A COMMUNICATION ONTOLOGY FOR IMPROVING QUALITY AND SAFETY MANAGEMENT IN AIR MEDICAL TRANSPORT

by

Joseph Desmond Dalto

A dissertation submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Department of Biomedical Informatics

The University of Utah

May 2015

The University of Utah Graduate School

STATEMENT OF DISSERTATION APPROVAL

The dissertation of Joseph Desmond Dalto has been approved by the following supervisory committee members:

Charlene R. Weir,	Chair	3/19/2015 Date Approved
Peter J. Haug,	Member	3/17/2015 Date Approved
R. Scott Evans,	Member	3/18/2015 Date Approved
Terry Clemmer,	Member	3/13/2015 Date Approved
Frank Drews,	Member	3/16/2015 Date Approved

and by Wendy Chapman, Chair of the Department of Biomedical Informatics

and by David B. Kieda, Dean of The Graduate School.

ABSTRACT

Air medical transport (AMT) is a complex process that requires coordination of aircraft and highly skilled professionals to transport critically ill patients to definitive care. To achieve optimal performance, medical transport services employ quality and safety management systems (QSMS) to report errors and evaluate performance. Unfortunately, there are no standards for classifying miscommunication in these systems. A thoughtfully developed ontology, based upon theoretical models, provides the foundation within a QSMS for reporting communication errors and standardizing analysis.

This research used a mixed-methods, pre-post design, with four distinct studies to analyze communication at the Life Flight AMT service. Study 1 was a qualitative study of communication and miscommunication. Study 2 (pre) was a quantitative study measuring communication errors in reports to the QSMS. Study 3 developed a new communication ontology for the QSMS to improve reporting and analysis of communication errors. Study 4 (post) implemented the new ontology and evaluated its performance for analyzing communication errors in the QSMS.

Study 1 showed that communication in this AMT service is a complex process that may require more than 28 communication interactions between 10 or more people and utilize as many as 6 different communication technologies. Omissions of information were the most frequent communication errors described. Study 2 revealed that Life Flight's ontology in their QSMS was inadequate for measuring communication errors.

Two hundred seventy-eight event reports were reviewed from the QSMS with 58 (21%) having evidence of a communication error during transport. Of those 58 reports, only 18 (31%) could be retrieved by a simple query. A new, theory-based, communication ontology was developed in Study 3. Study 4 showed the new communication ontology more than doubled the ability to retrieve reports with communication errors by simple query of the QSMS (71%). Furthermore, analysis showed that 50% of communication errors occurred at the initial phase of transport. The most frequent errors were information not being forwarded to key persons (37%).

This research provided the foundation for describing and measuring communication errors in an AMT Service. Further research is needed to identify strategies that will improve information distribution between persons involved with patient transport.

For my wife Charlene; your encouragement and support were essential for me to complete this work. There is a part of you in this research. For Tiffany, Jane, and Blake, who kept me grounded in the most important things in life while I muddled through the relentless details of my work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

I would like to give sincere thanks to my committee chair, Charlene Weir, for her guidance, insight, and patience. My deep appreciation to the entire committee for their input that ensured the quality and integrity of this research. A special thank you to Dr. Frank Thomas for his mentoring and our many discussions on the importance of good communication for quality and safety in air medical transport.

INTRODUCTION

Air medical transport (AMT) is a complex process that requires coordination of aircraft and highly skilled professionals to transport critically ill patients to definitive care. Modern civilian AMT services, utilizing helicopters, arose in the 1970s and have seen rapid growth in the last decade. As of Sept 2014, there were 300 air ambulance services in the U.S. located at 984 bases operating 1020 helicopter aircraft (i.e., rotor-wing) and 346 fixed-wing aircraft[1]. The Association of Air Medical Services estimates there are currently about 400,000 rotor-wing transports and 150,000 fixed-wing transports in the U.S., annually[2].

There is compelling evidence that miscommunication is a significant factor in adverse events in healthcare[3-6], aviation[7-10], and the nexus of these two industries, AMT[11]. In recent years, AMT has seen a spike in the number of accidents with fatalities causing concern and calls for action by regulators and stakeholders. The report by the National Transportation and Safety Board (NTSB) on one of these accidents, a mid-air collision of two medical transport helicopters in Flagstaff Arizona, found that poor communication was a causal factor[12].

Tracking problems (i.e., defects) is a time-honored method of quality improvement and is perhaps the most important way institutions have to reduce errors. While miscommunication can be frequent in AMT, it is rarely tracked in many programs or takes second seat to equipment or patient care issues. Application of computers to all aspects of AMT (e.g., avionics, navigation, physiologic monitoring, quality management) has created an ever-increasing volume of data about system performance. Humans need decision support for transforming these data into information and knowledge that can lead to improved performance[13,14] and communication problems are no exception.

Life Flight is an AMT service headquartered in Salt Lake City that serves Utah and neighboring states of the intermountain west[15]. Transport teams at Life Flight undergo regular and rigorous review of transport performance. These reviews are part of an overall quality management program that is integrated with safety management and operational management. The Life Flight quality management program includes review of selected transports, periodic reports of key metrics, focused quality improvement projects, and triennial accreditation by the Commission on Accreditation of Medical Transport Systems (CAMTS)[16].

To analyze risk and prevent adverse events, organizations such as Life Flight employ quality and safety management systems (QSMS). These systems provide functionality for key operational tasks such as risk identification, reporting adverse events, quality assurance (QA), and continuous quality improvement (CQI). Although miscommunication is recognized as a causal factor in adverse events, there are no standard frameworks or ontologies for these systems to classify and analyze communication issues. As a result, organizations often develop custom ontologies in their QSMS that lack granularity, or specificity, or a theoretical basis useful for analyzing communication issues.

The purpose of this research is to study communication in an AMT setting and utilize informatics to improve tracking and analysis of miscommunication for quality improvement (QI) purposes. While there may be technical differences between the terms *miscommunication*, *communication issue*, and *communication error*, for this research, they are considered synonymous in order to synchronize understanding by key participants.

OBJECTIVES AND SPECIFIC AIMS

The overarching goal of this research is two-fold: 1) describe key information management challenges for quality improvement in the area of communications in AMT and 2) apply informatics principles and solutions that improve measurement and understanding of miscommunication. To achieve this goal, a mixed-method design will be employed utilizing qualitative and quantitative methods. Qualitative methods will be used to explore, describe, and understand communication in an AMT setting. Quantitative methods will be used for measurement and analysis of miscommunication. Descriptions and methods of these four research aims are presented in the following sections.

AIM 1: Characterize communication and miscommunication at Life Flight. This study will employ qualitative methods using interviews, focus groups, observations, and document review to describe communication that takes place as part of the transport process.

AIM 2: Analyze communication errors at Life Flight: This study will employ quantitative methods to analyze miscommunication reported in the QSMS.

AIM 3: Develop and validate a communication ontology for use in the QSMS. This study will utilize nominal group techniques with domain experts.

AIM 4: Implement design changes to the QSMS, based upon the ontology from Aim 3, and utilize quantitative methods to evaluate the impact of the ontology on analyzing miscommunication.

This overall study design links each aim, in sequence, with each study building upon or extending the previous. Study 1 seeks to describe and understand communication and miscommunication in an AMT setting. Study 2 provides a baseline measure of performance of a QSMS related to reported miscommunication. Study 3 uses the knowledge from the previous two studies to design an improvement to the QSMS for analyzing miscommunication (i.e., communication ontology) and Study 4 implements the ontology and evaluates if performance was improved. Figure 1 depicts the organization and flow of this research. These studies comprise a pre-post study design evaluating how a communication ontology can provide decision support for improving quality and safety in AMT.

Although this research is presented in four distinct studies, the theoretical and analytical frameworks used in these studies compliment and build upon each other. Therefore, those frameworks are presented in the following section and serve as the background content for each of individual studies.

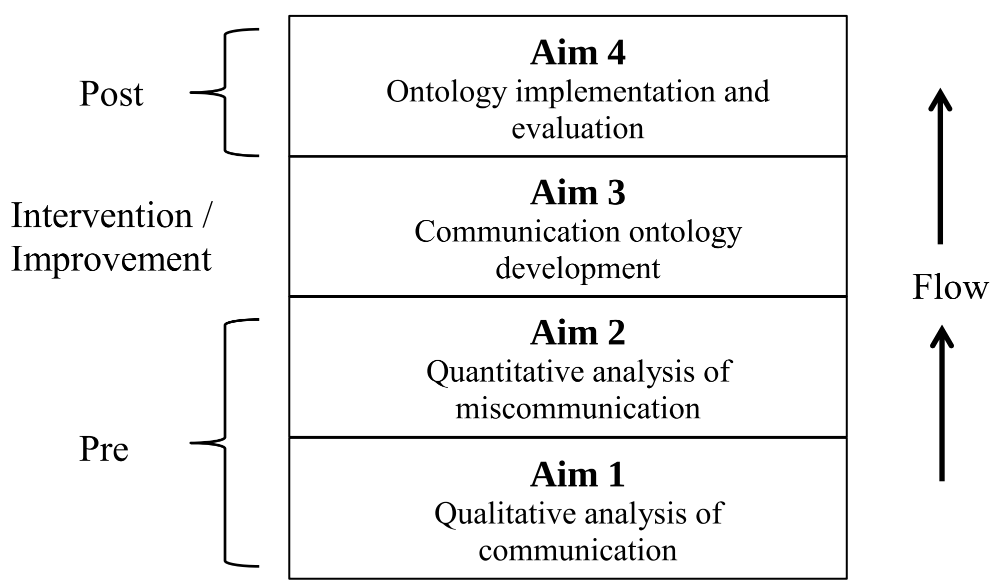


Figure 1. Organization and flow of research

BACKGROUND

This section provides foundational knowledge for this research. A review of relevant literature on communication and errors in AMT will be discussed first. Next, theoretical frameworks for quality improvement, communication, and human error are presented. The section concludes with a discussion of ontologies and concept mapping as a tool for development.

Communication and Errors in AMT

Civilian AMT is a relatively young field of medicine, and consequently, the quantity and maturity of research lags behind that of cardiovascular medicine, trauma, neonatal medicine, and many other disciplines. To date, research in AMT has concentrated largely on case studies of interesting transports[17-19] or evaluation studies of risks, benefits, and utilization[20-22]. While there are increasing numbers of studies on accidents and safety in AMT[23-25], only two were found on communication and errors[26,27]. One of those studies is the publication of Study 2 from this research. The other study by Vilensky analyzed the incidence and type of communication errors during the initial call to request a transport. Vilensky randomly sampled 98 calls and found that 42% of those had errors with the most frequent type being the omission of information. To find a useful body of literature on communication and errors, searches were conducted in domains related to AMT such as aviation, health care, communications, and human factors.

