1±0	1±0	1±0
Second arrival	1±0	1±0	1±0
Expose	1±0	1±0	**2±1**
Check physical status	1±0	1±0	1±0
Check mental status	1±0	1±0	1±0
Check breathing	3±1	3±1	3±1
Check pulse	**4±1**	3±1	3±1
Measure length	1±0	1±0	1±0
Attach pulse oximeter	1±0	1±0	1±0
Attach end-tidal CO2 monitor	1±0	**2±0**	1±0
Attach EKG (pads or leads)	1±0	1±0	1±0
Attach blood pressure cuff	1±0	1±0	1±0
Maintain cervical spine	1±0	1±0	**2±1**
Intubate	1±0	1±0	1±0
Ventilate with Bag Valve Mask (BVM)	4±1	4±1	4±2
Do cardiopulmonary resuscitation (CPR)	4±2	4±2	**2±0**
Establish an IO/IV line	1±0	1±0	1±0
Administer drugs	1±0	1±0	1±0
Transport the patient	**2±1**	1±0	1±0

Table 8: The median ± median average deviation of task frequencies for all teams, low performing teams, and high performing teams.

Table 8 shows the frequency of codes in all teams, low performing teams, and high performing teams. Teams performed the same tasks with the same number of attempts, save for a few differences. Low performing teams made more attempts attaching the end-tidal CO2 monitor and applying CPR. High performing teams made more attempts exposing the child for physical assessment and maintaining cervical spine. These differences were within one median average deviation of one another across performance groups.

5.5.3 Analysis

The number and types of events between low and high performing teams were similar, but the sequence of events were highly varied. This finding could be attributed to how the activities of multiple team members were collapsed into a unidimensional sequence. We nevertheless identify conserved events between them, because the expected procedure is algorithmic in nature and a core part of EMS training.

5.5.3.1 Pairwise Alignment

The pairwise similarity scores for the simulations were normally distributed with a mean of 50±8% and range of 29% to 72%. We also identified pairs that had a similar sequence of activities and divergent CTS™ scores. Groups 35 and 25 had a similarity of 71% and CTS™ scores of 1 (poor) and 5 (fair) respectively. The former group displayed little communication, whispered, used the two-thumb technique for compressions on an infant mannequin, and made bagging errors. The latter had adequate communication, but administered a ten-fold epinephrine overdose. Groups 46 and 47 had 53% similarity with CTS™ scores of 8 (good) and 4 (fair) respectively. The former group started BVM and ETCO2 early, while the latter group used an oxygen mask instead of BVM and intubated without attaching the pulse oximeter or obtaining IV access.

In these cases, the major indicators of performance depended on communication and task quality, which were not encoded in the sequence alignment. Also, variations in individual tasks could cause slight variations in the alignment, but have significant implications for patient outcomes.

5.5.3.2 Guide Tree

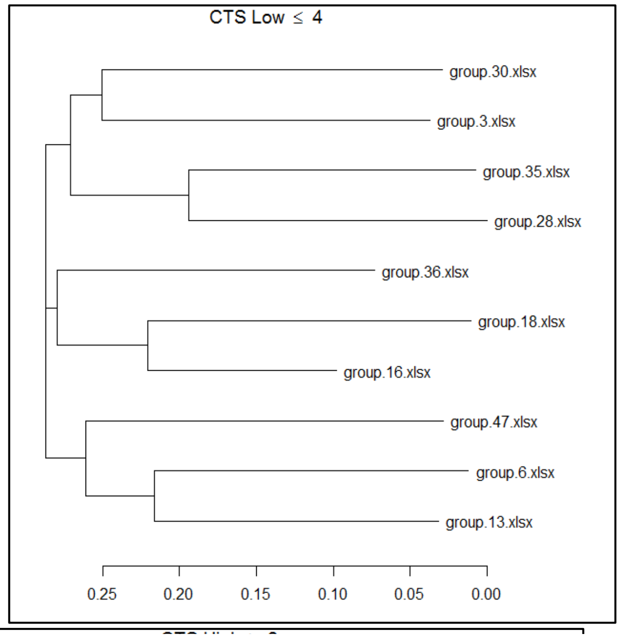


Figure 7: Guide trees of low (CTS ≤ 4) and high (CTS ≥ 8) performing teams

No meaningful clusters were found in the guide trees. Visual inspection seems to indicate that the low performing teams could be split into 3 groups and high performing teams 1 group with 3 singletons.

		Number of clusters							
		2	3	4	5	6	7	8	9
Low	Connectivity	2.67	7.17	9.17	9.17	10.33	12.33	14.33	16.33
	Dunn	0.79	0.86	0.76	0.81	0.89	1.00	1.02	0.87
	Silhouette	0.09	0.10	0.07	0.13	0.14	0.13	0.09	0.04
High	Connectivity	3.67	4.17	6.50	8.50	11.50	13.50	14.83	16.33
	Dunn	0.81	0.81	0.78	0.79	0.82	0.80	0.97	1.29
	Silhouette	0.08	0.03	0.01	0.06	0.09	0.06	0.09	0.06

Table 9: Validation of guide tree clusters

The connectivity metric indicates that the teams can be placed in 2 or fewer clusters. The Dunn Index indicates that the low performing teams could be split into 3 groups or more, while the optimal split for high performing groups is undetermined. The average silhouette widths indicate that no substantial structure was found in either group.

5.5.3.3 Multiple Alignment

group / position	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
13	Fst	---	---	---	Bre	---	Pul	Tra	Pox	---	---	---	---	Exp	---	---	---	---	---	Ekg	---	Bvm	Bre	---	Bre	---	---	---	---	Iov	Bre	---	---	Bvm	---
6	Fst	---	---	---	Snd	---	Pul	Phy	Pul	---	---	---	---	Exp	---	Bre	Exp	Pox	Phy	Ekg	Bre	Bvm	Bre	---	Exp	---	---	---	---	Tra	---	---	---	Bvm	---
47	Fst	Men	---	---	Bre	---	Pul	Tra	Cpr	Bvm	Bvm	Len	---	Exp	---	Bvm	Exp	---	---	---	---	Bvm	Ekg	---	Pul	---	---	---	---	Pul	Bpc	---	---	Bvm	Cpr
16	Fst	---	---	---	---	---	Pul	Bre	Bre	---	---	---	---	---	---	---	---	Pox	---	---	---	---	---	---	Pul	---	Len	Cpr	---	Int	Bpc	---	---	Bvm	Int
18	Fst	Men	Phy	Cpr	Bre	---	Pul	Cer	Bre	Pul	Phy	Snd	Ekg	Bvm	---	Cpr	Cpr	Pox	Bpc	---	---	Iov	Cpr	---	Pul	Cpr	Len	---	---	Int	Dru	Ent	---	Bvm	---
36	Fst	---	---	---	Bre	---	Pul	Snd	Bre	---	---	---	Ekg	Exp	---	---	---	---	---	---	---	---	Bre	---	Pul	Cpr	Pox	---	---	Tra	Bvm	Tra	---	Bvm	Cpr
28	Fst	Pul	Men	---	---	---	Pul	Cpr	Pox	Exp	---	Cpr	Ekg	Exp	Bvm	Cpr	Len	Cpr	Exp	---	---	---	---	---	Pul	---	---	---	---	---	---	---	---	---	Cpr
35	Fst	---	---	---	---	---	Pul	Cpr	---	---	---	Snd	Ekg	Exp	---	Cpr	Len	Ekg	Bvm	Pox	---	---	---	---	Pul	---	---	---	---	---	---	---	---	---	Cpr
3	Fst	---	---	---	---	---	Pul	Pul	---	---	---	Snd	Ekg	---	---	Bre	Pul	Pox	---	---	---	---	---	---	Pul	Bre	Phy	Bre	Bre	Tra	Bre	Men	Len	Pul	Cpr
30	Fst	---	---	---	---	---	Pul	Exp	---	---	---	---	---	---	---	Bre	Len	Pox	Ekg	---	---	---	---	---	Pul	---	---	---	---	---	---	Men	Bpc	Men	Cpr
conserved low	#	.			:		#	.	.			.	:	•		.	.	:		.		.	.		#	.	.			.	.	.		•	•
19	Fst	---	---	---	---	---	Pul	---	---	---	---	---	Pul	---	---	Bre	---	Pox	Bre	Exp	Phy	---	---	---	Snd	---	---	---	Bvm	Exp	Bvm	Bre	---	---	---
2	Fst	Phy	---	---	---	Cer	Pul	---	---	---	---	---	Pul	---	---	Bre	---	Pox	Ekg	---	---	---	---	---	Snd	---	---	---	Bvm	---	Bvm	Cpr	Cpr	Pox	---
10	Fst	Exp	---	---	---	Snd	Pul	---	---	---	---	---	Pul	Phy	---	Bre	Exp	Cer	Bre	---	---	---	---	---	Pul	---	---	---	Bvm	---	---	---	---	---	---
4	Fst	---	---	---	---	Snd	Pul	---	---	---	Phy	---	Pul	---	---	---	---	---	Ekg	Cer	---	---	---	---	---	---	---	---	Bvm	---	---	---	---	---	---
8	Fst	Pul	Cer	Pul	Bre	Snd	Pul	Len	Pox	Exp	Phy	Bvm	Pul	Ent	---	Cpr	Iov	Cpr	Ekg	Bpc	Int	---	---	---	Cpr	---	---	---	Bvm	---	---	---	---	---	---
17	Fst	---	---	---	---	---	Pul	Bre	Ekg	---	---	---	Pul	---	---	---	---	Pox	Cer	Bpc	Len	---	---	---	Cpr	Cpr	---	---	---	---	---	---	---	---	---
27	Fst	---	---	---	---	---	Pul	Bre	Bvm	---	---	---	Cer	---	---	---	---	Exp	Cer	Exp	Bvm	Exp	Pul	Snd	Cpr	Cpr	Cpr	Len	Bvm	Ekg	Bvm	Ekg	Bvm	Ekg	Bvm
46	Fst	Men	---	---	---	---	Pul	Bre	---	---	---	---	Pul	Snd	---	Bre	Bvm	Pox	Ekg	Ent	Len	---	---	---	Cpr	Pul	---	---	---	---	---	---	---	---	---
7	Fst	Phy	---	---	---	Snd	Pul	Bre	Exp	---	---	---	Pul	---	---	Bre	Bvm	Pox	---	---	Len	---	---	---	Cpr	---	---	---	---	---	---	---	---	---	---
20	Fst	---	---	---	---	---	Pul	---	---	---	---	---	Pul	---	---	---	Bvm	Pul	Snd	Cpr	Len	Pul	---	---	Cpr	---	---	---	---	---	---	---	---	---	---
conserved high	#	.				:	#	:			.		#			:	.	:	.	.	:				.	.			•		.				
conserved all	#				.	.	#	.					:	.		:		:	.		.				:	.			.		.			.	.

group / position	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
13	---	---	Bvm	---	---	Len	Int	---	---	---	---	---	---	---	---	---	---	---	Bvm	Bre	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
6	---	---	Bvm	Bpc	---	Len	Cpr	Ent	Bvm	Cpr	---	---	---	---	---	---	---	---	Bvm	Bre	Iov	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
47	Int	---	Bvm	---	---	Int	Cpr	Pox	Bvm	Cpr	Pul	---	---	---	---	---	---	---	Cpr	Bre	Ent	Pul	Pul	Pul	Ent	---	---	---	---	---	---	---	---	---	---	---
16	---	---	Bvm	---	---	Iov	Int	---	Bvm	Cpr	---	---	---	---	---	---	---	---	Bvm	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
18	---	---	Bvm	---	---	Ent	---	---	Bvm	Cpr	---	---	---	---	---	---	---	---	Bvm	Bre	---	---	Cpr	---	---	---	---	---	---	---	---	---	---	---	---	---
36	---	---	Bvm	Pul	Pul	Iov	Cpr	---	Bvm	Cpr	Ent	Cpr	---	---	---	---	---	---	Bvm	Bre	Pul	Bvm	Cpr	Len	Bre	---	---	---	---	---	---	---	---	---	---	---
28	Iov	Ent	Bvm	---	---	Dru	Pul	Ent	Tra	---	Pul	---	---	---	---	---	---	---	Bvm	Tra	Bvm	Pul	---	---	---	---	---	---	---	---	---	---	---	---	---	---
35	---	---	Bvm	Iov	---	Dru	Men	Bpc	---	---	Pul	---	---	---	---	---	---	---	Bvm	Phy	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
3	---	---	Bvm	Cpr	---	Cpr	Cpr	Iov	Dru	Cpr	Pul	---	---	---	---	---	---	---	Bvm	Cpr	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
30	Cer	---	Bvm	Pul	---	Cpr	Pox	Iov	---	---	Pul	Phy	---	---	---	---	---	---	Bvm	Cpr	Dru	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
conserved low			#	.		.	.	.	:	•	:								#	:		.	.													
19	Len	Bre	Bvm	---	---	Iov	Ekg	Tra	Bvm	Bpc	---	---	---	---	---	---	---	Tra	Bvm	Tra	Int	---	---	Bvm	Bre	---	Ent	---	Bvm	---	---	---	---	---	---	---
2	Pul	Bre	---	---	---	Iov	Men	Bre	Dru	---	---	---	---	---	---	---	---	Tra	Bvm	Cpr	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
10	Pul	Bre	Pox	---	---	Iov	Len	Tra	Cpr	Cpr	Ekg	Ent	Cer	Pul	Pul	Tra	Pul	Tra	Bvm	Bpc	Bvm	---	---	Int	Bre	---	Ent	---	Bvm	Bre	---	---	---	---	---	---
4	Len	Bre	Cer	Cpr	---	Iov	Ekg	---	Cpr	---	---	---	---	---	---	---	---	Tra	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
8	Bre	Bre	Cer	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Tra	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
17	---	---	Bvm	Ent	---	Iov	---	---	Bvm	---	---	---	---	---	Cpr	---	Cpr	Int	Bvm	---	Int	---	Cpr	Bvm	Bre	Pul	Cpr	Tra	---	---	---	---	---	---	---	---
27	Ekg	Ekg	Bvm	Cer	---	Iov	---	---	Bvm	Ekg	Pul	Dru	Cer	Bvm	Cpr	Bvm	Cpr	---	Bvm	Cer	Int	---	Cpr	Bvm	Bre	Dru	Int	Cer	Int	Cer	Bvm	Ent	Bvm	---	---	---
46	---	---	Bvm	---	---	---	---	---	---	---	Pul	---	---	---	Cpr	---	Iov	Int	Bvm	---	---	---	---	---	Bre	---	Ent	---	Bvm	Pul	Bvm	---	Bvm	---	---	---
7	---	---	Bvm	---	---	---	---	---	---	Ekg	Pul	Iov	---	---	Cpr	---	Cer	Int	Bvm	---	---	---	---	---	Bre	Iov	Ent	---	Bvm	---	---	---	---	---	---	---
20	---	---	---	---	---	---	---	---	---	---	Pul	---	---	---	---	---	Iov	Int	Bvm	---	---	---	Ekg	Pox	Bre	---	Ent	Bpc	Bvm	Bvm	Bvm	Tra	Bvm	Tra	Bvm	Bvm
conserved high	.	:	.			•	.	.	.	.	:		.		:		.	:	#		.		.	.	•		:		:		.		.			
conserved all		.	•			:	.		:	.	:				.			.	#	.			.		:		.		.							