There is a rich corpus of research on communication and errors in aviation. These studies include in-depth reviews of accidents[10] as well as detailed analysis of laboratory experiments in highly controlled simulator environments[7]. While errors and accidents are often the product of a unique set of circumstances, several themes emerge about communication from these studies. In a comprehensive study of the literature on team decision making, Orasanu[8] concluded that communication is central to team performance in nonroutine tasks (i.e., problem solving) and that communication is necessary to synchronize a shared understanding between team members who perform interdependent functions (i.e., shared mental models). A separate study by Orasanu and Fischer[9] found that causes of communication failure were related to problems with the transmission of information, problems with the content of communication, and problems with the social interaction style. In describing the role of communication, perhaps Orasanu and Fischer said it best:

> Communication is the glue that binds participants together in group interaction or team tasks. It is a transparent medium through which group work is organized and accomplished. . . . For tasks requiring interaction and coordination among multiple players, communication is the central issue. It is through communication that we make our intentions known to others, request and provide information, invite others to share their thoughts and suggestions, direct others to take actions, and manage social relations among participants. (p. 135)

In recent decades, increasing attention and research has been given to the role of communication in health care. Operations in a typical hospital will utilize paging systems, telephones, cell phones, faxes, email, and wireless radio, along with person-to-person communication as essential components for the provision of care. Health care processes are information intensive and communication dependent. In his analysis of the literature on communication, Coiera suggested that communication tasks are essential and related to information tasks through a continuum he described as the information –

communication task space [28]. The following passage eloquently describes this concept; "In summary, the communication space is apparently the largest part of the health system's information space. . . . The biggest information repository in health care lies in the people working in it, and the biggest information system is the web of conversations that link the actions of these individuals" (p. 278).

The importance of communication in health care reflects the evidence of its role in errors and adverse events. In a review of the literature on communication and errors in health care, Alvarez and Coiera[3] found numerous case reports, editorials, and studies that described the contribution of poor communication to errors and adverse events. In one study, about 50% of all adverse events were attributed to communication difficulties[4].

Theoretical Background

Quality improvement theory

Quality improvement theory is grounded in the scientific method and was born from the work of Walter Shewhart[29], W. Edwards Deming[30], and Joseph Juran[31,32]. There are core principles of quality improvement theory that underlie all modern approaches whether they be Total Quality Management (TQM)[33], Lean Manufacturing[34], Six Sigma[35], or others. Those principles are:

- Quality is defined by customer's requirements
- Top management has direct responsibility for quality improvement
- Variation is inherent in all work processes
- Improving quality requires reducing waste and reducing variation
- QI is a continuous effort of systematic analysis and improvement

The last principle is based upon the scientific method of hypothesis, experiment, and evaluation and reflects an important tool for continuous quality improvement. The most familiar example of that method is known as the Plan, Do, Check, Act (PDCA) cycle first described by Deming and shown in Figure 2.

The four elements of the PDCA cycle stand for; 1) Plan – establish the goals or objectives of the service or product, 2) Do – implement the service or product and collect data on performance, 3) Check – evaluate the results and compare with goals, 4) Act – make corrective actions or design changes that will improve performance and achieve goals. The PDCA cycle is an important tool in Life Flight's quality management program. As mentioned previously, this research is focused on the QI process with the objective to understand the problems in the QSMS for measuring quality waste (e.g., miscommunication) and improve performance of the system so that miscommunication can be effectively analyzed and reduced. Furthermore, the design of this research is

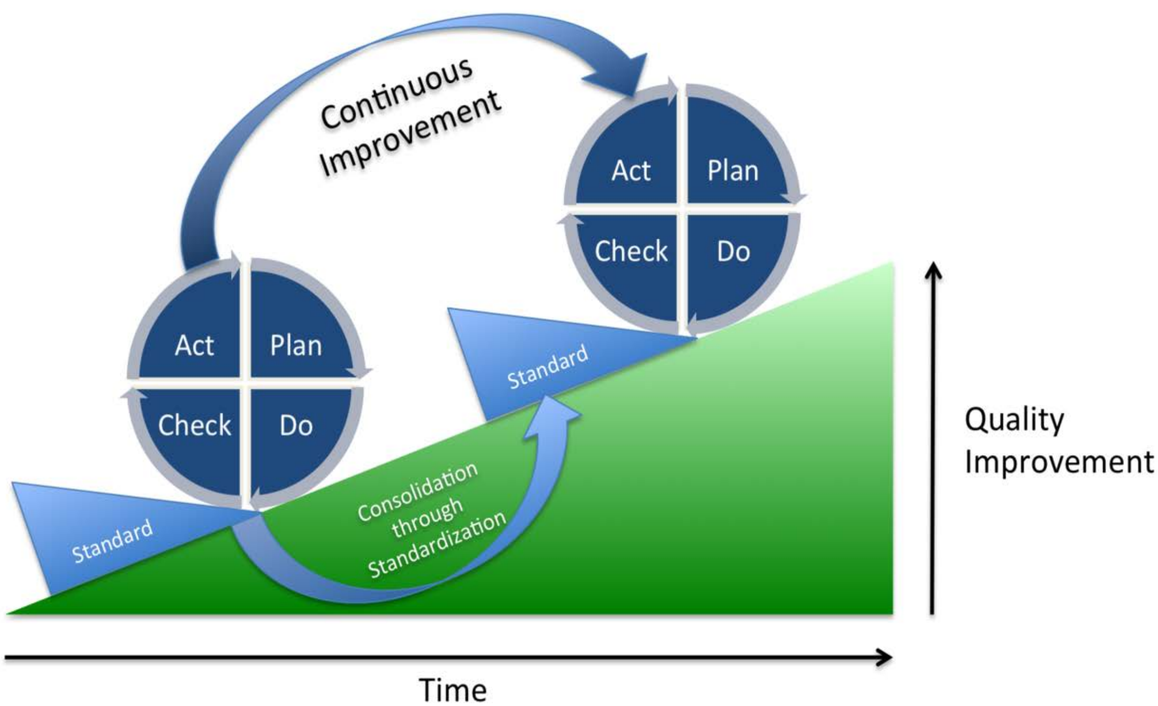


Figure 2. PDCA[36]

nicely aligned with PDCA with Aims 1 and 2 representing the Do and Check steps and Aims 3 and 4 representing the Act, Plan, and Do steps.

Communication theory

Communication is a broad subject with many contexts and thus many theories describing performance in those contexts. However, for this research, I have identified two frameworks that seem particularly useful for understanding and analysis of communication in AMT. The first is known as the Information Theory of Communication and provides a way to view communication in terms of quality, performance, and error. The groundwork for the Information Theory was described by Claude Shannon and Warren Weaver in their classic book, *The Mathematical Theory of Communication* [37]. The theory suggests that communication can be modeled as the transmission of information from a sender to a receiver through a channel. Information is defined as the measure of uncertainty in a situation or message. Performance is influenced on three levels: transmission of information, semantic information, and the effectiveness level[38]. The transmission level is the coding, transmission, and decoding of a message from a sender to a receiver. Performance at the transmission level is largely a result of physical systems external to the person sending or receiving. The semantic level involves the human element of interpretation and understanding. The effectiveness level has to do with the purposeful state of the individual and the extent to which a message changes the state of the individual through informing, instructing, or motivating. Performance at the semantic and effectiveness levels is a function of cognitive processes within the sender and receiver. Figure 3 provides a graphic of the Information Theory.

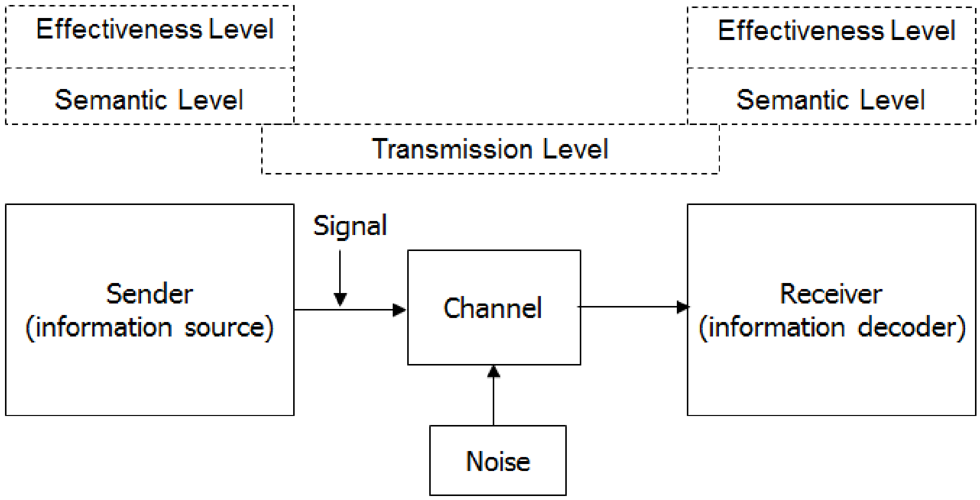


Figure 3. Information Theory of Communication

The second theoretical framework of communication useful for this research is described by Herbert Clark[39,40] and has similarities to the Information Theory of Communication. This framework, known as the Joint Action Ladder, was chosen because it focuses on communication as a social and linguistic phenomenon. Although Clark developed his theoretical ideas focusing on face-to-face communication, his concepts and taxonomy have been extended to human-computer communication as well[41].

According to Clark, mutual understanding or common ground is established through four progressive levels. Timothy Paek operationalized these four levels as Channel, Signal, Intention, and Conversation[41]. Level 1 or Channel actions constitute the establishment of a visual, auditory, or tactile method of communication between the sender and the receiver. Level 2 or Signal is the sound in a verbal communication, the visual symbols (e.g., text) in a data communication medium such as digital paging, or tactile symbols such as brail writing for the blind. Level 3 or Intention refers to the semantic meaning that is derived from the content within the signal. Level 4 or

Conversation refers to the joint activity that is understood between the sender and receiver.

Clark states that the relationship between the levels is hierarchical beginning with Level 1. Establishment of the Channel must be successfully accomplished in order to permit Signal. Next, the Signal must be successfully accomplished to enable Intention and so on. This property is known as “upward causality” with each level built on top of the previous. Upward causality means that when errors occur at a particular level, such as Signal, the higher levels are unable to be completed (e.g., Intention, Conversation). Likewise, successful completion of a level, such as Intention, implies successful completion of the lower levels (i.e., Channel, Signal). This property is known as “downward evidence”. A graphic of the Joint Action Ladder is shown in Figure 4.

At all levels, humans utilize whatever tools available to them with the overarching intention to maximize collaboration while minimizing use of cognitive resources. In a general sense, Clark’s Joint Action Ladder can be seen as encompassing the Information Theory model with Levels 1 and 2 of Clark’s model comprising the transmission level of Information Theory and Level’s 3 and 4 analogous to the semantic and effectiveness levels, respectively.

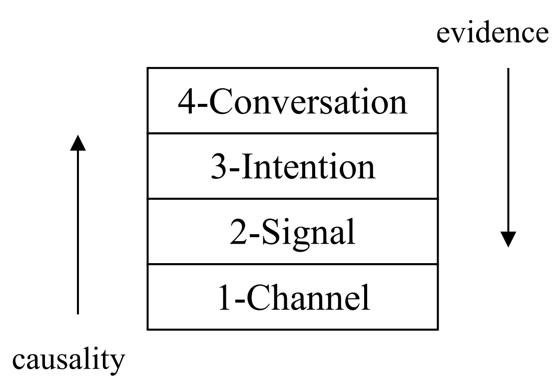


Figure 4. Joint Action Ladder framework of communication

The goal of analysis using the theoretical model is to better understand miscommunication so that causes and remedies will be apparent. Each level of Clark's model plays a unique role in communication. Each level is important because it is required for successful communication, and therefore, successful completion of the joint action. Knowing which level(s) of communication were or were not successful could inform reviewers to seek remedies such as improved communication equipment range in a Level 1 (Channel) failure versus better scripting with more specific information exchange (e.g., standardized report) with a Level 4 (Conversation) failure. For QI, it is not enough to know that miscommunication is occurring, but rather why and what can be done about it.

There are several common themes that have emerged from both the aviation and health care literature that support the application of Clark's model to the study of communication and error in AMT. Findings by Orasanu and Fischer[9] that causes of communication failure were related to problems in transmission and content of information reflect issues at Levels 1 and 2 (i.e., Channel, Signal). Likewise, in AMT, typical failures at these levels occur as distortion or loss of radio transmissions, failure of pages to go through, or difficulty in getting persons on the phone. Research by Orasanu[8] concluded that a shared mental model is needed for good team performance and that communication is necessary to develop a shared mental model. Similarly, Coiera[28] used the term 'common ground' to refer to shared knowledge between persons, and said that common ground must be developed between persons involved in a task in order to perform efficiently. The notion of shared mental models or common ground has impact at both Levels 3 and 4 of the Joint Action Ladder (i.e., Intention and Conversation levels).

In summary, the Information Theory of Communication and Joint Action Ladder provide useful frameworks for analysis of communication and miscommunication at Life Flight.

Human error

The human factors literature contains useful research on communication and errors in a variety of environments[42-45] as well as frameworks for analysis[46,47]. James Reason defines an error as a failure of planned actions to achieve their desired ends without the intervention of some unforeseeable event[48]. Errors can be further divided into slips, lapses, and mistakes. A slip is a failure in execution, such as a 'slip of the tongue' that transposes words in speech. A lapse is a memory retrieval failure, such as forgetting a step while performing a sequence. A mistake is a faulty plan where actions conformed to the plan, but the plan did not achieve the desired outcome. Another useful concept related to errors is a violation. Violations are deviations from standards, rules, or safe operating procedures. A violation may be due to an error or it may be a deliberate, planned action.

To protect against errors that can cause adverse events, organizations develop defenses, in multiple layers, to prevent or trap these errors. Reason uses a Swiss cheese model to describe the relationship between errors, defenses, and adverse events where defenses (i.e., slices of cheese) are imperfect, having holes, and organizations create multiple layers of these defenses to prevent errors from causing adverse events. On rare occasions, however, the holes line up so that an error penetrates the defenses and an adverse event occurs.

Ontologies

Clark's model of communication concepts and relationships provides the foundation for an ontology of communication. Ontologies are structures, containing concepts and their relationships, which provide a framework for representing knowledge about a particular domain. Ontologies are commonly used for organizing information, capturing knowledge, and communicating about a domain. Ontologies that are used in computers to model a system and that have explicit definitions of their concepts and relationships are known as computational ontologies.

The QSMS at Life Flight utilizes an internally developed computational ontology with concepts related to quality, safety, and operational performance. This ontology is implemented in the QA/Event Report and enables automated workflow and decision support for quality and safety management activities. Some of the concepts on the QA/Event Report indicate or imply a communication issue and it is these elements that are the focus of this research.

Computational ontologies have their origins in artificial intelligence (AI) used in expert systems to support decision-making. These ontologies have arguably had their greatest success in biomedicine[49]. Unfortunately, there is no standard methodology for building bio-ontologies and many are built on an ad hoc basis. Furthermore, a review of methodologies by Castro[50] found a lack of support for the use of domain experts with limited knowledge in developing ontologies.

Ontology development using concept maps

To better support the collaboration of domain experts in ontology development, Castro proposes a structured development method using concept maps. Concept mapping is an effective tool for developing bio-ontologies by enabling domain experts to create simple, intuitive, graphical representations of domain concepts and relationships that are easily shared and refined. Concept maps are graphs containing nodes that represent concepts and arcs that represent relationships between concepts[51]. The process for developing the ontology consists of six key steps:

1. Defining the purpose of the ontology
2. Identifying reusable elements from existing ontologies
3. Domain analysis and knowledge acquisition
4. Iterative building of informal ontology models (e.g., concepts, relationships)
5. Formalization
6. Evaluation of formalized ontology

Appendix A contains a concept map for a possible communication ontology for AMT that was developed as part of domain analysis and identification of ontologies that may be useful for this project.

Virtually all methods of ontology development emphasize the need to use or re-use elements of existing ontologies. Table 1 provides a set of references containing useful content for a communication ontology in AMT.

This section provided a review of knowledge on key subject matter for this research. Theoretical frameworks for quality improvement, communication, and human error were presented along with a discussion of ontologies. The following chapters utilize that knowledge to analyze communication in an AMT setting and develop a communication ontology for quality improvement.

Table 1. References for communication ontology development

Author	Domain	Description
Stetson[52]	Biomedical Informatics	Ontology of medical errors and information needs
Gong[53]	Biomedical Informatics	Clinical communication ontology for medical errors
Paek[41]	Computer Automation	Communication error taxonomy
Horan[54]	Biomedical Informatics	Ontology for mobile EMS
Weigmann & Shappel[55]	Human Factors / Aviation	Tool for investigation and analysis of human error in aviation (HFACS)
Shorrock & Kirwan[56]	Air Traffic Control (ATC)	Tool for analysis and correction of errors in ATC
Thomadsen[57]	Healthcare QA	Taxonometric guidance for developing quality assurance

STUDY 1 – QUALITATIVE ANALYSIS OF COMMUNICATION AT AN AMT SERVICE

Study Purpose

The purpose of this study is to describe the nature of communication at Life Flight, the types of errors, and the consequences of miscommunication in performing a transport. Achieving this purpose will require answering the following questions:

1. What communication activities take place as part of the patient transport process?
2. What technologies are currently used for communication?
3. What communication-related errors have occurred?
    a. What are the consequences of communication errors?
    b. How are communication errors reconciled or fixed at Life Flight?

Methods

Design

A case study approach was employed utilizing researcher training, individual interviews, group interviews, observations in the Communication Center, and document analysis. The combination of methods provided a rich body of data from diverse perspectives. This diversity enabled triangulation to offset shortcomings in the individual methods[58].

Setting

This study was conducted with the permission of the Life Flight AMT service. Life Flight is an AMT service located in Salt Lake City that serves Utah and neighboring states of the intermountain west. Life Flight has been operating since 1978 and is one of the oldest civilian helicopter AMT programs in the U.S. Life Flight operates a fleet of seven rotor-wing and three fixed-wing aircraft with bases in Salt Lake City, Ogden, Provo, and St. George, Utah. Life Flight performs over 3,500 transports annually, averaging 10 patient transports per day. To address unique patient needs, Life Flight maintains flight teams and services focused on adult, pediatric, and neonatal populations. A little over half of all Life Flight transports are for children or neonates and 70% of transports are for critical care patients needing interfacility transfers.

It is important to note that although Life Flight is known as an AMT service, its teams frequently transport patients by ground ambulance. Ground transport is typically used in three scenarios: 1) as a shuttle service between airports and hospitals when patients are transported by fixed wing aircraft, 2) when inclement weather prevents safe transport by aircraft, and 3) when distances are relatively short and local ambulance staff are unable to provide the level of care needed, such as with neonatal patients. Ground ambulance transport is not unique to Life Flight but is common with many AMT services. For ground ambulance transports, Life Flight contacts local ambulance services to provide the vehicle and driver while Life Flight provides the patient care team.

Participants

Participants for this study were volunteers from a variety of roles, including pilots and fight nurses who perform the actual patient transports, communication specialists and operational controllers that work in the Communications Center, and a medical control MD. Participants were a convenience sample, based upon their willingness to participate and their availability during the time period allocated for the study.

Procedures

Researcher training. Training was conducted to familiarize this researcher with the locations, processes, and key systems associated with communication. Training was conducted on three separate days covering radio communications, the Golden Hour dispatching system, and the Golden Hour patient care charting system. Golden Hour is a commercial vendor providing applications for the AMT industry. Radio communication training was conducted by volunteer Life Flight staff and Golden Hour training was part of a Life Flight training program conducted by Golden Hour consultants. Total training time covered 17 hours.

Interviews. Procedures for the interviews followed the recommendations in Lindoff and Taylor[59], which described good listening techniques, building rapport during the interview, and design of the questions to achieve the research purpose. Individual interviews were conducted with two flight nurses, one operational controller, and a medical control MD. Three group interviews were conducted with staff having specific roles (i.e., pilots, communication specialists, and flight nurses). Five pilots, three communication specialists, and four flight nurses attended their group interview sessions, respectively. A structured Interview Guide was developed to provide a consistent format and address the research questions. A copy of the guide is provided in Appendix B. The interviews were held in the conference room at Life Flight headquarters, and lasted between 40 and 55 minutes. An audio recorder was used to capture the discussion. All interviews began with a brief overview of the research objectives and asking the interviewee permission to record the session. All interviewees felt comfortable being recorded and the interviews proceeded using the Interview Guide.

Observations. Observations were conducted in the Life Flight Communication Center because it contained the widest variety of communication activities possible. The Communication Center is located at Salt Lake City International Airport and is the work area for communication specialists and the operations controller. Due to the attention demanding tasks in this environment, this researcher took the role of observer-as-participant to minimize impact on the communication specialists and operational controller[59]. An observation protocol was prepared to guide the process and provide structure for data collection[60]. Observations took place in four separate sessions over a three-month period with each session lasting from 1.5 to 6 hours. Observations covered operational hours between 5 a.m. and 11:30 p.m. The total time spent on observations was 17.5 hours. A copy of the Observation Guide is provided in Appendix C.

Document review. To understand Life Flight's organizational knowledge about communication, analysis was conducted on two documents that are important for transport operations, the Communications Center Protocols and Procedures and the Communication Specialist Training Binder.

Analysis. This study used the conceptual frameworks of Information Theory of Communication and human error from James Reason for describing communication and errors. Analysis for all methods of data collection (e.g., interviews, observations, document analysis) consisted of three phases: data management, data reduction, and conceptual development. This approach is commonly used and well described in qualitative methods literature[59]. Data management was important for organizing the large volume of data from the interview notes, observation field notes, and Life Flight documents. To facilitate organization and retrieval of salient data, a Microsoft Access application was developed that stored raw excerpts of data along with field notes, memos, and contextual information about the data collection environment. The application included analytic components (e.g., queries, and reports) that permitted retrieval and analysis of codes, categories, and themes in addition to the raw data. The application acted as a home-built computer-assisted qualitative data analysis tool (CAQDA).