Figure 8: Multiple Sequence Alignment of clinical tasks in prehospital pediatric simulations

Approximate time	0:00	0:10	0:15	0:40	1:30					2:30																
Gold standard	Men	Bre	Pul	Bvm	Ekg					Iov																
Approximate time	0:00		0:26		1:34	1:35	1:02	1:48		3:01		5:45	3:47				8:10	8:29	8:18			9:17	8:43			
Low performance	Fst		Pul		Ekg	Exp	*Bre*	Pox		Pul		Bvm	Cpr				Bvm	Cpr	Pul			Bvm	Bre			
Approximate time	0:00		0:24		1:03		1:04	1:40	2:28	3:35	3:07			4:43	4:21	4:23			5:31	6:51	7:49	8:09		9:10	9:46	10:04
High performance	Fst		Pul		Pul		Bre	Pox	Len	*Cpr*	Bvm			Bre	*Bvm*	Iov			Pul	Cpr	Tra	Bvm		Bre	Ent	Bvm

Figure 9: Simplified multiple alignment showing conserved activities and average times at which they occurred. Weakly conserved elements are highlighted in gray.

The multiple alignments identified sets of activities that were conserved across groups. The profile-profile alignment between low and high performing teams is shown in Figure 8, while a simplified version of the alignment shown in Figure 9. The simplified version compares the conserved activities against a gold standard. Missing activities, such as transporting the patient, does not mean that the activity was not performed, but that teams performed them at different times.

Low performing teams setup the EKG monitor, exposed the mannequin for physical assessment, and checked breathing earlier than high performing teams. On average, CPR was applied before BVM, with BVM starting much later in some cases. High performing teams had more conserved tasks, indicating that they implicitly followed a common process, and most tasks were performed earlier than the low performing teams. They applied BVM before CPR, established an IO/IV line, and transported the patient once vitals were stabilized. Half of the low performing teams, in contrast, transported the patient early in the simulation due to environmental cues of abuse.

5.6 Discussion

In this study, we use multiple sequence alignment to explore the differences in performance between EMS teams responding to simulated pediatric trauma codes. We do so by observing and coding the treatment they provide toward the patient, mapping those codes onto a unidimensional sequence, and using ClustalG to align those sequences across teams.

We have observed that teams perform approximately the same number of activities, which suggests that variations in performance are due to task quality or task sequence. For example, evaluators have commented on the CTS™ forms that some participants did poor bagging, pushing too much air by fully squeezing and adult-sized BVM; poor CPR quality, poor leadership, not assigning roles; etc.

The sequence analysis indicated that the order of tasks highly varied across teams, which could be attributed to two reasons. First, the teams have many degrees of freedom by which they can observe symptoms, diagnose problems, and treat underlying causes. For example, any combination of team members can check pulse, breathing, physical status, mental status, or attach equipment to track vitals. Once they observe an anomalous reading, they can then choose to treat, medicate, or transport. These systems of activity have a certain tolerance for variation in behavior, but can be sensitive to isolated events. For example, pulse checks can occur spontaneously and opportunistically to periodically check on the patient's status. If the patient is not breathing, however, teams are expected to initiate ventilation in the first minute of the encounter to prevent the patient from deteriorating further. Certain tasks are more critical than others in treating the patient successfully.

The second reason for variation is that that team activity is not well represented through a unidimensional sequence of symbols. Many of the observed activities were performed by different team members in parallel for different durations of time, thus demonstrating that teamwork is inherently multidimensional and temporal in nature. Researchers have addressed these limitations of alignment in modeling individuals' activities. Joh et al deconstructed sequences by their dimensional properties and reassembled them for the final alignment.[116] Kwan et al used Pareto ranking to score matches between multidimensional events.[117] Shoval dealt with the temporal problem by having each symbol in the sequence represent a minute of activity.[42] Syed and Das do the same, but treat transitions between events as explicit gaps.[118] These approaches look promising, but do not directly address sequences with overlapping symbols.

Despite the variation, there appeared to be a series of tasks that were heavily conserved and performed at similar times by EMS teams throughout the simulations. This series included checking for vitals, setting up equipment, and iterations of CPR and BVM ventilation. These conserved tasks could be interpreted as a "genotype" of activity whose ancestry is rooted in training and experience. Paramedics and EMTs are presumably taught the same material and mutations/variations arise when that material is applied in a novel situation. This activity could serve as the basis for a model, describing what events are expected to occur.

Sequence alignment provides a method to explicitly and systematically describe how team behavior varies across different levels of performance. For example, the low performing teams consistently setup monitoring equipment before proceeding with CPR and BVM. Low performing teams also seemed more primed to look for and treat a particular condition. In this case, it involved detecting a low pulse followed by CPR. For future work, we intend to target such points of deviation for interventions to improve team performance. We will also explore different algorithms for improving the quality of alignments for team activities.

5.7 Conclusion

Sequence alignment is a promising tool for describing variation in team behavior, but could use improvements to account for the multidimensionality and temporality of team activities. We find that it can be used to identify conserved tasks and points of deviation that could explain differences in performance across teams. Furthermore, it can be used to develop more accurate process models based on actual data.

Chapter 6

Using Process Mining to Model Variation of EMS Team Activity

6.1 Abstract

Background: EMS professionals are trained to work in teams adhere to best-practices guidelines. They may deviate from these guidelines for a variety of reasons, and these deviations may lead to delays or errors that cause harm to the patient. A number of simulation-based studies have identified isolated causes of errors, but few, if any, take a holistic approach to describing how dynamic processes affect team performance.

Objective: We demonstrate that process mining techniques can be used to identify variations in process that distinguish low and high performing EMS teams during prehospital pediatric simulations.

Methods: We recruited Emergency Medical Service teams from a major metropolitan city in the US to participate in a series of prehospital pediatric simulations. SMEs evaluated team performance using the CTS™. We recorded the simulations and coded events, where an event specifies patient-centric tasks, start time, end time, and the subject performing it. The events were placed into a log files using the Extensible Event Stream (XES) standard and were organized into two files: low performing teams (CTS < 4), and high performing teams (CTS > 6). ProM, the process mining workbench, was used to analyze the log files.

Results: Low and high performing EMS teams perform the same set of tasks, though with a different order of prioritization. Low performing teams place a greater emphasis on CPR and perform tasks that delay treatment: setting up the EKG monitor and transporting the patient to the ambulance. The high performing teams recognize the need for ventilation support and maintain it throughout the simulation.

Conclusion: We use process mining techniques on an atypical set of data, observational codes, to gain insight on process-related factors that distinguish low and high performing teams.

6.2 Introduction

In prehospital pediatric care, EMS teams are trained to adhere to guidelines and treat patients in a standardized manner. Variations occur in practice for a variety of reasons,[119] which can lead to errors that are harmful to the patient.[77,85] It has long been recognized that the health care delivery environment can have latent factors that make errors more likely and that errors are rarely sourced to a single cause or individual.[100] It is therefore useful to evaluate clinical teams holistically to understand how processes of care lead to good or bad outcomes.

6.3 Background

Process mining is a relatively new research discipline that is concerned with extracting knowledge from event logs to describe and enhance real-world processes.[45] An event log contains a set of cases. Each case contains a trace, or list of ordered events that occurred.[120,121] An event specifies a case, a well-defined step in the workflow, performer, and timestamp. There are three categories of analysis that are performed on event logs: *discovery*, *conformance*, and *enhancement*.[45]

Process models are represented as graphs, with nodes as tasks and edges as dependencies between tasks. Dependencies are *discovered* based on the relative order of events; e.g. if task A always precedes task B and task B never precedes task A, then B depends on A.[120,122] *Conformance* measures the degree to which a trace is represented by a model. A trace "fits" a model if the model can be used to parse the sequence of events, and a model is "appropriate" if it is minimal, or not overly generic.[48] For example, a fully connected graph would have high fitness and low appropriateness, whereas a graph with no connections would have the opposite characteristics. Lastly, *enhancement* involves updating the process model based on new logs or feedback from domain experts.

There have been a number of studies in healthcare that have applied process mining to describe[90,123–129] and compare[130,131] clinical workflows, which helped reveal inefficiencies and bottlenecks. All of these studies have been conducted in hospital settings using electronic logs that have been automatically generated by a computerized information system. We hypothesize that process mining can provide similar insights in the prehospital setting using observational data from pediatric trauma simulations.

Simulations are used in healthcare to provide training on critical events. [87,132] They often use mannequins that can receive treatment and emit vital signals in response, [133] allowing for the repeated observation of rare events with no risk to actual patients. [73] Most of the research regarding simulations has been focused on the development of technical skills, but there is a growing interest in the evaluation of team performance. [73,134,135]

6.4 Methods and Materials

We had 47 EMS teams participate in 4 pediatric simulations: cardiac arrest in newborn, cardiac arrest in child, accidental trauma, and non-accidental trauma. The simulations were recorded using an overhead GoPro™ and supplementary microphone. The EMS teams consisted of a 3-4 member fire crew and 2 member transport crew. The study was approved by the OHSU Institutional Review Board (IRB00006942). Participants signed both study and video consents and were given permission to opt out at any time. Participants were anonymized and identified by a colored tape in the videos.

In a previous study, we viewed, coded and aligned the patient-centric tasks that occurred in the non-accidental trauma simulations. This simulation made use of the SimNewB™ patient simulator from Laerdal™. The patient simulator was setup to emit vitals consistent with “shaken baby syndrome”. The EMS teams were expected to check the patient’s vitals, initiate ventilation support, attach monitors, and establish an IO or IV route. Two SMEs, JMG and MH, used the CTS instrument[1] to evaluate team behaviors with regards to communication, leadership, and decision making. The sequences, or trace of events, were grouped into files of low performing (CTS ≤4) or high performing (CTS ≥8) teams. We analyzed the same data in this study using process mining techniques.

6.4.1 ProM

There are several toolkits that can be used for process mining.[136] We have chosen to use ProM because it is open source, has several preexisting tools, and is most frequently used in academic community.[137, 138, 139] ProM currently has two major versions, 5.2 and 6.6, which have different levels of functionality and stability. We used the Heuristics Miner in version 6.6 to discover process models and the Conformance Checker in version 5.2 to evaluate the models.

6.4.2 Process Mining Pipeline

ProM has a large number of tools that perform different types of analysis on event logs and workflow models, which poses a threat to reproducibility. Researchers have consequently made recommendations to guide the application of process mining.

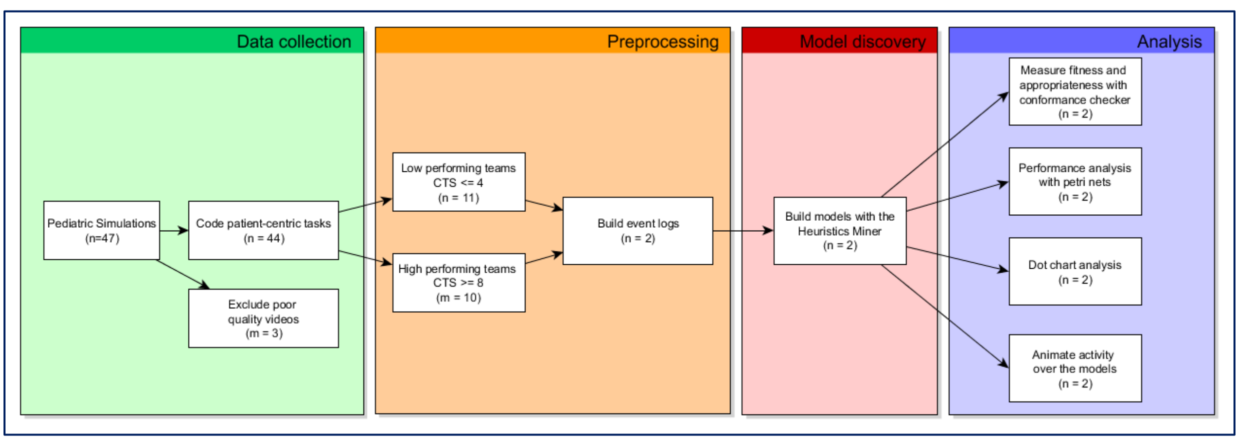


Figure 10: Process Mining Pipeline

Janssen identified patterns in the literature that consisted of the following phases: preprocessing, clustering, and mining.[140] Preprocessing includes extracting information from the computer information system, renaming events, aggregating duplicate events, and creating an event log. Clustering involves grouping traces together into homogenous subsets to improve process mining performance; e.g.

separating traces of an administrative process from traces of a surgery process. Mining results in a process model.

Mans et al[126] and Rebuge and Ferreira[128] analyzed hospital logs by three perspectives: control flow, organization, and performance. The control flow perspective is analogous to the mining step mentioned above. The organization perspective infers a social network based on the order of when people complete tasks. The process perspective attempts to identify inefficiencies by exploring the start, duration, and time between tasks.

We followed most of the recommended phases of analysis: data collection and preprocessing; control-flow analysis; and performance analysis. -We did not perform an organization analysis because the participants were anonymized and not recoded to any particular role.

6.4.3 Data Collection and Preprocessing

In most process mining studies, data is collected from logs generated by computer information systems and contain events that are irrelevant or belong to different processes. Our data is derived from observational codes of teams performing a single, pre-defined activity, which means that we do not have aggregate duplicate events or cluster traces by similarity.

In our data, a case is represented by a team responding to a simulated emergency call. A trace corresponds to the events that occurred, and an event corresponds to the interventions that were performed on the patient: e.g., check pulse, initiate BVM, administer drugs. The arrival of the first crew represents the start of the trace. An artificial end task was added to signify the end of the trace and improve the soundness of the mined process model. The cases were grouped into low (CTS ≤ 4) and high performing teams (CTS ≥ 8), and placed into files formatted according to the eXtensible Event Stream (XES) standard.[141]

6.4.4 Control-Flow Perspective

We used the Heuristics Miner[121] to discover process models for low and high performing teams. There are several tools that can be used to discover process models in ProM, but previous research has demonstrated that the Heuristics Miner can discover most control-flow structures, such as sequences, parallelism, forks, and loops in tasks[142,143]; and performs well on noisy, real-world data.[46] The Heuristics Miner works by counting the frequency of ordered events, AB versus BA, and selecting the dependency relationship with the stronger signal. There may be noise that indicates more sophisticated types of dependencies are possible: splits A→C AND/OR D, joins A AND/OR B → C, and long-distance relationships. Thresholds are applied to the frequency statistics to select the most prominent relationships for the model.