Early analysis began with the review of notes, recordings, and texts from the various sources and insertion of data into the CAQDA. Notes were attached to the raw data as they were formulated. An initial "prefigured" code sheet was developed using concepts from human error theory and information theory. During entry of the raw data and notes emergent, *in vivo* codes were also developed and assigned[61]. This process was helpful for coding excerpts that did not match well with any existing codes. Coding continued until all data had been reviewed and assigned codes that were meaningful. By completion of coding, all data had been reviewed at least two times, once for the initial data entry and once for the coding. During each review, thoughts and notes were generated and attached to the excerpts.

Data reduction consisted of developing stepwise, chronological, process summaries for answering research question 1, developing a matrix of communication technologies and their characteristics to answer research question 2, and analyzing codes to identify patterns and relationships that led to the development of categories and themes for all questions.

The final phase of analysis (i.e., conceptual development) placed the mapped codes and categories in relationship to one another in a framework of human error and communication theory. This was the interpretation phase. By using several sources of data (i.e., interviews, observations, and document analysis) the study design was able to enhance validity by having convergent data for some concepts from two or more sources. For example, excerpts from all sources verified the chronological communication activities during a patient transport as well as the communication tasks by role for the pilot, flight nurse, communication specialist, operational controller, medical control physician, and referring physician.

Maintaining privacy and confidentiality. Privacy to study participants and confidentiality of data were maintained by the following procedures:

- All participants in the interviews and observations were briefed on the consent form prior to participation.
- No identifiable data were collected.
- All hardcopy data, removable storage media, and research artifacts not being used were secured in a locked cabinet at this researcher's office that requires secure ID badge access.
- All electronic data not being stored on removable media were kept on a secure personal computer requiring login/password access that resides in this researchers office.

Results

Research question 1 - What communication activities take place as part of the patient transport process?

The communication required to transport a patient is a complex process that varies by the patient location, patient condition, and the aircraft or vehicle required. The transport of a patient from a community hospital, for example, to a hospital with a higher level of care, such as a Trauma 1 center, is known as an interfacility transport. The transport of a patient located at a nonhospital 'scene', such as a motor vehicle accident, for example, is known as a scene transport. Depending on patient need and location, the transport vehicle may be a helicopter (i.e., rotor-wing), an airplane (i.e., fixed-wing), or a ground ambulance. There are many communication steps involved in transporting a patient at Life Flight. Analysis shows there are at least 17 communication interactions involving at least 8 different people for an uneventful scene transport and typically 28 interactions involving at least 10 different people for an interfacility transport. A stepwise, chronological summary of communication activities is presented in Appendix D and E for scene and interfacility transports, respectively. This model, called the Task Timeline Model of Communication, is based upon the task, operator, machine, environment method (TOME) utilized for human factors analysis.

At Life Flight, pilots, medical crew, and communication center staff all receive training and education on communication tasks as part of orientation as well as ongoing training. This training involves use of communications equipment along with required communications that are part of operational activities (e.g., request for transport, interfacing with public safety personnel, interfacing with referring staff and medical control, reports to receiving facilities, debriefings, shift changes, and more.

Research question 2 - What technologies are currently used for communication?

A variety of technologies are necessary to transport a patient in a safe and timely manner. The transport team carries at least three different communication devices with them at all times (i.e., pager, cell phone, 800 Mhz radio) and during the course of a complex scene transport, they may utilize as many as six different communication devices. In the Life Flight Communication Center, the communication specialists utilize sophisticated paging, radio, and telephone systems having dozens of channels each, along with a state-of-the-art, computer-based dispatching application and satellite-based flight tracking systems. A table of communication technologies and their associated role is provided in Table 2.

Research question 3 - What communication related errors have occurred? What were the consequences and what did Life Flight do to prevent or reconcile the errors?

The most common error described by participants was a communication lapse (i.e., omission of information). This is consistent with other research on communication errors in AMT[27]. These lapses degrade the effectiveness level of communication and have a broad range of impact from nothing at all to delays in getting the patient to definitive care. An emergent theme that arose from analysis of the impact of lapses was anxiety about vulnerability and loss of control. At times, the flight nurses felt that the communication specialists were not providing all the information they had, that they were

Table 2. Technologies used for communication

Technology	Description/User/Use
Digital pager	Provides limited text information. Used by communications specialists or operational controllers to notify transport teams of a transport and provides subsequent information updates such as flight plan, contact information, latitude, and longitude.
Cell phone	Used by transport teams to contact Communication Center when on scene or at airport. Preferred over radio when outside aircraft unless coverage is poor.
Satellite phone	Used by transport teams in circumstances when cell phone or radio coverage is missing.
Landline phone	Used by all personnel when in a facility or when available. Preferred over cell phone and radio
800 Mhz radio	Utah Emergency Services communication band. Carried on person by transport teams at bases. Used by communication specialists or operational controllers to notify transport teams of a transport. Used to communicate between members of a transport team when separated at scene. Used to communicate with county dispatchers, sheriff's offices, search and rescue.
UHF radio	Radio located in aircraft. Used similar to 800 Mhz radio when 800 Mhz coverage is missing.
VHF radio	Radio located in aircraft. Similar to UHV, but using a different band.
Seimens multi-line phone system	Used by communications specialists or operational controllers to contact EMS, physicians, hospitals, and other services that have land line. Used to connect transport teams on site to medical control. Can connect up to 7 lines together in conference call.
Satellite flight tracking system	Displays current aircraft location graphically on large 3x4 display. Also shows weather. Used by communications specialists or operational controllers to keep track of aircraft.
Computer-based dispatch system	Manages call and transport information. Used by communications specialists and operational controllers to provide situational awareness of current and pending transports

"holding onto information." This created a lingering anxiety by the nurses having thoughts like ". . . Do I have the right equipment? . . . Am I going to the right place? . . . Am I prepared?" This theme is described in the following excerpt.

> I'd have to say that on every flight I go on there's a concern. Yeah, either I didn't get enough information or when I requested the information I

> wasn't given it or I wasn't told that things were being taken care of on the other end. . . . . I think that they (communication specialists) try to set standards or map out processes that indicate the need for specific information. Sometimes these are seen by people that have to do them as time consuming, and not important to them. Where they feel like it takes too much time to accomplish. Again, they're assuming their need to know that information isn't important so they don't see what my job is. So, a lot of times the team will call it holding onto information. Say a dispatcher gets a call from a referring, either scene or otherwise, and they'll say we have a 2-year-old that was struck by a car, unconscious, um, and he's also a diabetic. Enroute I may get, 'child struck by a car'. That's great, but if I know their age, I can estimate a weight and I can have my drugs drawn. They know that it was a closed head injury, unresponsive, but they haven't passed that to me. In my mind I'm thinking this is a possibility of intubation. I can um, calculate those intubation drugs, I can have all that done prior to arrival. . . . Where they just say, you know, 2-year-old struck by a car. And then you go back and listen to the recording and, you know, there's a lot more information there. They don't see the importance of passing it on to the provider. So it's lost information and it's information that isn't acted upon . . .

While the flight crew may feel a sense of anxiety and loss of control from lapses in communication by communication center staff, the opposite is also true. During the interview with an operational controller, who performs similar communication duties to the communication specialists, she stated that her greatest concern is ". . . not being able to find an aircraft." Sometimes this is caused by dead zones in the flight tracking system or radios. Other times it can be due to the failure of the transport team to perform an expected communication.

Another type of error in communication experienced at Life Flight is a slip. This happens infrequently, but persistently from time to time. One of the best examples is the mixing up of the locations of a patient. During an interview, a flight nurse described a transport where she was told the patient was in Richfield. While enroute to Richfield, a subsequent communication revealed that the patient was actually in Roosevelt and the Operational Controller had made a slip in stating Richfield. This caused a delay in arrival to the patient, added costs for refueling, and even impacted staffing because an additional pilot had to be called in when the original pilot could not receive the required rest between duty times.

In addition to slips and lapses, equipment-related problems were cited as a significant communication issue. One flight nurse was frustrated by the inconsistent performance of batteries in the radios: “Your 800 (Mhz radio) battery can go dead on you and it seems that it always comes at the most inopportune moment.” Dead zones in radio and cell phone coverage prevent communication from taking place. The radios are bulky and cumbersome to carry, which causes crew members to remove them from time to time and then leave them behind (lapse). The framework of Information Theory is useful for understanding some of these communication issues in the context of error theory. The inability to establish or maintain a communication link is a failure at the transmission level or the channel used to exchange information. Transmission errors also occur in the pager system. The pilots described anecdotes where a page was never received, or it was delayed by 20 minutes, or the text information was nonsense characters. These transmission failures created holes in defenses that increased the likelihood of mistakes (i.e., having the wrong plan) or other errors leading to adverse events. Life Flight has made a great investment in defenses against transmission failures, particularly redundant communication equipment. As mentioned previously, the transport team carries at least three different communication devices on their person at all times and may utilize as many as six different devices during a transport.

Perhaps the most significant theme to emerge from this study was the speed versus accuracy tension that was evident in all sources of data. In air medical transport, emphasis is placed on rapid transport of a patient. This affects all processes of the transport, including communication. Patients requiring air medical transport are the 'sickest of the sick' and time can literally mean a life saved or a life lost. There is growing awareness recently to rethink this emphasis because of the inherent risks of air medical transport[23]. In my introduction, I made the argument that good communication is necessary for reducing errors and adverse events. Good communication requires sufficient time and attention by those involved to understand what is being communicated and to validate the quality of the information so that any desired actions will be performed (i.e., success at the effectiveness level of the Information Theory model). The speed vs. accuracy tension is evident in the earlier excerpt from the flight nurse discussing communication lapses. I watched it playing out during my observation in the communication center. At one point during my observation, there were three transports in process, three pending requests, and communication traffic was occurring at about one per minute. I wrote in my field notes the following excerpt; ". . . At this point I cannot keep track of what's going on. I am totally overwhelmed. Phone calls and radio messages are coming in non-stop. I'm glad these people are experienced because there's a lot at stake right now."

Under these circumstances, the communication center staff has a dilemma of deciding, in very short order, how much time can be spent validating or double-checking information to ensure accuracy versus getting what information is available out to stakeholders who are waiting. Delaying or failing to attend to a contact may be just as risky as forwarding information that has not been validated. I found an exemplar of this tension in an excerpt from my analysis of a communications training document on radio techniques:

> . . . The foundation of a good dispatcher rests upon reliability and promptness.
>
> Reliability should never be sacrificed for speed, yet speed is of equal importance.
>
> . . . Any unit calling must be answered promptly. Under no circumstances allow a calling unit to go unheeded.
>
> A calling unit should never be asked to standby before its need for assistance has been ascertained.

Discussion and Conclusion

Due to the complex and frequent nature of communication at Life Flight, there are many opportunities for error. Fortunately, many layers of defenses minimize their impact so that the vast majority of transports succeed without problems or at worst, suffer minor inconveniences. The most common error described was a communication lapse that eroded the effectiveness level of communication. These lapses had a broad range of impact from nothing at all to delays in transporting the patient to feelings of vulnerability and loss of control by the staff. Equipment problems causing transmission level failures were also cited as significant communication issues that were impactful.

Life Flight employs a variety of strategies to prevent or mitigate communication errors. These strategies include *hard* defenses (i.e., physical/technical devices, such as their redundant communication systems) and *soft* defenses[46] such as redundant operational processes, postflight debriefings, flight reviews, training, education, and utilization of a QSMS. This study demonstrated the utility of a synthesized theoretical framework, based upon the Information Theory and human error theory, for analysis of communication at an air medical transport service. While the risks of the air medical transport environment motivate Life Flight to continually improve defenses, it is unclear how or what defenses can be used to mitigate the effects of the speed vs. accuracy dilemma.

STUDY 2 – QUANTITATIVE ANALYSIS OF COMMUNICATION ERRORS AT AN AMT SERVICE

Study Purpose

The purpose of this study is three-fold: 1) determine the frequency of communication errors reported, 2) analyze how staff classified communication errors, and 3) analyze communication errors using Clark's Joint Action Ladder framework of communication. Achieving this purpose will require answering the following questions:

1. How often are communication errors evident in QA/Event Reports?
2. How are communication errors classified by staff?
3. What is the distribution of communication errors across the levels of the Joint Action Ladder?

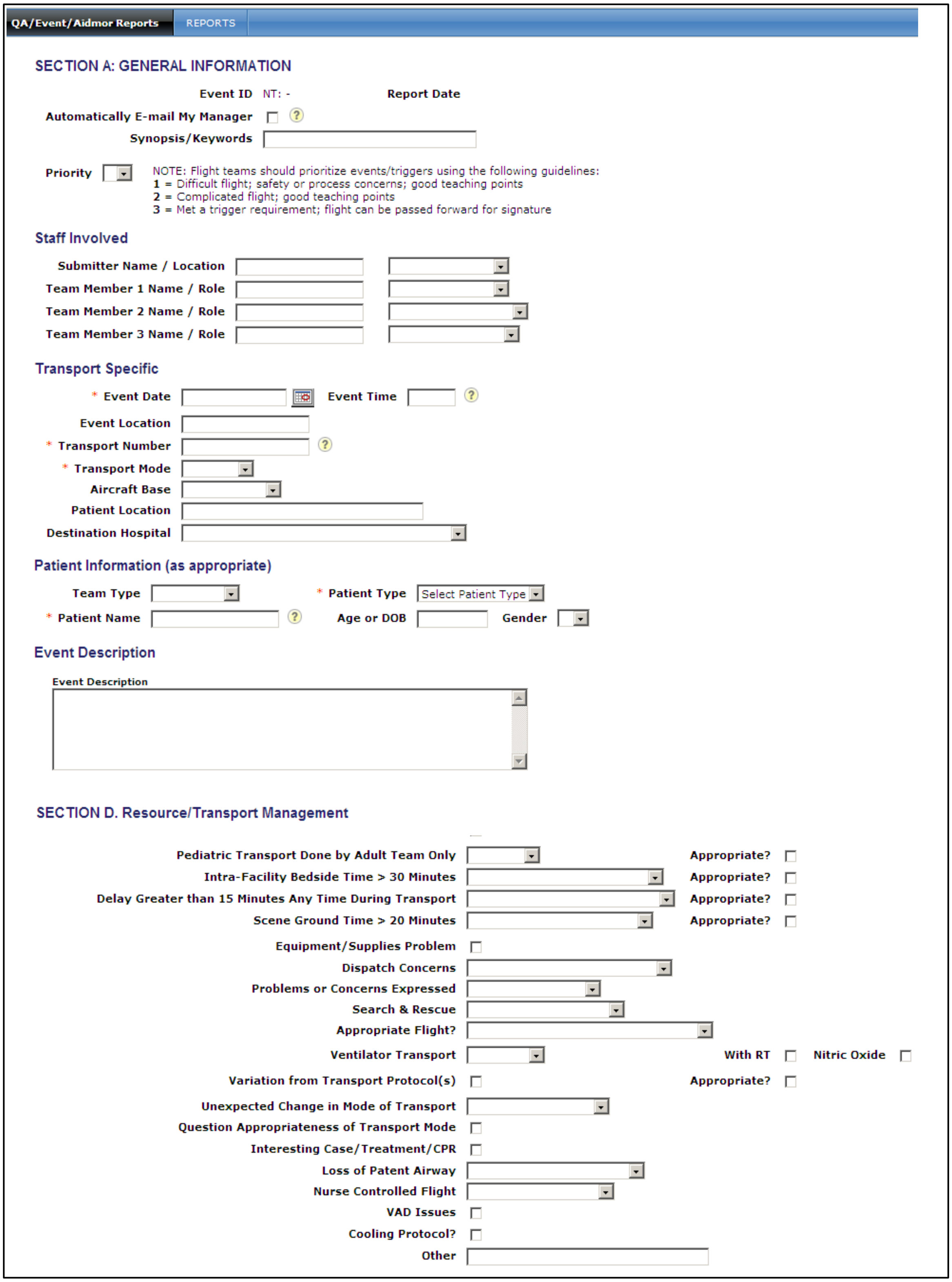
This study is the quantitative segment of a mixed-methods design to characterize communication and miscommunication at Life Flight. The quantitative data are derived from Life Flight's QSMS, which is utilized for reporting communication issues as well as any potential or actual adverse event. A description of the QSMS is provided in the following section.

Background

The QSMS

The Life Flight QSMS is a web-based system, developed internally using an online database application platform called Intuit Quickbase[62]. The QSMS enables all services to manage key operational activities, including scheduling, submitting event reports, logging procedures, and more. The QSMS has functionality for event review and loop closure as well as for querying and analysis of event reports. This AMT service has developed systematic rules for reporting. For example, reports are required for any transport with a scene time greater than 20 minutes. Reports are also required for high-risk processes regardless of outcome (e.g., oral intubation – successful or not). The interface, known as the QA/Event Report, is a structured form with check boxes, dropdown boxes, and text fields for inputting demographics, designated events, procedures, and narrative descriptions. The designated events are referred to as "triggers." A screenshot of the top section of the QA/Event Report is provided in Figure 5.

There are approximately 150 different triggers that staff can use to classify an event. Some triggers exist as a unique event (e.g., Interesting case) while most exist as a subcategory of a more generic event (e.g., Dispatch Concerns - type of vehicle selection). This interface structure creates two levels of detail. The first level is made up of unique, broad triggers. The second is made up of subset triggers within the first level. Life Flight staff have been coached to select all triggers that apply, so that a report from a single mission may have multiple triggers selected. Within the QSMS, there are 22 triggers that imply a communication problem. These triggers provide the spectrum of possibilities for staff in classifying communication errors and are shown in Table 3.



QA/Event/Aidmor Reports | REPORTS

SECTION A: GENERAL INFORMATION

Event ID NT: -
Report Date
Automatically E-mail My Manager
Synopsis/Keywords
Priority

NOTE: Flight teams should prioritize events/triggers using the following guidelines:
1 = Difficult flight; safety or process concerns; good teaching points
2 = Complicated flight; good teaching points
3 = Met a trigger requirement; flight can be passed forward for signature

Staff Involved

Submitter Name / Location
Team Member 1 Name / Role
Team Member 2 Name / Role
Team Member 3 Name / Role

Transport Specific

* Event Date
Event Time
Event Location
* Transport Number
* Transport Mode
Aircraft Base
Patient Location
Destination Hospital

Patient Information (as appropriate)

Team Type
* Patient Type Select Patient Type
* Patient Name
Age or DOB
Gender

Event Description

Event Description

SECTION D. Resource/Transport Management

Pediatric Transport Done by Adult Team Only — Appropriate?
Intra-Facility Bedside Time > 30 Minutes — Appropriate?
Delay Greater than 15 Minutes Any Time During Transport — Appropriate?
Scene Ground Time > 20 Minutes — Appropriate?
Equipment/Supplies Problem
Dispatch Concerns
Problems or Concerns Expressed
Search & Rescue
Appropriate Flight?
Ventilator Transport — With RT — Nitric Oxide
Variation from Transport Protocol(s) — Appropriate?
Unexpected Change in Mode of Transport
Question Appropriateness of Transport Mode
Interesting Case/Treatment/CPR
Loss of Patent Airway
Nurse Controlled Flight
VAD Issues
Cooling Protocol?
Other

Figure 5. Screenshot of QA/Event Report

Table 3. QA/Event Report triggers that imply a communication issue

BEDSIDE TIME > 30 MIN: Dispatch
DELAY>15MIN: Dispatch
DELAY>15MIN:Ambulance not notified
DELAY>15MIN:Ambulance not notified by Other Dispatch Center
DELAY>15MIN:Comm equipment failure
DELAY>15MIN:Did not activate a team member(s)
DELAY>15MIN:Miscommunication - Ambiguity
DELAY>15MIN:Miscommunication - Breach of Standard
DELAY>15MIN:Miscommunication - Lapse-incomplete/inaccurate
DELAY>15MIN:Miscommunication - Slip/Omission
DELAY>15MIN:Unable to contact Medical Group
DELAY>15MIN:Unable to contact team member(s)
DISPATCH_CONCERN:Comm center equipment
DISPATCH_CONCERN:Failure to dispatch team member
DISPATCH_CONCERN:Failure to dispatch vehicle
DISPATCH_CONCERN:Inadequate transfer info
EQUIPMENT FAILURE: Paging
EQUIPMENT FAILURE: Radio
EQUIPMENT FAILURE: Telephone
PROBLEMS/CONCERNS: Double dispatch
SAFETY_CONCERN: AMRM
SAFETY_CONCERN: Communications issues

Methods

Design

This study used a retrospective, exploratory design. Data for this study were obtained from 278 randomly selected QA/Event Reports from the 825 total reports submitted to the QSMS from Jan 1, 2009 through Dec. 31, 2009. An earlier, unpublished, pilot study by this researcher[personal communication] indicated that approximately 20% of reports have evidence of communication errors. To assure an adequate sample size and statistical validity, a random sample of 34% was chosen.

The 825 reports submitted in 2009 represented 22% of the 3,588 transports that year. For the purposes of this study, a transport was defined as an activity that requires transporting a patient from one location to another. These do not include missed transports, canceled transports, aircraft repositioning, or public relations events. Table 4 shows the distribution of transport by service and mode. Tables 5 and 6 show the frequency of transports and QA/Event reports by service and mode, respectively.

Procedure

To determine the frequency and types of communication errors, each of the randomly selected 278 reports was read entirely for the triggers selected, event narrative, and follow-up remarks. For each report, the triggers selected by staff were recorded and any communication error was noted if it occurred.

Table 4. Frequency of transports by service and mode– Study 2.

Service	Fixed-wing	Ground	Rotor-wing	Total
Adult	539	78	991	1608
Neonatal	188	798	202	1188
Pediatric	264	47	481	792
Total	991	923	1674	3588

Table 5. Frequency of transports and QA/Event Reports by service – Study 2.