Process mining algorithms try to balance understandability and accuracy by constructing minimal models that maximally describe observed data.[46] It is important to check the quality of the resulting models to verify that they fit these criteria. The complexity of a model, which has been negatively associated with understandability,[144] can be measured by the average connector degree, the number of incoming and outgoing edges on a node, and density, the number of edges divided by the total number of possible edges. The accuracy of a model can be framed in terms of precision, recall, and F-score. Precision measures how well observed processes comply with a model and recall measures how well the model describes observed processes. We used the Conformance Checker,[48] to measure simple behavioral appropriateness and fitness, which are analogous to precision and recall.

Simple behavioral appropriateness is flawed in that it is biased by the structure of the model. It is recommended that this metric only be used for comparative means.[48] We used it to compare models of low and high performing teams because it is implemented in ProM, computationally efficient, and sufficient for our use case.

6.4.5 Performance Perspective

There is a collection of tools that are commonly used to explore the dynamics and performance of a clinical system.[145] Three of those tools, which are integrated into ProM, are dot charts, performance analysis with petri nets, and animations of activity over the model. The Dot Chart tool displays events as dots on a chart, with the time and event type as the X and Y axes.[129] This provides a high level view of the event distribution across all cases. The Performance Analysis with Petri Net tool measures the time between events and labels the waiting time as being low, medium, or high,[146] which helps to identify bottlenecks in the process that may slow teams down. The Fuzzy Miner in ProM is a discovery tool that can animate the transitions between task.[147] We did not using the Fuzzy Miner to discover a model, but to convert the heuristic models we do have into a fuzzy model. We then describe the activity at two minute intervals. The results are visually compared to identify differences in activity dynamics.

6.5 Results

We recorded 47 EMS teams participating in a series of prehospital pediatric simulations involving non-accidental trauma. Three simulations were excluded from analysis due to poor video and audio quality. The teams were composed of 6±1 members with expertise ranging from EMT to paramedic. They were anonymized and the members assigned roles during the simulations. There were 11 low performing teams (CTS ≤ 4) and 10 high performing (CTS ≥ 8) teams. We coded their patient-centric activities and placed them into log files based on performance.

6.5.1 ProM

We encountered a few missing and broken features which led us to using the two versions of ProM that are currently available. The first issue we identified was that the Heuristics Miner produces different results for the same input in version 5.2 and 6.6. We emailed the developers, posted questions on the forums, and read the version control logs, located at <https://svn.win.tue.nl/trac/prom>. We were not able to identify what changes were made, but they appear to be bug fixes in response to earlier feedback.[148] The model in version 6.6 contained fewer short, noisy loops and more comprehensible with respect to the observations. The second issue was that the Conformance Checker, a useful tool for evaluating model quality, was not implemented natively into version 6.6. A plugin and standalone application were made available,[149] but we found it less complicated to use the one implemented in ProM 5.2.

6.5.2 Process Mining Pipeline

The following sections describe the results from each stage of analysis.

6.5.3 Data Collection and Preprocessing

The number of tasks did not distinguish performance levels between teams. Teams with low CTS scores (CTS ≤ 4) performed a median of 25±5 patient-centric tasks over an average time of 10:57 minutes. Teams with high CTS scores (CTS ≥ 8) performed a median of 27±3 patient-centric tasks over an average of 10:45 minutes. The tasks had nonparametric distributions in low and high performing teams. There was no significant difference between these groups (Mann-Whitney U=44.5, p = 0.70).

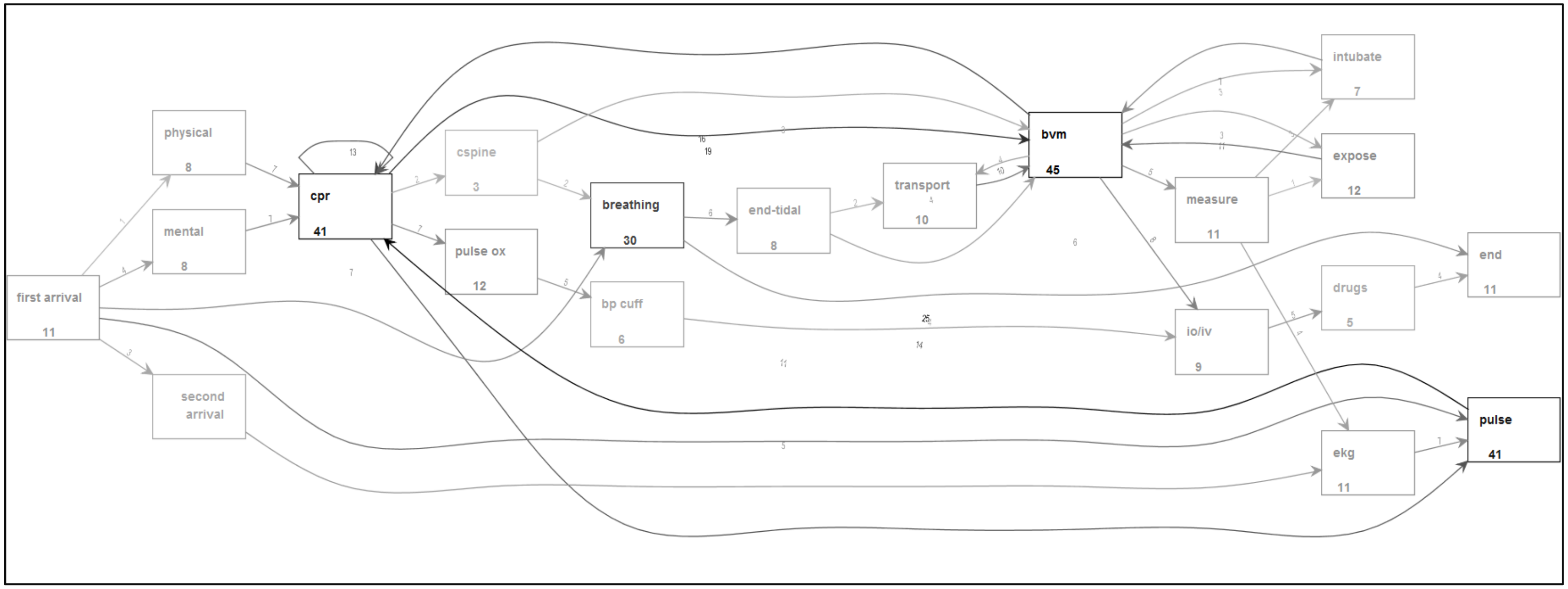
6.5.4 Control-Flow Perspective

The heuristic nets for the low and high performing teams are structurally similar, with approximately the same degree of connectivity and density.

	# Task Nodes	# Edges	Average Connector Degree	Density
Low (CTS ≤ 4)	19	71	3.74	0.21
High (CTS ≥ 8)	19	74	3.89	0.22

Table 10: Structural properties of heuristics models

There are few differences the activity surrounding certain tasks. The low performing teams seem to have more variability in the actions they perform, following first arrival. The top process model in Figure 11 indicates that different vitals may be checked first: physical status, mental status, pulse, and/or breathing; or setup the EKG monitor. They also have a greater degree of activity surrounding the CPR task. The model of high performing teams, in contrast, indicates that they check pulse or mental status first. They also have cervical spine, intubation, and transport nodes with a greater degree of connectivity to other tasks.



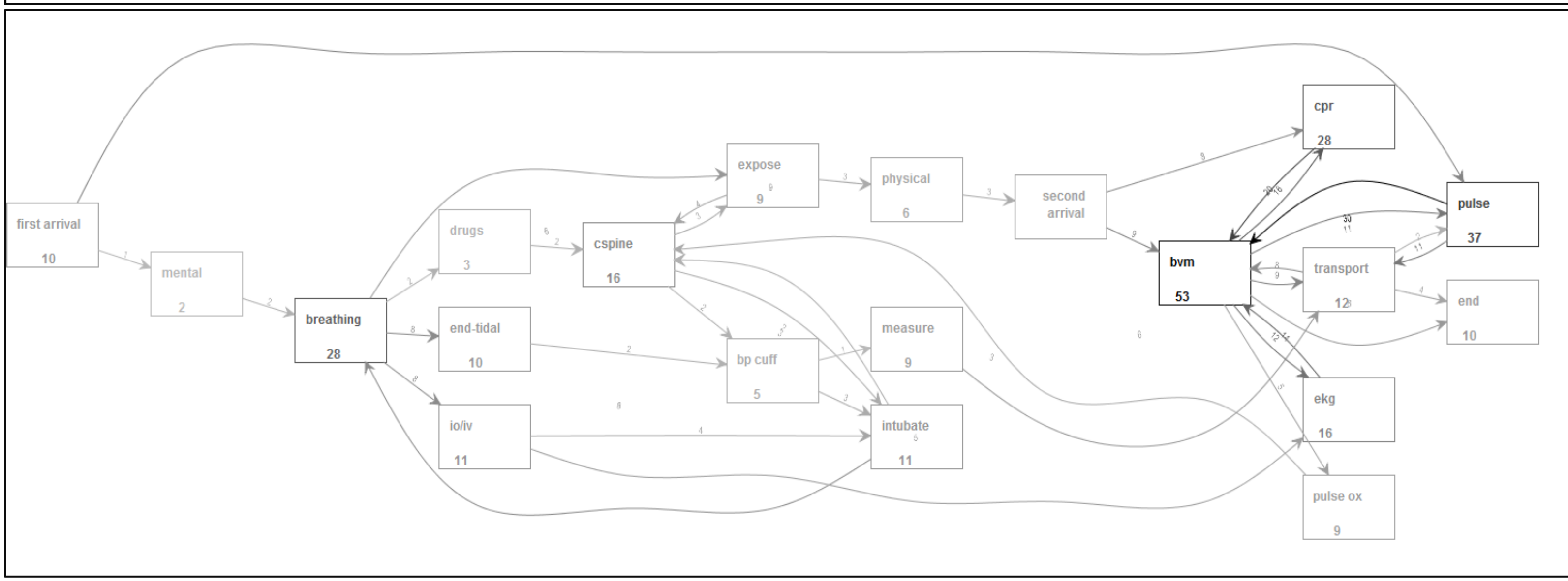


Figure 11: Heuristics models of low performing and high performing teams

In terms of quality, the models have approximately the same level of precision and recall.

	Appropriateness (a.k.a. Precision)	**Fitness (a.k.a Recall)**	**F1-score**
Low (CTS ≤ 4)	0.62	0.79	0.69
High (CTS ≤ 8)	0.62	0.80	0.70

Table 11: Quality of heuristics models

6.5.5 Performance Perspective

Performance analysis with petri nets revealed that the delays for most teams occurred between the first arrival and initial assessment of the patient. The petri nets Figure 12 highlight these delays as pink or yellow nodes. The delays lasted 10 to 20 seconds for both teams. One of the low performing teams was an outlier, and waited almost a minute before assessing the patient. The low performing teams had a noticeable delay between the arrival of the second crew and setup of the EKG. This time may have been spent orienting the second crew to the situation. There was also a delay between checking pulse and performing CPR. This delay could reflect difficulty in checking the mannequin's pulse or developing a care plan.

The petri nets also indicate that there was a delay between the arrival of the second crew and setup of the EKG, and between checking pulse and performing CPR. These delays were caused by a different team. The remaining transitions indicate that the wait times between tasks were low for both teams.

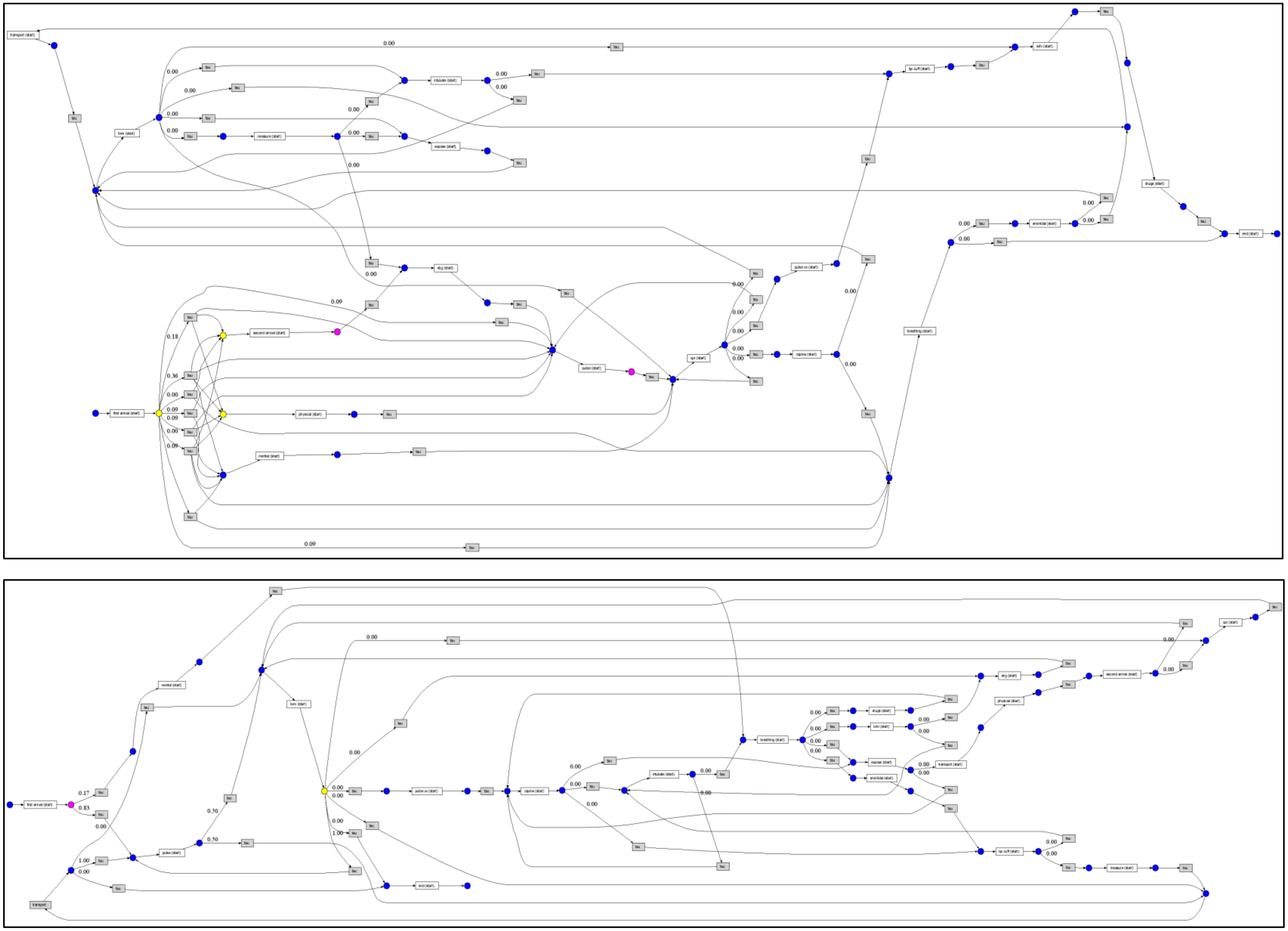
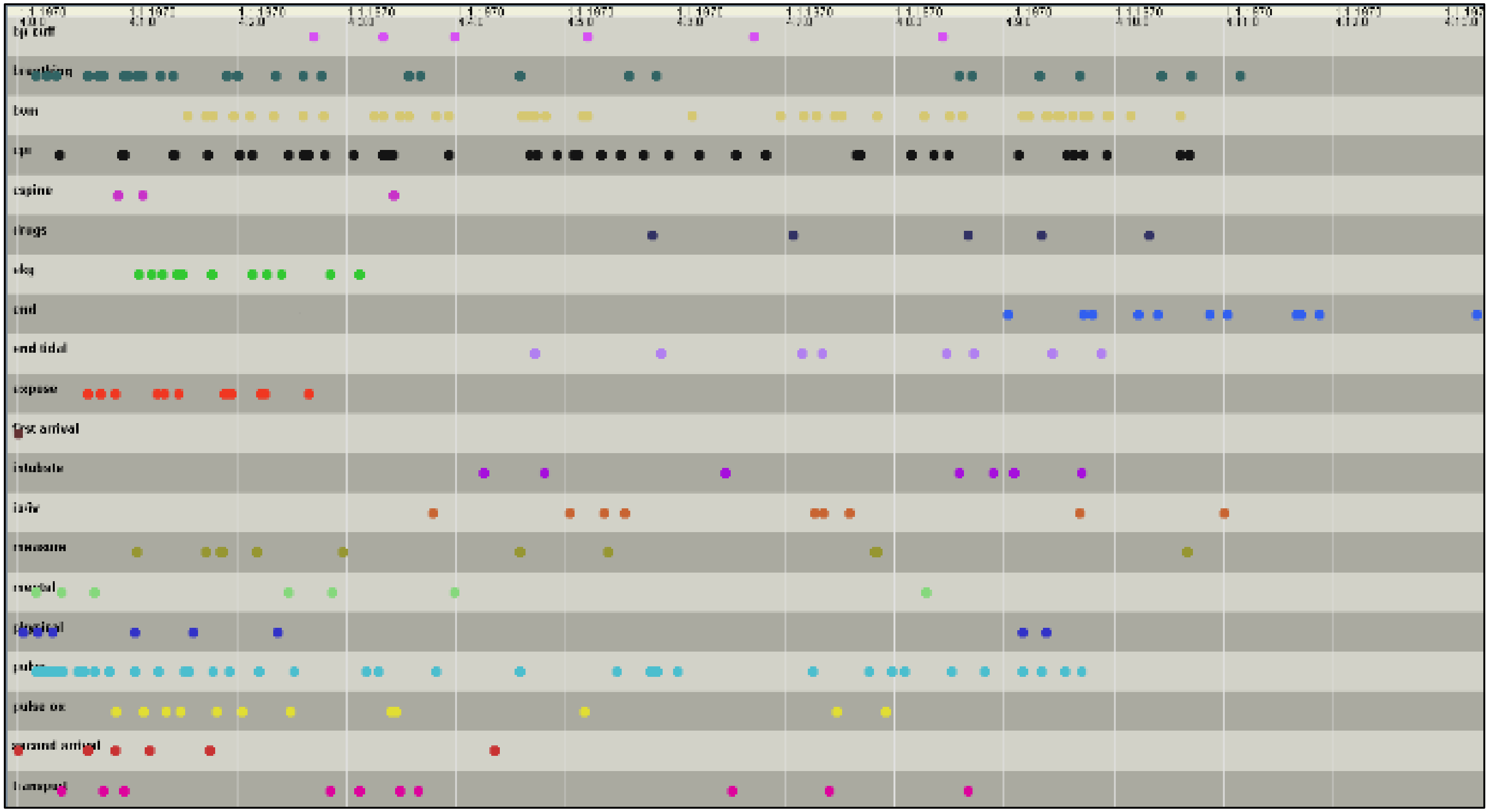


Figure 12: Performance analysis of the Petri nets for low and high performing teams.

The dot charts are useful for comparing the distribution of tasks across teams. Figure 13 indicates that the low performing teams, shown on the left, have a slight preference for applying CPR before the BVM. They are also more inclined to setup the EKG monitor and transport the patient earlier. The high performing teams, shown on the right, apply the BVM before or at the same time as when they initiate CPR. They place a stronger emphasis on maintaining the cervical spine and (recommended trauma protocol) are more inclined to transport after having provided life support (recommended in prehospital cardiac arrest).



drugs
end tidal
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first arrival
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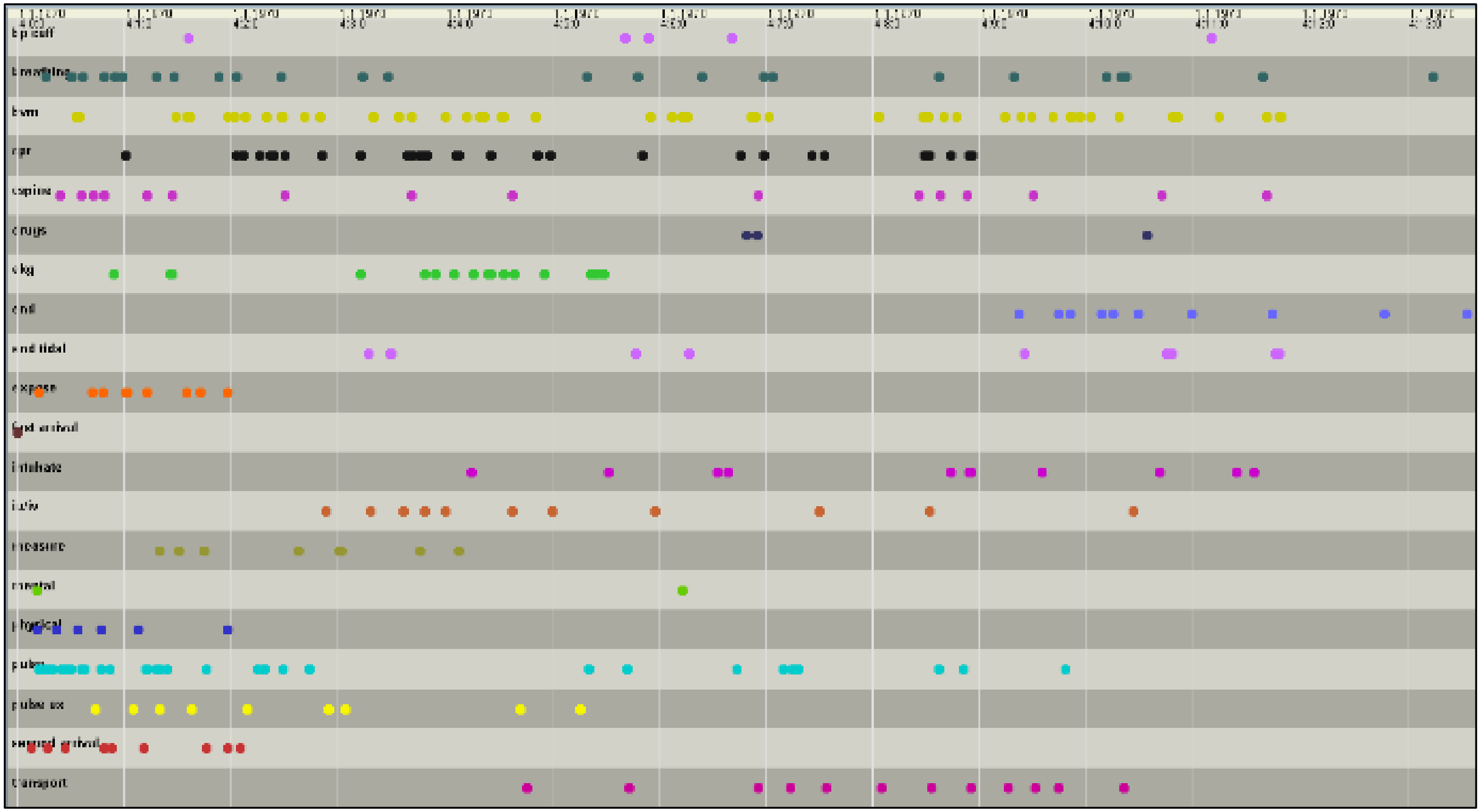

Figure 13: Dot charts of low and high performing teams.

In the low performance group, at minute 2, we observe that about half of the teams (4 of 10 low performing teams) have performed a pulse check and initiated CPR. There is some activity to apply the BVM (3/10), after having exposed the patient or initiating transport. At minute 4, half of the teams (5/10) have initiated transport or transported the patient to the ambulance, while maintaining CPR and BVM. Some teams (2/10) started to establish an IO/IV line. At minute 6, all of the teams were maintaining focus on CPR and BVM. About half the teams established an IO/IV line (4/10) and one administered drugs. At minute 8, most of the teams (7/10) have transported and established an IO/IV line. A few teams (3/10) started intubation. At minute 10, all teams performed routine checks on the patient's vitals and half had administered drugs.

In the high performance group, at minute two, all teams assessed the patient's breathing status. At this time, the second crews were arriving and half of the teams (6 of 10 high performing teams) were maintaining cervical spine (following trauma protocol), attached the pulse oximeter (4/10), and applied the BVM (5/10). At minute four, the teams had measured the patient (8/10, required for medications and equipment sizing), were maintaining cervical spine (4/10), applying BVM (10/10), and performing CPR (6/4). Half of the teams (5/5) established an IO/IV line and attached the EKG monitor. At minute 6, the teams focused on applying BVM (10/10), and some (3/10) were starting to intubate the patient. At minute 8, the teams (4/10) transported the patient to the ambulance, while maintaining BVM. The teams (3/10) that performed intubation followed up with breath checks. At minute 10, the teams finished transporting (6/10) and intubating (7/10) the patient. At this point, they still maintained BVM (10/10), but discontinued CPR (10/10).

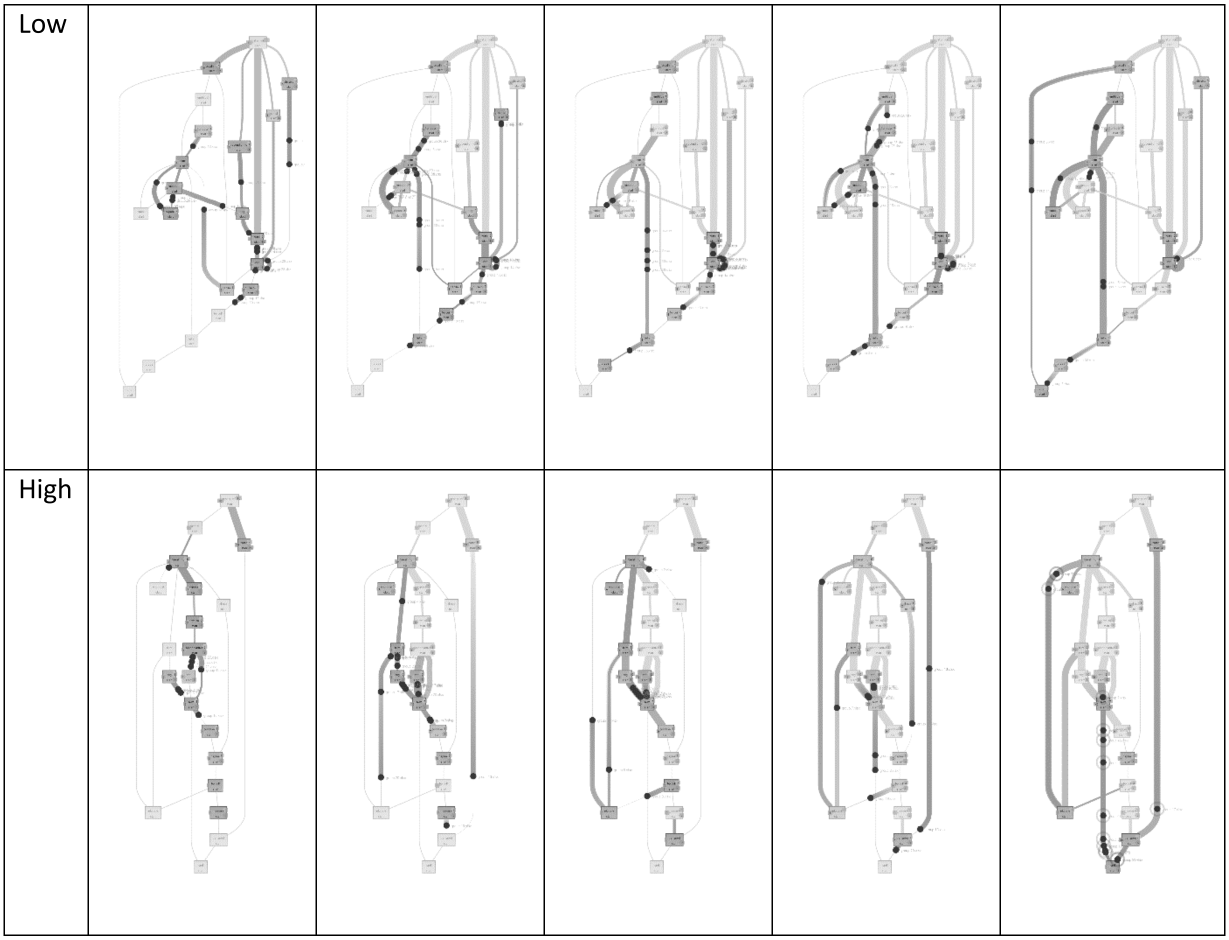

Figure 14: Animation sequences for low and high performing teams.