Service	Transports	QA/Event Reports
Adult	1608 (45%)	473 (57%)
Neonatal	1188 (33%)	107 (13%)
Pediatric	792 (22%)	245 (30%)
Total	3588(100%)	825(100%)

Table 6. Frequency of transports and QA/Event Reports by mode – Study 2.

Mode	Transports	QA/Event Reports
Fixed-wing	991(27%)	278 (34%)
Ground	923 (26%)	98 (12%)
Rotor-wing	1674 (47%)	449 (54%)
Total	3588(100%)	825(100%)

For this study, a communication error was defined as one or more of the following: the failure to communicate, inability to communicate, delayed communication, communicating wrong or incomplete information, or a misunderstanding of plans and goals. The specific categories used for this study and examples are provided in Table 7.

The following questions were used to evaluate each of the selected reports: 1) Was there evidence of a communication error? 2) If so, what was the communication error category as defined in Table 7? 3) At what level of the Joint Action Ladder hierarchy did the communication error occur? The communication error was assigned the lowest level applicable as described by Clark. Table 8 provides the levels with definitions and Table 9 provides the variables collected for this study.

Initial review of reports and classification of communication errors, including refining definitions, was done by this researcher, the Thesis Committee chairperson, and the Life Flight medical director for the Adult Service. The process was iterative, with each of the reviewers independently reading and classifying the same set of reports and then comparing results. Disagreements were discussed and debated until a consensus was reached. During each round, definitions and classification of communication errors were refined. Four successive rounds of QA/Event Report coding were done by the three raters to achieve adequate interrater reliability. Each round contained between 15 – 20 reports. To measure interrater reliability, a generalized version of Cohen's Kappa statistic was calculated for each round[63]. The first round achieved a Kappa of 0.35 for the theoretical communication level and 0.24 for defined communication error categories. By the end of the fourth round, a total of 69 reports had been reviewed, yielding a Kappa of 0.88 for the communication level and 0.81 for defined communication error categories.

Table 7. Categories defining communication errors.

Call/page not returned

Example: Start of shift page (i.e., communication check) to 'On Call' crew member was not returned.

Communication not received

Example: 911 dispatcher was unable to relay information to local EMS agency about rendezvous location.

Communication procedures not followed

Example: Pilot failed to provide in- flight status update (Expected every 15 min. during flight).

Failure to communicate - change in status or plans

Example: Dispatch failed to update referring facility of delayed arrival of flight crew due to weather.

Failure to communicate – expectations not communicated

Example: Expectations for range of blood pressure control by receiving MD did not get passed along to flight nurse.

Inability to communicate - communication equipment not working adequately

Example: Batteries died in handheld radio.

Incomplete info

Example: Medical control MD failed to inform flight nurse during report that CT showed patient had an epidural bleed.

Misunderstanding of plans, goals

Example: Flight nurse directed crew to launch helicopter and pick up patient from referring facility when medical control MD wanted crew to remain on standby pending information from referring facility.

Unplanned/inefficient steps

Example: When respiratory therapist (RT) was unable to fill a call shift, there was no backup plan and as a result, dispatch made multiple calls to RT supervisor and others to get RT support for transport.

Wrong info

Example: Dispatch told flight crew they had a transport to one location (Richfield) when it was actually to a different location (Roosevelt).

Table 8. Definitions for levels of Joint Action Ladder.

Level 1 (Channel): Failure with initiating communication. Either unable to communicate or failed to communicate when indicated.

Examples:

Communication equipment out of range (e.g., radio).

Pilot failed to provide in- flight status update (Expected every 15 minutes. during flight).

Level 2 (Signal): Communication initiated (i.e., Level 1 achieved), but signal was intermittent or incoherent.

Examples:

Crew members have difficulty hearing each other because they are wearing protective masks that interfere with clarity of voice communication.

Crew member receives text page with random, garbled alphanumeric characters.

Level 3 (Intention): Communication initiated, signal is perceived, (i.e., Levels 1&2 achieved), but the meaning of the content in the signal is not understood.

Examples:

Hand signals used by crew during hoist operation were not standard or commonly understood by participants.

Pilot tells crew to maintain a "sterile cockpit", however, one crew member does not know what "sterile cockpit" means.

Level 4 (Conversation): Communication initiated, signal is perceived, the meaning in content of signal is understood (i.e., Levels 1-3 achieved), but the goals or joint activity of the communication are not accomplished in an efficient or effective manner.

Example: Flight nurse and medical control MD have discussion about whether to launch aircraft and begin transport. After conversation, flight nurse directs crew to launch helicopter to referring facility. However, control MD wanted crew/aircraft to remain on standby pending certain information from referring facility.

Table 9. Variables for Study 2

Variable	Definition
Transports	Numeric, count of Life Flight patient transports during the study period. Used for descriptive statistics
QA reports	Numeric, count of QA/Event Reports filed during the study period. Used for descriptive statistics
Service	Categorical, identifying the service submitting the QA/Event Report (e.g., Adult, Pediatric, Neonatal). Used for descriptive statistics.
Mode	Categorical, vehicle type indicated by the transport on the QA/Event Report (e.g., Rotor-wing, Fixed-wing, Ground). Used for descriptive statistics.
Communication error	Categorical, one of a set of 8 possible communication error categories that was indicated on the QA/Event Report. See Table 6 for specific definitions.
Reports with communication error	Numeric, count of QA/Event Reports indicating a communication error occurred. Used for descriptive statistics.
Communication level	Categorical, the specific level from a set of 4 possible theoretical levels that indicate where communication was not successfully achieved when a communication error occurred. See Table 7 for specific definitions.
Communication error trigger category	Categorical, the communication error related trigger selected by staff on the QA/Event Report when a communication error occurred. Table 3 provides the complete list.

Having obtained sufficient interrater reliability, the first author then completed review and classification of the remaining 209 reports.

Analysis. Descriptive statistics were used for reporting demographics, prevalence of communication errors, and classification categories. The Kappa statistic was used to evaluate interrater reliability. The two tailed Chi-squared test was performed to determine if there were differences in the submission rates of reports by service or mode and if there were differences in miscommunication reported by service or mode. When multiple, pairwise comparisons were made, Bonferroni adjusted p-values were calculated. A p-value of < 0.05 was considered statistically significant.

Results

Reporting demographics

Chi-squared analysis showed a statistically significant difference between the proportion of transports by service versus the proportion of reports submitted by service (Table 5, Chi-squared = 150.407, $p < 0.0001$, 2 degrees of freedom). Further pairwise analysis showed a difference between Neonatal report submissions compared with either Adult (Chi-squared = 138.2, $p < 0.0001$, Bonferroni adjusted, 1 degree of freedom) or Pediatric submissions (Chi-squared = 127.9, $p < 0.0001$, Bonferroni adjusted, 1 degree of freedom). There was no difference between the proportion of reports submitted for Adults and Pediatric service compared with the proportion of transports (Chi-squared = 0.226, $p = 1.0$, Bonferroni adjusted, 1 degree of freedom).

There was a statistically significant difference between the proportion of transports by mode versus the proportion of reports submitted by mode (Table 6, Chi-squared = 86.653, $p < 0.0001$, 2 degrees of freedom). Further pairwise analysis showed a difference between Ground associated report submissions compared with either Fixed-wing (Chi-squared = 73.4, $p < 0.0001$, Bonferroni adjusted, 1 degree of freedom) or Rotor-wing associated submissions (Chi-squared = 73.6, $p < 0.0001$, Bonferroni adjusted, 1 degree of freedom). There was no difference between the proportion of reports submitted for Fixed-wing and Rotor-wing modes compared with the proportion of transports for those modes (Chi-squared = 0.377, $p = 1.0$, Bonferroni adjusted, 1 degree of freedom).

Research question 1 - How often are communication errors evident in QA reports?

Of the 278 reports reviewed, 58 had evidence of a communication error (21%). Table 10 provides the distribution of reports with communication errors by service and mode, while Table 11 provides the distribution of reports reviewed by service and mode.

Chi-squared analysis showed no statistically significant differences between services (Chi-squared = 1.346, p = 0.510) or mode of transport (Chi-squared = 2.510, p = 0.285) when comparing the proportion of communication errors versus the proportion of reports reviewed.

Research question 2 - How are communication errors classified by staff?

There were 64 total communication errors detected in the 58 reports, with several reports having multiple errors. Only 18 of the 64 identified errors (28%) were classified by staff using a communication-related trigger. Table 12 provides the frequency of communication error by report trigger. The remaining 46 communication issues were only evident from the narrative text event descriptions. The 18 communication errors that

Table 10. Frequency of reports with communication errors – Study 2.

Service	Fixed-wing	Ground	Rotor-wing	Total
Adult	13	4	18	35 (60%)
Neonatal	3	5	0	8 (14%)
Pediatric	5	1	9	15 (26%)
Total	21 (36%)	10(17%)	27 (47%)	58 (100%)

Table 11. Frequency of reports reviewed – Study 2.

Service	Fixed-wing	Ground	Rotor-wing	Total
Adult	59	12	92	163 (59%)
Neonatal	10	14	5	29 (10%)
Pediatric	30	5	51	86 (31%)
Total	99 (36%)	31 (11%)	148 (53%)	278 (100%)

Table 12. Frequency of communication errors by QA/Event Report trigger.

Triggers	Count
DELAY>15MIN: Dispatch	2 (11%)
DELAY>15MIN:Unable to contact team member(s)	1 (6%)
DISPATCH_CONCERN: Failure to dispatch team member	1 (6%)
DISPATCH_CONCERN: Inadequate transfer info	5 (27%)
PROBLEMS/CONCERNS: Double dispatch	1 (6%)
SAFETY CONCERN: Communications issues	8 (44%)
Total	18 (100%)

were identified using communication triggers occurred on 18 different reports and were distributed among only 6 of the 22 possible categories.

Research question 3 - What is the distribution of communication errors across the levels of the Joint Action Ladder?

Analysis using Clark's levels of communication revealed a very uneven distribution with 66% of communication errors occurring at Level 1 (n=42/64), 33% occurring at Level 4 (n=21/64), 1% occurring at Level 3, and no reported communication errors occurring at Level 2. Figure 6 shows the distribution of communication errors by level. The following are examples of communication failures categorized at Levels 1, 3, and 4. There were no instances of Level 2 (Signal) communication failures.

Level 1 – Crew member did not call back in response to page for shift-change.

Level 3 – Hand signals between ground crew and aircraft crew were not understood.

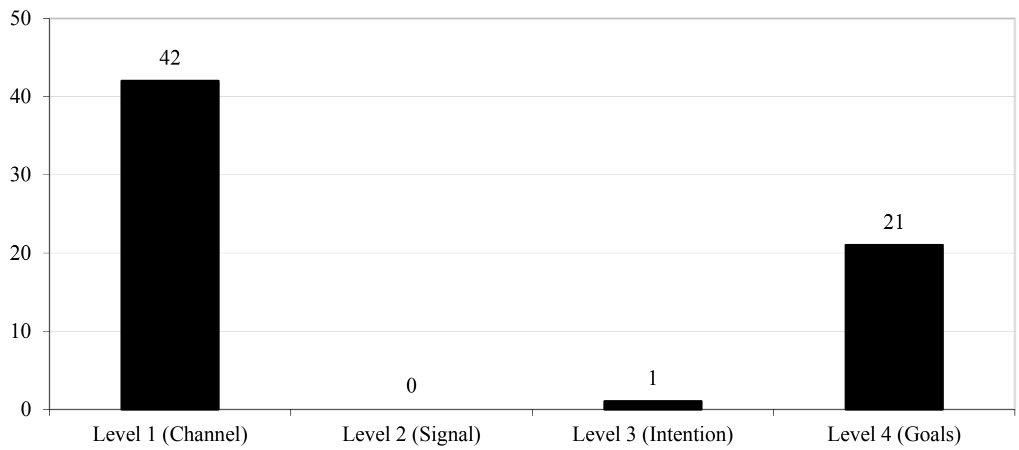


Figure 6. Communication errors for Joint Action Ladder

Level 4 – Report on patient from referring facility was incomplete. Patient's severity of illness was not given.

Analysis of communication errors by the categories used to define errors (Table 7) shows 'Failure to communicate – change in status or plans' being the most frequent communication error category (31%), followed by 'Communication procedures not followed' (13%) and 'Incomplete info' (13%). Table 13 provides the frequency of errors by definition category.

Discussion

The key objectives of this study were to analyze QA/Event Reports to determine the frequency, types, and distribution pattern of communication errors within a theoretical framework.

Reporting Demographics

Analysis of reporting patterns showed differences in the number of reports filed by service and mode that is not explained by the number of transports (Tables 5, 6). This result is not surprising and is largely due to the unique nature of neonatal transports. At

Table 13. Frequency of communication errors by definition category.

Category	Count (%)
Call/page not returned	4 (6%)
Communication not received	2 (3%)
Communication procedures not followed	8 (13%)
Failure to communicate - change in status or plans	20 (31%)
Failure to communicate - expectations	6 (9%)
Inability to communicate - comm equip. not working adequately	4 (6%)
Incomplete information	8 (13%)
Misunderstanding of plans, goals	6 (9%)
Unplanned/inefficient steps	3 (5%)
Wrong information	3 (5%)
Total	64 (100%)

this AMT service, neonatal transports are less variable than adult and pediatric transports because they are always interfacility transports and utilize ground ambulance to a much greater degree than the other services. Approximately half of all neonatal transports use ground ambulance, whereas adult and pediatric transports utilize fixed-wing or rotor-wing greater than 90% of the time.

Requests for neonatal transport are exclusively a result of provider to provider referrals for a patient population with a limited set of diagnoses. While the QA/Event Report contains triggers common to all services, each service also has their own set of unique triggers that may increase or decrease the need to report compared with other services. Scene and search and rescue-related triggers used by the Adult and Pediatric service are not used by the Neonatal service. Less variability in neonatal transports means more frequently repeated processes by the crew and fewer triggers on the report that can be selected.

Research question 1 - How often are communication errors evident in QA reports?

This study found that communication errors are evident in 21% of all QA/Event Reports (n=58/278). This pattern was similar across all services and modes (i.e., the differences were not statistically significant). These results are consistent with a previous, unpublished pilot study that showed communication errors evident in 20% of QA/Event Reports. It is important to note that these errors do not reflect all communication errors, but those flagged by trigger or otherwise described by staff on an event report. Communication errors that are recognized and repaired immediately or that have little or no consequence during the transport are not required to be reported. Life Flight staff are coached to document communication problems on reports if they are a result of equipment failure or if they cause delays, safety concerns, issues with referring or receiving staff, or if they are otherwise noteworthy.

Research question 2 - How are communication errors classified by staff?

Although the QA/Event Report provides 22 categories (i.e., triggers) in which to classify communication issues, this study found only six categories were utilized by staff and only 28% of the total communication errors were flagged using a communication error trigger (n=18/64). Most communication errors were not flagged by a trigger and were only apparent by reading the event narrative. Correspondingly, only 31% of the reports with communication errors had a communication error trigger utilized by staff (n=18/58).

There are a variety of reasons for why the QA/Event Report's communication triggers were seldom used. First, many of the communication triggers are grouped under either ‘Delay > 15 min’ or ‘Dispatch Concern,’ which limits their presentation to the user if those outcomes are not apparent. Second, many triggers are not mutually exclusive and so when faced with multiple trigger possibilities, the staff may select the most familiar trigger, such as ‘Problems/Concerns – Receiving facility/staff,’ rather than a communication-related trigger. Third, a communication error may not be the key causal factor for submitting the report. It may be noted in a narrative, but not by selecting a specific communication trigger. Fourth and last, staff may not have recognized the problem as a communication error.

Research question 3 - What is the distribution of communication errors across Clark’s levels of the Joint Action Ladder?

Evaluating communication errors using Clark’s theoretical model showed that virtually all errors occurred at either the lowest level (i.e., Level 1 - establishing communication) or the highest level (i.e., Level 4 - goals/purpose of communication). This may be explained by the nature of communication in the transport environment. It is not surprising to see a high rate of Level 1 (Channel) issues. There are many communication tasks that are required during the course of a transport. Frequently, these tasks involve remote communication, such as dispatcher-to-transport team, flight nurse-to-receiving nurse, or referring MD-to-medical control MD. There is no single communication link (e.g., mobile phone, radio, land line, pager) that meets the diversity of needs. These links all get used at various times and sometimes all are required on a single transport. Geographical separation, isolation, mobility, and system limitations present challenges to establishing communication. Furthermore, some participants such as referring MDs, receiving MDs, and medical control MDs may be involved with other high priority tasks (e.g., other patients) and may not be able to respond when communication is requested.

Level 1 (Channel) triggers are the most numerous communication-related triggers within the structure of the QA/Event Report. Of the 22 triggers that imply a communication error, 12 triggers can be related to the Channel (e.g., ‘failure to contact/notify,’ ‘unable to contact,’ comm. equipment failures). Despite the number and variety of Channel triggers on the QA/Event Report, only 2 of the 42 Channel communication errors identified in this study were flagged by staff using these triggers.

One third of the communication errors occurred at Level 4 (Conversation). These are akin to the phrase “. . . being on the same sheet of music.” With these errors, both participants are engaged in the communication, they understand the meaning of the words spoken, but for a variety of reasons, the goal of the joint activity is not accomplished in an efficient or effective manner. These issues often result from ambiguity and vagueness in phrasing or the omission of key information stemming from the false assumption of shared knowledge. The following excerpt provides an example.

> We were located at the airport due to weather. We were dispatched to do a ground transport. We waited over forty minutes for an ambulance, because the ambulance had gone to the wrong location (at the airport). … Dispatch needs to be very clear about where they are sending the ambulance.

In this case, the ambulance crew was told by dispatch to meet the team at the airport, but not given the team’s specific location at the airport. The ambulance crew assumed a specific location at the airport they were to meet the team, but their assumption was incorrect. The instructions from dispatch were not specific enough.

There was only one Level 3 (Intention/semantic) communication error identified in this study. This was a case during a hoist operation where there was confusion on whether the signal “tapping on the head” meant ‘”operations normal” or “Ok for forward flight.” The paucity of Level 3 instances may be due to several factors. First, communication in this work environment is often predictable, if not scripted. Participants speak the same language, they are familiar with each other’s role, and they use standard phrases and terms. Second, the descriptions in the reports may not have contained sufficient detail for the researchers to differentiate an Intention/semantic level issue from an issue that was more easily interpreted as Conversation level.

There were no Level 2 (Signal) communication errors identified in this study. Signal issues are rare because in most cases, the signal and channel are tightly coupled. In other words, if the signal is marginal or lost it is usually due to a failure of the channel. An example of a Signal level issue would be if the crew needed to wear protective masks in the aircraft to prevent the spread of infection. The masks could make it difficult to understand what was being said[64].

In contrast to the theoretical communication levels, the occurrences of our defined communication error categories were more evenly distributed (Table 13). These descriptions are more specific and reveal more information about the types of issues across the hierarchy of communication levels. Even so, there were still a few miscommunication scenarios that were not accurately described by the defined communication error choices. One example is when a pilot failed to provide a planned 15-minute update of flight status. This might be more accurately described by a category such as ‘Failure to communicate – planned update or status.’

A key goal of this study was to evaluate the usefulness of analyzing communication errors by using Clark’s levels to determine where these errors occur. This analysis validated existing perceptions. That is, much of the communication is synchronous, person-to-person, which makes connecting persons in separate locations who have differing priorities a challenge (i.e., Level 1 - Channel issues). Clark's model provided some additional information about communication errors. In this regard, the model contributes to a framework for improvement.

By default, structured forms such as the QA/Event Report establish standard terms and concepts. These terms and concepts can be viewed as a taxonomy or perhaps even more usefully as an ontology. While the purpose of a taxonomy is to define and classify terms in a domain, an ontology goes farther by defining terms, concepts, and their relationships in a manner that can be processed by computer[65]. As a result, ontologies are useful for exchanging data and information between humans and machines, such as with information retrieval (e.g., queries), data mining, analysis, decision support, and performance simulation[54]. Given the large volume of information in Life Flight's QSMS, computer-assisted analysis and decision support are essential for individuals responsible for quality and safety.

Limitations

There are several limitations with this study. First, this study collects data from one safety management system in one AMT service and the results may have limited usefulness for other services and scenarios. Second, there was measurement error associated with coding data from QA/Event Reports. Data from these reports often had limited and cryptic descriptions of the communication scenarios. Therefore, some assignment of categories relied on knowledge of roles and operational tasks. Third, data are self-reported so that counts and types of communication errors are biased by individual perceptions of benefits or consequences of reporting, self-image, cultural norms, and organizational expectations.

Conclusion

The most frequent analysis asked of quality and safety management systems is ‘How many and of what type?’ Results from this study indicate that Life Flight’s QSMS is inadequate for quality improvement related to communication errors. Fewer than half of QA/Event Reports with communication issues would be retrieved by queries of coded data from communication error triggers (31%). While sensitivity could be increased by applying sophisticated keyword/phrase queries to the narrative text fields or by natural language processing, those solutions are complex, requiring scarce technical resources, and still may not capture all errors. Therefore, analyzing communication errors to make improvements would require painstaking manual review of all reports. Such effort in a continuous cycle of improvement would be impractical.

While the ultimate goal of analyzing communication errors is to identify remedies to improve performance and reduce potential adverse events, the purpose of this study was more foundational. Quality improvement theory requires establishment of a reliable measurement system to determine baseline performance and when changes have taken place (e.g., improvement). This research was intended to assess Life Flight’s current communication error measurement system as the first step towards improvement. Further research is needed to establish a standard, theory-based ontology to enable efficient retrieval and analysis of communication errors from QA/Event Reports. Reducing communication errors would further enhance the safety of air medical services.