6.6 Discussion

We performed a comparative analysis on prehospital pediatric systems using the process mining tools provided by ProM. Our findings indicate that both high and low performing teams carried out the same set of tasks, but in a different order. Specifically, low performing teams preferred to perform CPR, setup the EKG monitor, and transport earlier. We hypothesize that the low performing teams may be less familiar with pediatric guidelines and are may be applying their knowledge of adult treatment algorithms. This finding is consistent with post-survey responses and debriefs, in which some participants expressed anxiety over not having sufficient knowledge.

Tasks, such as setting up the EKG monitor and transporting, were not inappropriate, but when out of sequence, could cause delays in higher priority treatments. The EKG monitor provides important feedback on the patient's stability and guides subsequent decision making. This task, however, involved removing the patient's clothes and attaching leads or defibrillator pads. The leads required fine motor skills to disentangle the wires and attach to a small baby. The leads often fell off the patient's silicone skin and needed reattachment. The defibrillator pads also had wires to disentangle, and a strong adhesive that could stick to anything, but the patient. Regarding transport, we provided cues that suggested the environment was not safe. The scene consisted of an apathetic boyfriend in a disheveled home, who was verbally abusive on the phone during EMS care. This behavior led some teams to prioritize crew safety by moving the patient to the ambulance before providing CPR or ventilation support.

The high performing teams, in contrast, seemed to focus immediately and consistently on providing effective ventilation support. ProM can animate activity by displaying tokens that progress from node to node on the process model. These animations show if tasks are performed at similar times across a group of teams. The animations appeared to be less scattered in the high performing teams versus the low performing teams, suggesting that the high performing teams recognized and followed the same course of action with less variability. They may have had the requisite knowledge to respond more efficiently in this case.

Process mining was useful in describing behavior in complex sociotechnical systems, such as an EMS team. We have demonstrated that such techniques can be used on observational codes and not just computer generated logs. Thus, process mining could be applied to other types of qualitative research if the observations come from repeated samples of the same underlying process. While process mining describes what systems do, it is outside its scope to explain why a particular course of action occurred. Other research communities have identified that leadership, communication, and coordination, play key roles in promoting effective teamwork.[1,51,150] Future work should involve overlaying other types of information, such as communications, onto the foundation that the process models provide. This approach would then provide a useful framework for determining whether certain individual behaviors cause a given process.

6.7 Conclusion

In this work, we have demonstrated that process mining provides insight into factors that distinguish low and high performing EMS teams during prehospital pediatric trauma simulations. We specifically found that low performing teams focused on applying CPR, attaching EKG monitors, and transporting early. High performing teams, in contrast, correctly recognized the need for and applied ventilation support from minimal assessment. These insights were derived from manually-collected observational codes, which is atypical for any process mining study, further demonstrating that process mining has untapped potential for other scientific endeavors.

Chapter 7

Description of EMS Teamwork Involved in Process Variations

7.1 Abstract

Background: EMS providers follow best-practice guidelines to treat and transport patients in serious conditions. Process variations can lead to delays or errors that ultimately harm the patient.

Objective: The objective of this study is to describe team interactions indicative of process variations associated with high and low performance in simulation.

Methods: In previous work, we recruited 47 EMS teams to participate in prehospital pediatric trauma simulations. A process model was constructed by aligning the sequence of patient-centric tasks in high performing teams. The model included tasks that were included in >50% of the teams, and excluded the other tasks as noise. One high and one low performing team were selected for comparative analysis. Their process sequences were aligned to the model. A task performed by teams, compare to the model, could represent a: 1) match, 2) deletion, 3) insertion, or 4) mismatch in the model. We specifically analyzed behaviors around insertions and mismatches, because they offered the most potential for insight regarding how teams behaved. The behaviors included: whether the task was implicit or explicit, who requested the task, who performed the task, when was it requested, and when was it performed.

Results: There was little difference in the number of explicit and implicit variations between the high performing and low performing teams. In the high performing team, the Person In Charge (PIC) actively made requests while other members carried out tasks. By contrast, in low performing teams, the PIC was more passive and team members independently announced and performed their own tasks.

Conclusion: We developed a new method to explore the dynamics of teamwork and describe how certain team-level traits correlate with performance.

7.2 Introduction

In EMS there is an ideal that teams should emulate pit crews when delivering care.[151] Pit crew refers to the team of 2-20 mechanics that service cars in motorsports by refueling, swapping tires, making repairs, and the like. They are admired for the alacrity, coordination, and efficiency by which they perform their tasks and ensure their car finishes the race in the fastest time. The same ideals are valued in EMS teams that race against time to prevent serious injury and death in patients.

In earlier work,[152] we found significant variation in task processes between high and low performing teams in prehospital pediatric trauma simulations. While EMS teams go through a significant amount of training to improve their teamwork,[87,153,154] there are many degrees of freedom by which they can assess, diagnose, and treat patients. Variations can be problematic when they correspond to deviations from practice-based guidelines. Deviations can cause delays or errors in care that ultimately harm the patient.[95,155]

Variations occur because team members make decisions, based on local information and knowledge that determines the trajectory of care. This work examines the team behaviors that underlie process variations in a high performing and a low performing team, with respect to models of expected care. The goal is to recognize patterns of behavior that are associated with errors in order to design strategies that reduce potentially hazardous variation.

7.3 Background

There is a growing sentiment that teams should be studied holistically based on the interactions that occur between team members in context.[12,156] One approach is to introduce a "roadblock" that place the team in an unfamiliar situation, and to explore how they react under different experimental conditions.[70] An alternative approach would be to study team interactions that cause variations with respect to a normative process model.

In an earlier study, we used multiple sequence alignment (MSA) techniques to create process models of high and low performing EMS teams in prehospital pediatric trauma simulations.[152] MSA is a visual-analytical technique that is primarily used to explore the homology of biological sequences in DNA and protein.[101] It involves lining up elements across sequences to identify and measure similarity between them. These technique has been adapted to sociological event sequences to describe patterns of behavior in individuals.[41,42,117,157,158]

Forty seven EMS teams were recruited to participate in prehospital pediatric trauma simulations. Two SMEs (JMG and MH) rated team performance using the CTS™,[1] an instrument that scores team performance on communication, situational awareness/resource management, decision making, leadership/role responsibility, patient friendliness and overall performance. The teams were organized into high, mid, and low performing groups based on their CTS scores.

Task	**Code**	**Task**	**Code**
First arrival	Fst	Attach EKG (pads or leads)	Ekg
Second arrival	Snd	Attach blood pressure cuff	Bpc
Expose	Exp	Maintain cervical spine	Cer
Check physical status	Phy	Intubate	Int
Check mental status	Men	Ventilate with Bag Valve Mask (BVM)	Bvm
Check breathing	Bre	Do cardiopulmonary resuscitation (CPR)	Cpr
Check pulse	Pul	Establish an IO/IV line	Iov
Measure length	Len	Administer drugs	Dru
Attach pulse oximeter	Pox	Transport the patient	Tra
Attach end-tidal CO2 monitor	Ent		

Table 12: Patient-centric tasks and codes.

Furthermore, a process log was created for each team. The process logs contained a list of patient-centric tasks, presented in Table 5, which were ordered by the times team members started performing the tasks. The logs were converted into a fasta-like sequences and ClustalG[41] was used to align the sequences of high and low performing groups. The aligned tasks were considered “conserved” and represented the general activity that occurred in a group of teams.

7.4 Methods and Materials

We selected a high performing and a low performing team for a comparative analysis of behaviors involved in process variations. In the trauma simulations, the patient was presented as a 1-year-old who “fell” from the couch in an environment suggestive of abuse. We used the SimNewB™ mannequin from Laredal™ as a stand-in for the child patient. It was configured to exhibit signs and symptoms consistent with increased intracranial pressure (ICP) from shaken baby syndrome: irregular breathing, bradycardia, increased blood pressure, and moulaged bruises to indicate abuse.

A process variation is defined as a task that does not line up with a corresponding task in a reference model, which is akin to conformance checking in process mining.[45,48] We used two reference models: 1) a gold standard and 2) a reference model of what high performing teams do. The gold standard was created, based on a SMEs expectation (MH) of what teams should during the simulations: check pulse and breathing, initiate airway management, protect cervical spine, monitor vitals, initiate CPR, establish IO or IV access, and transport the patient to the hospital. The reference model was created by performing a multiple sequence alignment on task processes from high performing teams and extracting the conserved tasks. Teams were defined as high performing if they had an overall CTS score ≥ 8. Tasks were considered conserved if they occurred across >50% of the teams in the group.

7.4.1 Process Variation

The task sequences of the high performing team and low performing team were aligned to the MSA of the high performing teams. The alignments subsequently were, manually adjusted to improve matches between tasks. For example, the high performing team established an IO route at 4m00s. This was aligned to the BVM task at 3m07s average, instead of the IO task at 4m23s average in the high performing group. In such cases, the alignment was shifted to tasks that had the same label and occurred at approximately the same times to help maximize similarity between sequence and reference model. These types of manual adjustments used to be applied to biological sequences, before algorithms achieved an acceptable level of performance.[159] Alignment algorithms are currently not designed for sociological sequences, but some progress has been made to account for the multidimensionality[117] and temporality[118] of events.

Process variations were identified as differences between the reference model and candidate sequences. A subset of variations are considered for analysis. First, there are four types of alignments that can occur between sequence elements: 1) a match, aligning two common elements; 2) a deletion, matching an element in the reference model to a gap in the candidate sequence; 3) an insertion, matching a gap in the reference model to an element in the candidate sequence; and 4) a mismatch, aligning two different elements. Only insertions and mismatches are considered, because they can be traced back to a deviation in the candidate sequence.

Second, some tasks were excluded because they were perceived as adding noise to the analysis of behaviors during process variations. Tasks are considered noise, when they can occur spontaneously, with no communication and with minimal disruption to the overall process. For example, a paramedic can check the patient's pulse while other teammates are performing CPR, supporting ventilation with BVM, and establishing an IO route. Noisy tasks include: checking pulse (Pul), checking breathing (Bre), expose or remove clothing (Exp), physical assessment (Phy), maintaining cervical spine (Cer), and arrival of the second crew (Snd).

7.4.2 Team Cognition in Context

Activity occurs due to implicit or explicit decisions made within the team. A set of questions can be answered to describe the mechanics of the decision making process:

0. What was the variation?
1. Is the decision associated with the process variation implicit or explicit?
   If explicit …
2. Why was the decision made?
3. Who made the decision?
4. Who carried out the decision?
5. When was the decision made?
6. When was the decision carried out?

These questions were informed by the taxonomy of implicit and explicit coordination developed by Kolbe et al. [63]Question 1 provides information on whether a process variation was prompted by communication. Question 2 describes the rationale, which could be reviewed for logic errors. Questions 3 and 4 describe the organizational dynamics in performing the task. Examples include if the leader makes a request and a follower carries it out, or if a leader announces and carries out a task. Questions 5 and 6 could be used to measure the time between request and execution. Certain processes could be planned for early in advance, or prompted in reaction to a situational cue.

7.5 Results

Two teams were selected for analysis based on their contrasting high and low CTS ratings. The high performing team was composed of 6 members: 3 paramedics and 3 EMTs from the same fire department. SMEs rated their performance 9 of 10 and found no major errors. This team had middling scores in patient friendliness (4 of 10) and situation awareness. (6 of 10). Their performance spanned 10m04s (10 minutes and 4 seconds), with 347 transcribed utterances. The low performing team was composed of 5 members: 1 paramedic and 2 EMTs from a fire department, and 2 paramedics from a transport crew. SMEs rated their performance 4.5 of 10 and noted this team administered a massive tenfold epinephrine overdose. This team had a middling score in communication (6 of 10), and low scores in situation awareness (4 of 10) and decision making (4 of 10). Their performance spanned 10m59s with 457 transcribed utterances.

7.5.1 Process Variation

Figure 15 presents the alignment between the sequence of tasks in the high performing team and low performing team against the models of the gold standard and conserved tasks of high performing teams. Tasks in the models are **bolded** to indicate that they are aggregated over multiple observations. Tasks that are excluded from further analysis are presented in a gray-font color. The approximate start times that tasks start, are listed next to their corresponding label. Looking only at the alignment between reference model and candidate sequences, there was nothing to indicate that one team had the better process.

The gold standard is notably sparse compared to the reference model of high performing teams. There was an expectation that ventilation support with the BVM should occur within 0m40s and the IO route should be established at 2m30s. These tasks generally occurred later across the set of high performing teams at 3m07s and 4m23s respectively. The reference model captured cycles of BVM+CPR as team members periodically swapped roles, measuring length, attaching the pulse oximeter and ETCO2 monitors, and transporting the patient. Performing CPR was not necessary in this case, but most teams did it anyway. Overall, the reference model provides a richer representation of activity that occurs in simulation.

The high performing and low performing teams had 8 and 11 major process variations with respect to the reference model. The high performing team measured the patient's length early, attached the EKG machine late, performed intubation, and transported near 10m00s. Intubation was not expected given the model, but was not considered an error by the SMEs. The low performing team attached EKG leads at the expected time, but it disrupted CPR and BVM tasks. CPR was stopped at 2m37s (not displayed in the figure) and resumed at 8m05s. They also measured the patient's length, administered epinephrine, and intubated the patient. The patient did not need epinephrine and this was considered an error in addition to the overdose mentioned earlier.

Row Id	Expected time	Gold standard	Avg time	Model: High performance	Time Started	High Performance	Time Started	Low Performance	Include / Exclude	Reason
1	0:00	Men	0:00	Fst	0:00	Fst	0:00	Fst	Exclude	Concordant
2	0:10	Bre			0:16	Pul	0:14	Exp	Exclude	Discordant, noise
3					0:16	Pul			Exclude	Discordant, noise
4					0:36	Cer			Exclude	Discordant, noise
5					0:36	Pul	0:37	Pul	Exclude	Concordant
6					0:37	Bre			Exclude	Discordant, noise
7					0:49	Snd			Exclude	Discordant, noise
8	0:15	Pul	0:24	Pul	0:52	Pul	0:52	Pul	Exclude	Concordant
9	0:40	Bvm							Exclude	Deletion
10							1:18	Cpr	Include	Insertion
11					1:31	Len			Include	Insertion
12							1:55	Snd	Exclude	Discordant, noise
13	1:30	Ekg	**1:03**	**Pul**			1:59	Ekg	Include	Discordant
14							2:17	Exp	Exclude	Discordant, noise
15			**1:04**	**Bre**			2:17	Cpr	Include	Discordant
16							2:28	Bvm	Include	Insertion
17			1:40	Pox	1:38	Pox	2:38	Pox	Exclude	Concordant
18					1:58	Exp	2:40	Exp	Exclude	Concordant
19					1:58	Phy			Exclude	Discordant, noise
20					2:08	Bvm			Include	Insertion
21			2:28	Len					Exclude	Deletion
22					2:44	Pul	2:48	Pul	Exclude	Concordant
23							2:48	Bre	Exclude	Discordant, noise
24							2:51	Bre	Exclude	Discordant, noise
25	2:30	Iov					3:10	Pul	Exclude	Discordant, noise
26					3:30	Ent	3:53	Ent	Exclude	Concordant
27									Exclude	Deletion
28			3:35	*Cpr*	3:50	Cpr			Exclude	Deletion
29			3:07	Bvm			3:58	Bvm	Exclude	Deletion
30			4:43	Bre					Exclude	Deletion
31			4:21	Bvm					Exclude	Deletion
32			4:23	Iov	4:00	Iov	4:25	Iov	Exclude	Deletion
33					4:26	Cpr			Include	Insertion
34					4:39	Ekg			Include	Insertion
35							4:53	Bre	Exclude	Discordant, noise
36							5:37	Len	Include	Insertion
37					5:41	Bpc			Include	Insertion
38			5:31	Pul			6:38	Pul	Exclude	Discordant, noise
39					6:33	Int			Include	Insertion
40			6:51	Cpr	6:46	Cpr			Exclude	Deletion
41					6:56	Bvm			Include	Insertion
42					6:59	Bre			Exclude	Discordant, noise
43					7:37	Bre			Exclude	Discordant, noise
44							6:53	Dru	Include	Insertion
45							7:44	Bpc	Include	Insertion
46			7:49	Tra					Exclude	Deletion
47			8:09	Bvm			8:00	Pul	Exclude	Discordant, noise
48							8:05	Cpr	Include	Insertion
49							8:09	Cpr	Include	Insertion
50							8:14	Int	Include	Insertion
51							9:15	Bvm	Include	Insertion
52			9:10	Bre			9:32	Pul	Exclude	Discordant, noise
53					9:30	Cer			Exclude	Discordant, noise
54					9:44	Tra			Include	Insertion
55			9:46	Ent					Exclude	Deletion
56			10:04	Bvm					Exclude	Deletion

Figure 15: Alignment of a high performing team and a low performing team to the gold standard and reference model of the high performing teams. Tasks in the reference model are bolded **to indicate that they are aggregated over multiple observations. Concordant tasks, deleted tasks, and noisy tasks are excluded from further analysis, and displayed in a gray-colored font.**

7.5.2 Team Communication and Coordination

We identified 8 variations of interest in the high performing team, described in Table 13. Two of these variations occurred implicitly, which involved measuring the patient's length and attaching the blood pressure cuff. Six variations occurred with explicit communication between the team members. There were 11 variations of interest in the low performing team. One implicit variation occurred, in which an EMT paused and resumed CPR to allow another member to attach EKG pads on the patient's chest and back. Ten variations occurred by explicit communication.

	High Performing Team	Low Performing Team
# Variations	8	11
# Implicit	2	1
# Explicit	6	10

Table 13: Count of total, implicit, and explicit variations in the high performing team and low performing team.

Table 14 provides a summary of the activity involved in the explicit variations. In the high performing team, the average time between request and execution was 1m12s ± 1m13s. The PIC made the most requests and other team members, labeled by their role in the simulation, were involved in performing the tasks. In the low performing team, different team members made requests for tasks to be performed, and were often involved in carrying out their own requests. In other words, they would announce what they were doing and carry out that activity.

	High Performing Team				**Low Performing Team**			
	Δ (E – R)	**Task**	**Requester**	**Performer**	**Δ (E – R)**	**Task**	**Requester**	**Performer**
	0m58s	1st BVM	PIC	BVM Sup.	0m32s	1st CPR	Support	Self
	0m15s	1st CPR	PIC	CPR Sup.	1m30s	EKG setup	PIC	Support
	0m05s	EKG setup	PIC	Self	1m17s	1st BVM	PIC	BVM Sup.
	2m59s	Intubate	PIC	Support	0m15s	Meas. Len	IO Sup.	Support

	0m32s	BVM	Support	BVM Sup.	1m53s	Admin. Epi	IO Sup.	Self
	2m28s	Transport	PIC	Team	1m52s	Meas. BP	BVM Sup.	IO Sup.
					0m03s	CPR	PIC	IO Sup.
					0m04s	CPR	CPR Sup.	Self
					0m00s	Intubate	BVM Sup.	Self
					0m06s	BVM	BVM Sup.	Self
Avg	1m12s				0m45s			
Stdev	1m13s				0m47s			

Table 14: Explicit task variations: delta time Δ $(\mathrm{T} - \mathrm{R})$ between Execution and Request, task, requestor, and performer.

There are a couple observations to note about the timing and organization of the tasks. First, a greater length of time between request and execution appears to be associated with task complexity. Tasks, such as intubation, administering epinephrine, and transporting the patient, depend on the coordination of multiple members and tools. The requests catalyzed a series of lower level tasks that naturally consumed more time, such as fetching equipment. Second, certain tasks occur in coordination with other tasks. For example, BVM must be paused to allow for intubation, and CPR must be paused to attach EKG leads or defibrillator pads to the patient's chest. Communication in these situations was expected to occur between the coordinating members, rather than guided by the PIC.

7.6 Discussion

In an ideal world, EMS teams would provide the same high quality care to all patients. However, variations will naturally occur due to differences in situation, knowledge, experience, and interpersonal relationships among team members. This work examined team interactions in a fixed case, which should minimize situational variation. This study design enabled us to create a normative process model that guided the analysis of team interactions. The intent was to describe the underlying mechanisms of process variations, the time it takes to manifest, and their association with quality of performance.

There were modest differences between the high and low performing teams, when comparing them to the reference model. Both had a comparable number of variations that were explicit and implicit. An EMS process can be considered objectively better if the team performs the requisite tasks sooner and does not perform unnecessary tasks. Both teams performed CPR, but it was not needed to treat the patient. In the high performing team, the PIC recognized need for ventilation and directed team members to apply BVM a few seconds earlier. The low performing team administered epinephrine, which in this case, was considered an error. The EMTs were unable to detect a pulse, which led to a focus on circulation. The paramedic establishing the IO route, was informed of the patient's pulses and "dropping" oxygen saturation, which may have led them to administer epinephrine.

The process variations emerged from interactions amongst team members. In the high performing team, we observed that most of the requests or directives for tasks came from the PIC and were carried out by other team members. The opposite pattern occurred in the low performing team. Different members announced and carried out their own tasks in a distributed manner. The PIC in this team had a passive leadership style, which allowed other members to perform tasks as they saw fit. This style of leadership most likely failed to prevent an epinephrine overdose, even with the use of good closed-loop communication.

Member	**Utterance**
PIC	Here's a one cc syringe if you want it.
IO	I am good … on that.
PIC	Isn't each one of those ... that's a ten cc.
IO	Yup.
BVM	Ok.
PIC	Ok.
IO	So I'm pushing point three cc's.
PIC	Point three cc's.

The expected dose of epinephrine was 0.3 ml, not 3. The syringes were checked after the simulation was over, to verify the amount given.

One key difference between the two teams is that the high performing team was composed of members from the same fire department while the low performing team had a mix of members from a public fire department and a private transport organization. It is possible that the PIC adopted a passive leadership style to be considerate of members they were not familiar with. It is useful to remember that the teams were participating in simulations. Professional etiquette may have interfered with explicit communication and impacted patient safety in this case. Nevertheless, a serious error occurred by both the omission and commission of multiple team members.

7.6.1 Limitations and Future Work

This study compared only two teams and found only modest number of process variations with respect to a normative model of best performance. We focused on task insertions, because they were perceived as providing the most distinguishing information on team behaviors. Concordant tasks were excluded with the assumption that the underlying behaviors would be the same across teams. Deleted tasks were excluded because they often occur implicitly with no observable evidence. For example, a participant may not perform a task, because they forgot or felt it was unnecessary. Only a debrief interview would reveal how and why such thoughts occurred. Future work would involve validating these methods and findings on more samples, and testing the hypothesis that concordant processes arise from concordant behaviors.

7.7 Conclusion

We developed a method for analyzing the dynamics of teamwork with respect to its situational context. Our approach revealed that EMS teams with strong leadership acted as a cohesive unit, while teams with passive leadership acted in a more autonomous and distributed manner. Furthermore, passive leadership allowed for serious, preventable errors to occur. These findings present evidence that the emergent interactions between team members can have an effect on performance and outcomes. Future work includes applying these methods on a larger sample of data and validating the findings. Certain interactions may lead to different types of behaviors, which may cause good or bad performance.

Chapter 8

Discussion

The purpose of this research was to develop a holistic and objective method to analyze the dynamics of emergency medical services (EMS) teamwork. Teamwork in EMS is considered important because it affects the timeliness and quality of care, which has direct implications for patient safety and outcomes. The theoretical perspective adopted for studying teamwork was Interactive Team Cognition (ITC).[12] This theory defines team cognition, how teams understand and respond to a situation, as the interactions that occur between team members. It asserts that team cognition is an activity, should be measured at the team level, and is inextricably tied to context. The underlying hypothesis is that interactions provide indicators of performance and can inform interventions to increase team effectiveness.

Current methods used to measure interactions, include communication content, intention, and patterns of turn-taking. Some examples include the number of direction statements, ratings of leadership utterances, and completeness of closed-loop-communication. These methods provide a coarse view of teamwork by summarizing behavior of an event into a single value, which consequently excludes the context that induced the behaviors from analysis. During pilot simulations, there were observable phases of care in which teamwork, in the form of communication and coordination, adapted to fit the situation. For example, at the start of the simulations, support members would implicitly setup equipment while the Person In Charge (PIC) checked on the patient and interviewed bystanders. After the equipment was setup, they would explicitly seek or offer to take on tasks from the PIC. These patterns of behavior are not well-represented in existing measures of teamwork, hence the need for new methods that incorporate context.

Based on our preliminary observation and ITC theory, it is apparent that longitudinal context is an important factor to consider in the analysis of team interactions. In this research, the development of a method for analyzing teamwork as it evolves over time was approached in three phases:

1. Compare communication behaviors
2. Model task processes
3. Describe behaviors during variations from model

The first phase measured communication measures in high and low performing EMS teams, using new and established techniques from the literature. This work helped establish behaviors that distinguished levels of EMS team performance. The second phase involved novel modeling of team processes using the two methods Multiple Sequence Alignment (MSA) and Process Mining (PM). The process models answered questions regarding: what do teams typically do and how team activities vary during simulation? The process models also provided a means of grouping and exploring behaviors by comparable events, which in this case, were variations from expected care. It was hypothesized that team dynamics would provide insight on why such variations occurred.

8.1 Findings

The overall Clinical Teamwork Scale (CTS™) score was used to subjectively classify teams into high and low performing groups. These groupings were established to evaluate if MSA and PM could distinguish quality of teamwork. Each phase of this research yielded multiple findings with respect to performance and are discussed in turn.

8.1.1 Compare communication behaviors

We compared the communication behaviors of high and low performing teams participating in trauma simulations. The communication behaviors were operationalized using metrics established in the literature: communication rate, anticipation ratio, explicit coordination ratio, and use of orientation statements.[52,58,68]

The **communication rate** was defined as $\left(\frac{\#utterances}{\#minute}\right)$. Variation of communication type in this study observed in this metric appeared to be related to simulation type rather than team performance. During the NAT simulations, EMS teams treated the patient on site. Conversely, in the MVC simulation, EMS teams immediately moved the patient from the street into the ambulance. The MVC simulation may have had lower communication rates because: 1) moving the patient was a complex task that required 1-2 minutes of the 10 minute simulation time, which relied more on implicit coordination rather than explicit communication and 2) fewer team members could fit in the back of the ambulance to treat the patient. This finding complements observations by Parush et al,[160] who observed that the situation affects communication processes and suggests that exploring the impact of specific events on teamwork in different contexts is important.

The **anticipation ratio** was defined as $\left(\frac{\#inform\ utterances}{\#request\ information}\right)$, following Entin and Entin's conceptualization of team communication as the exchange of information (transfers, requests, or acknowledgements) between team members.[52] The anticipation ratio reflects the relative proportion of information transfers to information requests, so that values greater than 1 indicate that information is provided more frequently than requested and information needs are being met, where as values between zero and one indicate information is more often supplied only when requested. In our simulations, this measure did not appear to distinguish performance levels of EMS teams, as teams had similar scores of ~2. A possible explanation is that EMS teams are trained communicate openly and therefore even the poorly performing teams made frequent communications. Because the quality of communication is not evaluated, the anticipation ratio may be insensitive to the distinction between teams that provide needed information versus teams that provide unneeded and unsolicited information.

The **explicit coordination ratio** was defined as $\left(\frac{\#announce\ self-directions}{\#directions}\right)$. This new metric was developed in this research and inspired by the previous work of Entin and Entin who defined the anticipation ratio as $\left(\frac{\#action\ transfers}{\#action\ requests}\right)$.[52] Here, action refers to utterances about actions that will be performed or are requested, and describes the team's efficiency in carrying out tasks. Similarly, we observed that team members made unsolicited offers and announcements to perform actions, e.g. "I'll pull the chair out". These announcements were interpreted as examples of explicit coordination in which a member would communicate and perform actions to support other members. This observation led to the explicit coordination ratio, which promised to more accurately reflect team's activity efficiency. Explicit coordination ratios greater than 1 indicate that a team's need for activities are being anticipated and met.

In this study, high performing EMS teams had more explicit coordination than low performing teams. The EMS setting has certain features that may explain why the explicit coordination ratio provided more discriminating results than the anticipation ratio. First, much of the task-relevant information is present in the environment, such as pulse on the heart monitor, rising chest with breathing, etc. and therefore requires less explicit communication. Sharing information may then be a matter of procedure that does not vary over levels of performance. Second, EMS professionals receive highly standardized training and testing, such as Basic Life Support, Advanced Cardiac Life Support, Pediatric Advanced Life Support, and Neonatal Resuscitation Program.[88,93] This common training promotes shared mental models, which allow EMS members to know and predict the trajectory of care. Team members who are more engaged may be inclined to provide preemptive support. These findings suggest the face validity of the explicit coordination ratio and offer another perspective for describing teamwork.

Orientation statements were coded according to the SBAR framework (Situation, Background, Assessment, and Recommendation) and displayed on a timeline. SBAR is a method widely used in healthcare to structure information transfer in patient handoffs.[58] The purpose of this approach has primarily been to transfer information and responsibility from outgoing to incoming provider groups during patient transfers and shift changes. EMS team members used many utterances that could be coded according to SBAR categories to orient team members and establish goals. For example, an EMS member uttered the following statement, coded as "Situation" during pilot simulations: "We're cyanotic. So we're getting ready to give oxygen right now." The timelines of SBAR coded statements revealed that PICs in high performing teams regularly used orientation statements throughout the simulations while the PICs in low performing teams did not. Furthermore, orienting statements occurred in the approximate order of SBAR: Situation and Background statements occurred first as teams gathered information; Assessments were made about the patient's status; and leaders ultimately made Recommendation statements about the patient's care, suggesting that orienting statements were used to support shared situation awareness and goals to improve team performance during the evolving simulation.

Some of the methods discussed in this section successfully distinguished high versus low of performance between EMS teams in simulation. Beyond that, a reoccurring theme emerged that described teamwork as interacting with the changing context of the simulation. This finding inspired subsequent work with the following questions: how does the delivery of care vary across teams and how do team behaviors influence variations delivery of care?

8.1.2 Model Task Processes

Process models are abstract representations of activity that describe what could, should, or must occur. Using terms from the Process Mining discipline,[120,161] process models are derived from *cases*. A *case* is a process instance that is composed of a sequence of ordered *events*, where events refer to tasks or well-defined steps. In this research, case refers to an EMS simulation and events are the patient-centric interventions performed by care providers, such as CPR and intubation. A process model is created by analyzing multiple cases and identifying functional dependencies between events. For example, CPR always follows checking pulse, therefore pulse checks are a prerequisite for performing CPR.

The creation and interpretation of process models depends on the *representation*, *manipulation*, and *presentation* of data. *Representation* refers to what properties of a phenomenon are considered for analysis. For example, events typically contain information about who did what when, such as a paramedic ventilating a patient with the BVM at 9:32AM. Properties afford different types of analysis, which ultimately affect manipulation. Time, for instance, allows events to be listed in the order of their occurrence. *Manipulation* refers to how data is processed to model activity across cases, which may involve counting the frequency of events, grouping events by order, or some other analysis. *Presentation* refers to how data is visualized to communicate results. The properties and manipulations of data may lend themselves to one type of visualization or another, such as graphs versus networks.

Two techniques were applied to model EMS processes during simulation: MSA and PM. The concepts of representation, manipulation, and representation are introduced to provide background for the techniques and their respective findings. For MSA, a case is represented as a sequence of coded events, similar to letters in a word or residues in biological sequences.[101] Sequences are manipulated and presented as an alignment of matching events across cases. Aligned events describe the backbone of activity that generally occurs across simulations and events that do not align across cases are considered variations of activity. The findings indicated that high performing teams correctly prioritized ventilation while low performing teams prioritized CPR, which is considered more appropriate in an adult life support context.

The alignments were useful in producing a general description of the process and in recognizing variations. However, the findings were difficult to interpret because tasks were represented as discrete and sequential where as actual team activity was continuous and sometimes concurrent. This is a limitation of existing tools and algorithms that were originally designed to work on particular types of data, such as words and biological sequences. Application of these techniques to hum activities such as healthcare will require that they be adapted to accommodate these differences.

PM represents activity in a log. A log contains one or more cases made up of an ordered sequence of events. Events specified the task, task state (start or stop), task performer, and time. PM algorithms manipulate the log to infer relationships between events, e.g. if an event A precedes event B, then A is a prerequisite of B; if A and B can precede and follow one another, they occur in parallel, etc. These relations are then assembled and visualized as a graph-based model. The PM software ProM was used to generate models of activity for high and low performing teams. Internal validation, measured as appropriateness and fitness,[48] indicated that the models had similar levels of quality. Visual inspection suggested that the PM models were concordant with the MSA models in finding that high performing teams prioritized ventilation while low performing teams prioritized CPR.

The graphical models were difficult to interpret beyond this because the simulations contained cycles where certain tasks were repeated over the course of the simulation, such as stopping and restarting CPR. The static nature of the diagrams makes it difficult to know which path activity takes through the cycles. ProM does offer tools for animating the figures, which helps for following and understanding the flow of activity. A second concern is that PM algorithms make the assumption that sequential order implies functional dependency. In the EMS setting, tasks may occur in a certain order due to convention as opposed to strict rules. For example, paramedics might always setup the EKG machine after checking pulse and before CPR, but the machine may not be required in delivering care. PM offers a promising framework for extracting information about the precedence of events, interpretation requires caution due to these limitations of the models.

MSA and PM provide complementary computational approaches for modeling activity. They were selected over a manual approach, because they offered explicit and reproducible methods for modeling. MSA is a top-down approach that attempts to match whole sequences of events. PM is a bottom-up approach that attempts to infer a model from the pairwise occurrence of events. Both appeared to triangulate on similar descriptions of activity amongst high and low performing teams, however, there are currently no methods to evaluate the external validity of the models, or if one approach is better than the other. The alignment models were used in subsequent analysis because: 1) sequence alignments made fewer assumptions about the relations between events and 2) the model contained the original sequences (with gaps inserted), which allowed for direct comparison to other cases.

8.1.3 Describe Behaviors During Variations from Model

In this phase of the research, a method was developed to describe patterns of interactions associated with variations from expected care. Interactions were defined as a set of behaviors that induced patient-centric tasks. If the task was explicitly verbalized, we coded the following attributes: who requested the task, who performed the task, when was the task requested, and when was the task performed. Variations were defined as tasks performed by teams that deviated from the reference model. The reference model, in this case, was the multiple sequence alignment of tasks from 10 high performing teams. The underlying hypothesis is that certain patterns of interactions lead to productive or unproductive activity.

The high and low performing teams were comparable in terms of the number of variations from the reference model. For certain tasks, there was a greater time between a request and its execution, e.g. almost two minutes compared to ten seconds. This discrepancy appeared to depend more on task type than performance level. Certain tasks, such as setting up the EKG machine and transporting the patient, involve coordinating more resources than basic tasks, like checking pulse.

In high performing teams, the PIC made more requests while other team members carried out those requests, suggesting a hierarchical structure of organization. In the low performing team, multiple team members announced and carried out their own tasks, suggesting the team had an independent, federated organization. The low performing team committed an error, in which the PIC verbally recognized but failed to prevent another member from administering an overdose of epinephrine. We suspect that federated organization may cause team members to be more focused and assertive over their own tasks.

The method proposed in this section revealed unique characteristics regarding the dynamics of the high and low performing teams. Team behaviors and activity processes have typically been studied as separate phenomena. For example, team behaviors might include counting or rating clarity of directions (leadership), offering help (followership), use of closed-loop communication, etc. Process analysis is often concerned with quality and throughput, such as how many patients are treated in an hour. When these two phenomena are considered together, they can provide complementary insight on how behavior affects activity. For example, Gorman et al explored how teams under different conditions overcame a “roadblock” in the form of a communications glitch.[70] Distributed teams were found to be more efficient because fewer minimal members were involved in resolving the roadblock, while collocated teams were less efficient because all members were involved in resolving the roadblock. This research used variations as a point of comparison, instead of roadblocks, to identify differences between teams. This approach provides a general method to analyze teamwork in a naturalistic setting.

8. 2 Limitations

A number of limitations should be considered when interpreting this research. Some correspond to the practical constraints of having a small number of researchers process a large volume of data. Others were discovered as new techniques were developed or existing techniques were used in a novel manner to describe complex teamwork in a naturalistic setting**.** The limitations are presented in the order of their respective phases.

One potential limitation that pervades our research design is the use of the CTS™ as the measure of performance. The CTS™ is a subjective behavioral rating instrument and its results are subject to biases of the rater. The simulations had scores from only one rater and input from multiple raters would increase confidence in asserting levels of team performance. However, the CTS™ has been validated in multiple clinical settings and demonstrated to reliably distinguish high and low performance. We used the upper and lower extremes of the sale to ensure separation.

8.2.1 Compare of Communication Behaviors

This phase of research involved coding transcripts of 2 pairs of simulations for comparative analysis. The sample size is small due to the labor intensive process of transcribing audio recordings of team communications in the simulation environment with its inherent background noise. The 4 simulations included 1 high performing team in each of the NAT and MVC simulation scenarios, 1 low performing team in NAT and 1 low performing team in MVC scenarios. Behaviors associated with high performance cannot be confidently generalized because only one high performing team was analyzed. Also, it is difficult to determine if differences in behaviors can be associated with levels of performance or simulation type, due to the use of data from different types of simulation, NAT and MVC. Two researchers were involved in coding communication behaviors. Differences were resolved by discussion and reaching a consensus. A more robust solution in the future might be to add a third expert to arbitrate disagreements.

8.2.2 Model Task Processes

Process modeling involves creating an abstract representation of activity, which includes the following steps: 1) creating a coding framework; 2) using codes to abstract out events; and 3) describing relations between events. Each step requires tradeoffs between accuracy and comprehensibility of the data. In the first step, only patient-centric tasks, defined as tasks that involved physical contact with the patient, were considered for analysis. Tasks that did not involve physical contact were excluded, such as scribing, setting up equipment, driving, etc. The patient-centric tasks were viewed as providing a concise representation of care that was relevant to team performance and outcomes, but exclusion of non "patient-centric" tasks might conceivably have affected the findings. Another limitation is that the codes did not include values for task quality, which means that teams could perform exactly the same activity but have very different results based on their execution.

The second step involved labeling tasks, start times, end times, and performers. EMS tasks do not have definitive start or end times and the members performing a task can shift on a moment by moment basis, making the act of labeling tasks prone to ambiguity. Start and end times were defined as moments where the provider's hands were close to the patient, approximately 3 to 12 inches, and in the act of starting or stopping a task. Tasks, start times, and end times, were also labeled when members handed off tools and responsibilities to one another, such as when a paramedic ventilating with the BVM places the device in the hands of an EMT. A second researcher was recruited to double code events in 2 simulations. There was an agreement with a Jaccard coefficient of 0.58 (22/38 tasks and properties). Most disagreements involved the timing of CPR and BVM, which are frequently swapped, to preserve member stamina and quality of task performance. One researcher coded the remaining simulations, because the level of agreement was considered high, given the degrees of freedom by which a task can be specified.

The third step involved exploring two techniques to describe relations between events: MSA and PM. MSA was originally developed to measure homology between biological sequences by aligning discrete, sequential elements in sequences, such as nucleotides and amino acids found in DNA and protein respectively. [101]EMS activity, however, is continuous and concurrent. When complex human activity is reduced into a one-dimensional sequence it loses fidelity in representation that ultimately affects the results. For example, suppose that 1) team A performs pulse check, intubation, and CPR while team B performs pulse check, CPR, and intubation; and 2) that the start times for CPR and intubation are different but their time spans overlap. In the MSA framework the symbols for CPR and intubation would be misaligned even though their activity is similar. Given this limitation, the alignments of EMS activity were very noisy and difficult to interpret.

PM is a discipline that emerged from the need to extract workflow knowledge from electronic logs, such as those generated by ATMs and EHRs.[161] Process discovery is a prominent task in the discipline and involves constructing graphical representation of activity by inferring dependency relations between sequential events. There are a few limitations with existing algorithms. First, task order does not necessarily imply task dependency in the EMS setting. Certain tasks, such as checking pulse and breathing, may occur spontaneously to monitor the patient's status. They often occur at the beginning of a simulation, but their subsequent occurrences add noise to the model. Second, existing algorithms do not represent reoccurring processes and sub-processes well. The graphical model uses back-arrows to represent reoccurring tasks. These cycles make it difficult to determine which are typically traversed by teams or if there is a typical path. These problems are partially mitigated by tools, offered by ProM, to filter noise and animate activity in the models, but the problem of modeling dynamic behavior in a complex system with potential loops or cycles remains an important one.

8.2.3 Describe Behaviors During Variations from Model

The third phase of this research involved analyzing communications and process data. A pair of teams, one high performing and one low performing, was selected for analysis. Variations were identified by comparing their process sequences to a reference model of "good" performance. The variations were then used to identify and describe team interactions. The hypothesis was that certain patterns of interaction caused variations, which affected outcomes.

The first limitation is that the sample size was small, which potentially limits the reliability of findings. This limitation is primarily due to the labor intensive process of collecting results. More data would need to be collected to verify the patterns of high and low performing teams. A second limitation is that variations in the form of task deletions were excluded from analysis. These types of events were excluded because it is difficult to infer why tasks were not performed without interviewing the subjects *post hoc*. For example, were tasks forgotten, re-prioritized, or ignored? A third limitation is that only behaviors during variations were analyzed. It is possible that similar processes may result from different interactions. This aspect of teamwork could be explored in future research.

In summary, this research introduced novel approaches towards studying teamwork in the context of specific activities, but exposed important limitations in the process. The following questions should be addressed in order to improve these methods of analyzing teamwork in future research: 1) what are the best guidelines for coding non-verbal behaviors, 2) how can MSA and PM be improved to model teamwork in an EMS activity system, and 3) what are some of the synergistic insights can be achieved by combining different modes of analysis?

8.3 Implications

The findings presented in this research have implications for both clinical practice and the methods used to study teamwork. The clinical implications highlight behaviors that could be emulated or corrected to improve delivery of care. The methodological implications demonstrate that existing informatics tools can be used to study teamwork and makes suggestions for improvement.

8.3.1 Clinicians

This research presents three perspectives on EMS teamwork: communication, process, and variations driven by communication. CTS™ scores were used to group teams by performance levels and provided a basis for interpreting the utility of certain behaviors. The findings regarding communications suggested that teams performed well when members preemptively offered to take on tasks and PICs led by periodically orienting team members. These findings could provide the basis for training more effective teams.

The process models provided a useful framework for comparing EMS activity across teams. Process models are commonly used to diagnose workflow problems, and in this research, it was observed that tasks were prioritized differently across performance levels. High performing teams correctly focused on ventilation in the pediatric trauma cases while low performing teams focused on CPR. The low performing teams appeared to lack pediatric knowledge and adapting adult-based algorithms to the situation, suggesting that some teams could use additional training to improve performance in the field.

The final aspect of this research explored process variations that were driven by communication. It was hypothesized that interactions amongst team members influenced how care was delivered in the EMS setting. Findings indicated that a high performing team had hierarchical, centralized leadership, which led to a structured execution of tasks. A low performing team had distributed, federated leadership, which potentially led to more variation as members selected and focused on their own tasks. This finding reinforces the stance that leadership is involved in organizing task work and that associated training could improve processes in delivering care.

8.3.2 Methodologists

A number of different techniques both established and new, were used to study EMS teamwork. The established techniques included: measuring the communication rate and anticipation ratio, and using MSA and PM to model task processes. The communication rate and anticipation ratio did not discriminate EMS teams by performance level, suggesting that the quality of teamwork should be measured by other means. MSA was adapted to compare EMS task sequences, but the results were noisy and difficult to interpret, partially due to collapsing data on continuous concurrent tasks down into a sequence of discrete elements. Further development in MSA algorithms could include the representation and comparison of activity between teams. PM works by constructing a graphical model based on pairs of consecutive tasks. Activity in the EMS work system tends to be spontaneous and opportunistic. EMS models that are generated through this technique should be validated by clinical experts.

New techniques were developed to explore behaviors that were observed during pilot simulations, including the explicit coordination ratio and interactions that caused activity to occur. A number of different communication measures have been created to explore the exchange of information between team members. In the EMS setting, activity occurred in 3 ways: 1) without verbalization, 2) a direction issued from one member to another, or 3) offered and carried out by one member. It was hypothesized that teams are more efficient when supporting members anticipate and coordinate with their leader. The results appear to support this hypothesis for our small sample, but more testing is needed to validate the measure. The second technique involved exploring communication patterns that drove activity. Interactions and communications are often studied in isolation, but Gorman et al.'s work[70] demonstrated that certain phenomena, such as a roadblock, elicit distinctive interactions amongst team members. Exploring the connection between interactions and processes could provide further insight on cognitive structures and dynamics at the team level.

8.4 Conclusion

The research presented in this dissertation explores different facets of EMS teamwork and attempts to combine those layers in a novel manner. The overall findings reveal patterns of communication and coordination that can inform subsequent interventions for improvement. Furthermore, new methods are introduced that reveal properties of organizational structure and team dynamics. Future research will focus on refining these methods to provide a more robust description of activity in a complex socio-technical activity system.

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Appendix

A.1 Non-accidental Trauma, 1-year-old

A.1.1 Target Audience

- Pre-hospital care providers from fire services and emergency medical services
- EMT-Basics, Paramedics.

A.1.2 Environment

- **Location and Staging:** Living room of a disorderly, unkempt home. Patient on bed or couch. Boyfriend in room.
- **Patient Simulator:** Laerdal Sim NewB w/ SimPad user interface.
- **Costume / Moulage:** Patient simulator in age appropriate clothing. Multiple bruises of varying age on extremities.
- **Lines & Drains:** IO placed draining to leg reservoir.
- **Monitor Set-up:** Tablet/ PC running SimPad Patient Monitor to replace portable monitor defibrillator display.
- **Props:** Environment suggestive of poor upkeep and alcohol/drug abuse. Detritus strewn around home. Empty beer/alcohol bottles. Overflowing garbage., etc.
- **Confederates:** Sketchy boyfriend, provides dubious history, see scripted responses for boyfriend.

A.1.3 Case Narrative

EMS Report: "UN1 Unconscious Patient"
Patient: 1 year old female
Chief complaint: "fell off bed an hit her head"
HPI: According to Boyfriend, patient was sleeping in bed (of approximate 2 foot height). Patient fell from bed and hit head on wooden trundle bed. Patient was crying and then became unresponsive
PMHx: Febrile seizure, 6 months prior.
PSHx: None.
Immunizations: None, has not seen pediatrician lately.
Medications: None.
Allergies: NKDA
FamilyHx: Unknown
Social Hx: Lives at home with biologic mother and boyfriend.
ROS: (+) No tone/activity, unresponsive, no respiratory effort. Pupils fixed and dilated.
Physical Exam:

- General: Unconscious, apneic
- **HEENT:** Redness and bruising to forehead
- **Neck:** WNL
- **CV:**Pulse detectable, weak
- **Pulm.:** Apneic, CTAB, resistance with ventilation
- **Abd.:** Bruising noted
- **Ext.:** Delayed capillary refill, skin cool, pale & dry, bruising of varying ages / stages of healing
- **Neuro:** Unresponsive, GCS = 3

A.1.4 Clinical Progression

Initial Prompt: Arrive to find unconscious patient on bed/couch. Boyfriend is in room, away from patient.Boyfriend provides history inconsistent with severity of injury.

TIME: 00:00	**HR** = 65	**BP** =135/80	**Temp.** = 37°C	**RR** = 0	**SpO_2** = 99%	**$EtCO_2$** = 60 mm Hg

Optimal Management Pathway: Initiate airway management. Protect cervical spine. Monitor vital signs. Initiate CPR. Establish IV/IO access. Transport.

***Adequate ventilation will lower **$EtCO_2$** to 45 mm Hg. Hyperventilation will lower **$EtCO_2$** to 35 mm Hg.

TIME: 02:00	**HR** = 70	**BP** 165/115	**Temp.** = 37°C	**RR** = 0	**SpO_2** = 99%	**$EtCO_2$** = *45 / 35 mm Hg

TIME: 4:00	**HR** = 160	**BP** = 175/130	**Temp.** = 37°C	**RR** = 0	**SpO_2** = 99%	**$EtCO_2$** = *45 / 35 mm Hg

TIME: 6:00	**HR** = 125	**BP** =140/105	**Temp.** = 37°C	**RR** = 0	**SpO_2** = 99%	**$EtCO_2$** = *45 / 35 mm Hg

END SCENARIO

Consults

MRH DR. JUI instructs continuation of high-quality CPR until 10 minutes on-scene has elapsed. After 10 minutes, **DR. JUI** advises discontinuation of resuscitation efforts.

A.1.5 Authors and Contributors

Case drafted by James McNulty, B.S. with contributions and updates by the Children's Safety Initiative – EMS Simulation Team.

Reviewed and edited with references by Jeanne-Marie Guise, M.D., M.P.H. Mattew Hansen, M.D. and Jonathan Jui, M.D.

A.1.6 References

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A.1.7 Scripted Response for Boyfriend

[Boyfriend should act "suspicious". Does not volunteer information. Answers are short. Does not seemed appropriately concerned for child.]

EMS: What happened?
Boyfriend: I don't know. She was asleep and I was in the other room. I heard a thump and I camein . I guess she had fallen and hit the lower bed. She seemed OK at first but isn't moving anymore.

EMS: Have you tried to help?
Boyfriend: I don't know what to do. That's why I called you.

EMS: Did you notice any other injuries?
Boyfriend: No.

EMS: Does she have any allergies?
Boyfriend: No.

EMS: Does she take any medications?
Boyfriend: Not that I know of.

EMS: Does she have any medical history?
Boyfriend: She had a bad fever once and had one of those spells, but the doctors said she was fine.

EMS: How did she seem before she went to bed?
Boyfriend: Just fine I guess.

EMS: When did she last eat or have anything to drink?
Boyfriend: I don't know. What does that matter? She had a bottle with her mom before she left.

EMS: When did she leave and where did she go?
Boyfriend: She left 2 hours. She went to her mom's, baby's grandma's house.

A2. Motor-vehicle crash, 1-year old

A.2.1 Target Audience

- Pre-hospital care providers from fire services and emergency medical services
- EMT-Basics, Paramedics.

A.2.2 Environment

- **Location and Staging:** On residential street corner.
- **Patient Simulator:** Laerdal Sim NewB w/ SimPad user interface.
- **Costume / Moulage:** Patient simulator in age appropriate clothing. Patient simulator held by mother. 3" abrasion and bruising on right forehead. 4" abrasion on left elbow.
- **Lines & Drains:** IO placed draining to leg reservoir.
- **Monitor Set-up:** Tablet/ PC running SimPad Patient Monitor to replace portable monitor defibrillator display.
- **Props:** Stroller overturned near curb. Minor damage.
- **Confederates:** mother, who provides history of incident. See scripted responses for mother.

A.2.3 Case Narrative

EMS Report: "TA1PEDTraffic Accident Pedestrian"
Patient: 1 year old female
Chief complaint: "pedestrian v.-auto- pediatric patient stroller"
HPI: According to Mother, patient was in stroller while struck by small truck/SUV. Stroller was pulled under front of truck. Mother pulled out stroller and released patient. Mother denies loss of consciousness. Patient is calm in mother's arms, cries at EMS approach.
PMHx: None
PSHx: None
Immunizations: Up-to-date
Medications: None.
Allergies: NKDA
FamilyHx: Unknown
Social Hx: Lives at home with biologic mother and father. Out for a walk.
ROS: (+) No tone/activity, unresponsive, no respiratory effort. Pupils fixed and dilated.
Physical Exam:

- **General:** Conscious, alert, oriented for age. Crying, consolable, eye tracking.
- **HEENT:** Redness and bruising to forehead
- **Neck:** WNL
- **CV:** Pulse detectable, strong, rapid
- **Pulm.:** CTAB
- **Abd.:** WNL
- **Ext.:** 2 sec capillary refill, skin warm, pink, dry
- **Neuro:** GCS = 15

A.2.4 Clinical Progression

Initial Prompt: Arrive to find baby in mother's arms, standing at curb. Stroller is overturned near to front of SUV on side of road. Baby cries at EMS approach patient.

TIME:	**HR** = 118	**BP** =125/75	**Temp.** = 37°C	**RR** = 20	**SpO_2** = 99%	**$EtCO_2$** = 60 mm Hg

00:00						
	Trending to ICP, 2 minute					

Optimal Management Pathway: Initiate airway management. Protect cervical spine. Monitor vital signs.

	Increased ICP					
TIME: 02:00	**HR** = 70	**BP** =140/77	**Temp.** = 37°C	**RR** = 6	**SpO_2** =90%	**$EtCO_2$** = 65 mm Hg

MOTHER calls for help, directs attention to progressing unresponsiveness.

Optimal Management Pathway: Ventilate the patient. Adequate ventilation preserves condition. No further deterioration. Adequate ventilation will lower **$EtCO_2$** to 45 mm Hg. Hyperventilation will lower **$EtCO_2$** to 35 mm Hg

	Apneic, trending to bradycardia					
TIME: 02:00	**HR** = 68	**BP** =145/80	**Temp.** = 37°C	**RR** = 0	**SpO_2** =80%	**$EtCO_2$** = 70 mm Hg

	Bradycardic PEA arrest					
TIME: 02:00	**HR** = 40	**BP** =0/0	**Temp.** = 37°C	**RR** = 0	**SpO_2** =0	**$EtCO_2$** = 0 mm Hg

	Asystolic Arrest					
TIME: 02:00	**HR** = 0	**BP** =0/0	**Temp.** = 37°C	**RR**0	**SpO_2** =0%	**$EtCO_2$** = 0 mm Hg

No change in transport.

END SCENARIO

Consults

MRH DR. JUI instructs continuation of high-quality CPR until 10 minutes on-scene has elapsed. After 10 minutes, **DR. JUI** advises discontinuation of resuscitation efforts.

A.2.5 Authors and contributors

Case drafted by James McNulty, B.S. with contributions and updates by the Children's Safety Initiative – EMS Simulation Team.

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A.2.7 Scripted Response for Mother

[Mother's account of traffic accident:]
Mother: *Improvise on going for a walk to the park when a car hit the stroller.*
[Possible Questions the EMTs will ask:]
EMT: Does she have any history of medical problems or illness?
Mother: *No, she has always been healthy.*

A.3 Clinical Teamwork Scale (CTS™)

Please note: *Not relevant*- The task was not applicable to the scenario.

Overall	Not Relevant	Unacceptable	Poor			Average			Good			Perfect
1. How would you rate teamwork during this delivery/emergency?	☐	0	1	2	3	4	5	6	7	8	9	10

Communication	Not Relevant	Unacceptable	Poor			Average			Good			Perfect
Overall Communication Rating:	☐	0	1	2	3	4	5	6	7	8	9	10
1. Orient new members (SBAR)	☐	0	1	2	3	4	5	6	7	8	9	10
2. Transparent thinking	☐	0	1	2	3	4	5	6	7	8	9	10
3. Directed communication	☐	0	1	2	3	4	5	6	7	8	9	10
4. Closed loop communication	☐	0	1	2	3	4	5	6	7	8	9	10

Situational Awareness	Not Relevant	Unacceptable	Poor			Average			Good			Perfect
Overall Situational Awareness Rating:	☐	0	1	2	3	4	5	6	7	8	9	10
1. Resource allocation	☐	0	1	2	3	4	5	6	7	8	9	10
2. Target fixation	☐ Yes	☐ No										

Decision Making	Not Relevant	Unacceptable	Poor			Average			Good			Perfect
Overall Decision Making Rating:	☐	0	1	2	3	4	5	6	7	8	9	10
1. Prioritize	☐	0	1	2	3	4	5	6	7	8	9	10

Role Responsibility	Not Relevant	Unacceptable	Poor			Average			Good			Perfect
Overall Role Responsibility (Leader/Helper) Rating:	☐	0	1	2	3	4	5	6	7	8	9	10
1. Role clarity	☐	0	1	2	3	4	5	6	7	8	9	10
2. Perform as a leader	☐	0	1	2	3	4	5	6	7	8	9	10
3. Perform as a helper	☐	0	1	2	3	4	5	6	7	8	9	10

Other	Not Relevant	Unacceptable	Poor			Average			Good			Perfect
1. Patient friendly	☐	0	1	2	3	4	5	6	7	8	9	10

Additional Notes (Anything regarding individual performance, assertion of position, etc?):

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On-Site Reviewer ____

Print Name *Sign* *Date*

CTS™ Descriptive Anchors

TEAMWORK COMPONENT	DESCRIPTIVE ANCHOR
Overall	
1. How would you rate teamwork during this delivery/emergency?	What is your gut feeling about the overall quality of teamwork in this situation/scenario?
Communication	
1. Orient new members (SBAR)	As each new team member joined the scenario, they were oriented to the patient situation through a systematic communication, for example using the SBAR format (full or condensed as appropriate): S (Situation): What is going on with the patient B (Background): Pertinent medical background data A (Assessment): Current problem we are dealing with R (Response): What I/we need you to do
2. Transparent thinking	The team members use "think aloud" communication so that all team members share the same mental model of the situation.
3. Directed communication	Team members assign requests (including orders) either verbally or visually to a specific person.
4. Closed loop communication	Team members acknowledge request and report back to the person issuing an order or requesting a specific action when the task is complete.
Situational Awareness	
1. Situational Awareness	Team members vigilantly survey surroundings to be aware of all human and technological resources available and how to access them quickly.
2. Resource allocation	The team efficiently management human and material (equipment) resources. Example: As new team members appear a specific role or function is assigned.
3. Target fixation	Team members do not exhibit tunnel vision that prevents progress from being made in the management of the entire clinical situation.
Decision Making	
1. Prioritize	Clear, proper identification and ranking of items, actions, and/or issues pertinent to the management of the clinical situation
Role Responsibility (Leader/Helper)	

1. Role clarity	Leaders and helpers were identified among the team members (roles can change)
2. Perform as leader/helper	Effectiveness of performance of team members as leaders and/or helpers (roles can change)
Other	
1. Patient friendly teamwork	Communication and care were mindful of the patient