STUDY 3 - ONTOLOGY DEVELOPMENT

Study Purpose

Study 2 revealed the shortcomings of Life Flight's QSMS for analyzing miscommunication. Specifically, the ontology as operationalized in the QA/Event Report was inadequate for identifying and analyzing communication errors. The purpose of this study is to develop an improved ontology that enables more accurate and useful measurement of communication errors. Achieving this goal will enable simple queries of ontology concepts to retrieve a much greater percentage of reports with communication errors than the current ontology (31%). Since this study is about development rather than experimentation, a qualitative descriptive approach is used to explain the process and factors influencing the evolution of the ontology.

Methods

The process for developing the ontology followed the method described by Castro[50] that consists of six key steps:

1. Defining the purpose of the ontology
2. Identifying reusable elements from existing ontologies
3. Domain analysis and knowledge acquisition
4. Iterative building of informal ontology models using concept maps
5. Formalization
6. Evaluation of the ontology

Steps 1 - 3 provide the foundational knowledge for steps 4 – 6 which are the actual ontology building steps. Steps 1 – 3 have been completed as a result of literature reviews and the research from studies 1 and 2. The focus of this study was on steps 4 – 6. Building the ontology involved group collaboration methods with domain experts. Ontology development took place in a series of meetings over the course of one year. To support group collaboration and formalize the ontology, Cmap Tools[66] was used to create concept maps and WebProtégé for documentation[67]. Protégé implements knowledge-modeling structures and actions that support the creation, visualization, and manipulation of ontologies in various representation formats.

Evaluation was done in two steps. First the ontology was tested for reliability using a set of miscommunication scenarios coded by a subgroup of the ontology development team. Second the development team evaluated the final ontology with a set of competency questions. Competency questions are key questions, expressed in natural language, that the ontology was designed to address. An example competency question could be “How often did communication errors occur over the past year?” Details of the ontology development process are provided in the Procedure section.

Participants

Identification of domain experts was done through a one-on-one meeting with the Adult Services medical director of Life Flight. The medical director recommended a group size of four to six experts to provide diversity of roles without over burdening the organization. Participants included a fixed-wing pilot, an operations controller, two Adult Services flight nurses, and a Children’s Service flight nurse. Criteria for participation was at least 10 years experience and currently performing operational duties in AMT. Each participant was asked if they were willing to participate in the ontology development project and each agreed. Including this researcher, the development team consisted of six persons, three male, and three female.

Procedure

The kickoff meeting for ontology development was held on Feb. 20, 2013. One week prior to the meeting, key reference materials were distributed to the team that included a copy of the published research article on Study 2[26] and the seed concept map (Appendix A). The meeting lasted for 120 minutes with a short break for lunch in the middle. The first 30 minutes was used by this researcher to explain the research from Study 2 that highlighted the shortcomings of the current QSMS in querying events with communication issues. The next 30 minutes was used to explain ontologies, concept maps, and how the current ontology of the QSMS was inadequate for analyzing communication errors from QA/Event Report data. The seed concept map along with a concept map of Life Flight's QA/Event Report showing communication triggers was presented (Appendix F). While the original plan for this meeting included developing new ontology concepts and competency questions, only the first two objectives of the meeting were covered due to the number of questions the staff had about the project. Among the questions were; "Why are we doing this?," "Is this simply someone's research project or is this something that is a priority for us?," "Do we really need to fix the QA/Event Report?," "Communication problems are everywhere, why don't we fix issues with the Communications Center first?" Although the entire planned agenda was not completed, the team agreed to attend follow-up meetings to continue the project.

The second meeting for ontology development was scheduled for Apr. 3, 2013.

Between the first and second meeting, additional information was sent to the group, via email, addressing the concerns from the first meeting as well as a proposed agenda for the second meeting. From that email discussion, the team agreed the goal of the second meeting was to brainstorm communication error-related concepts and competency questions that could be answered using the new ontology.

The ontology development meeting on Apr. 3 lasted 90 minutes and all participants from the first meeting were present. A brief review of ontologies was given followed by review of Clark's theoretical model of communication. Over the course of the meeting, the domain experts brainstormed a set of communication error concepts and competency questions. Table 14 provides the list of communication error concepts and Table 15 provides the competency questions developed at the meeting. At conclusion, the group agreed to plan the next meeting for mid-June. Following the meeting, the list of concepts, competency questions, and concept map were emailed to the team with instructions to consider what additions or revisions were needed. Figure 7 is the concept map and Figure 8 is a screen shot from WebProtégé.

Shortly after meeting two, a planning meeting was held with the Adult Services medical director and this researcher. Progress and issues with the ontology development project were discussed. Off line, several team members had been expressing their concern with the purpose, motivation, and implications of the project. The medical director suggested time be given at the beginning of the meeting to explain the "big picture" purpose for the project and importance of developing an improved ontology. An outline to explain the "big picture" and purpose was developed. Email was used to schedule meeting three for June 18.

Table 14. Communication ontology concepts – meeting 2

Concept	Description/definition
Communications	Similar to that used for Safety Concern on QA/Event report.
Communications Level	Levels 1-4 as described by Clark. Determined by trained QA nurse.
Involved persons	Those involved in miscommunication, identified by role.
Level 1 - Channel	The medium used such as phone.
Level 2 - Signal	Clarity and strength.
Level 3 - Semantics	The meaning as defined in language.
Level 4 - Goals	The person was misunderstood.

Table 15. Competency questions – meeting 2

How often do communication errors occur?
At what level of Clark's hierarchy do errors occur?
What team members need to be involved?
Do we have input from other team members?
Who was involved in the communication issue?
Was the communication issue resolved during transport?
Was a procedure in place? Was it clear? Was it followed
Was equipment involved?

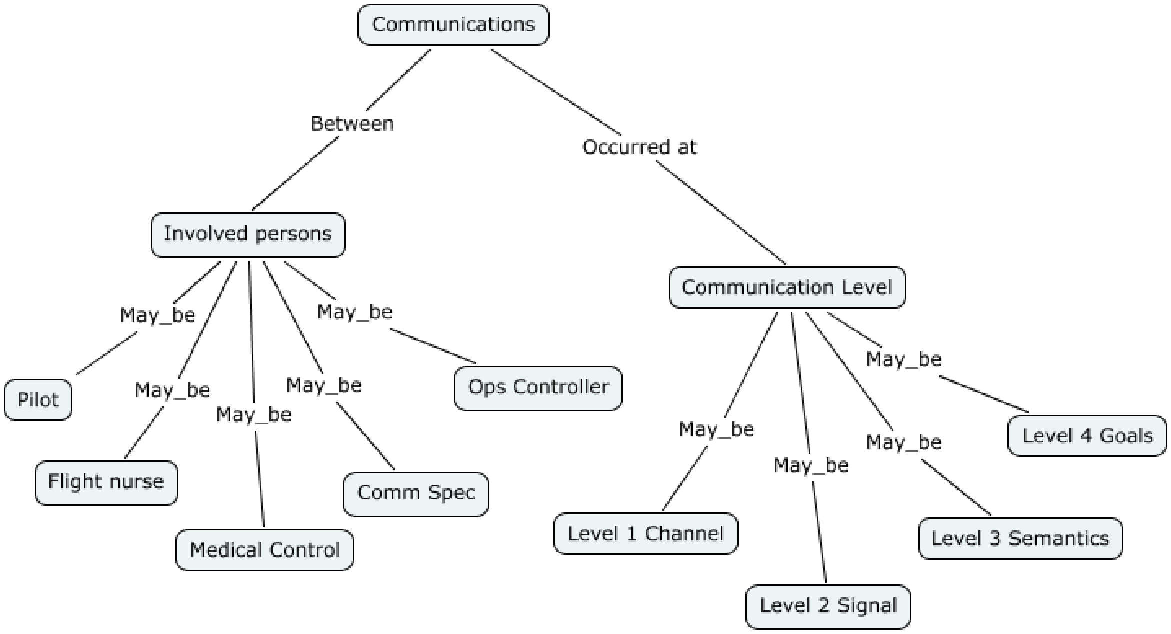


Figure 7. Concept map - meeting 2

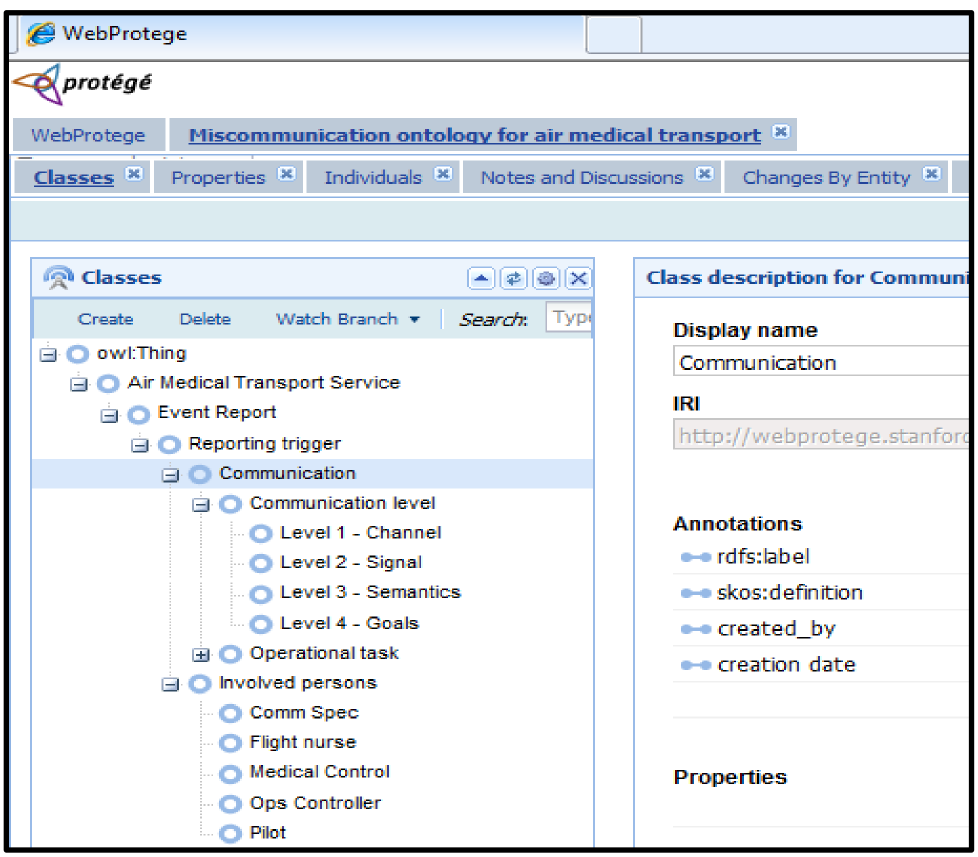


Figure 8. Screen shot from WebProtégé – meeting 2

The ontology development meeting on June 18 (meeting 3) lasted 90 minutes and all team members were present. The meeting began with the “big picture” overview and importance of the ontology development project for improving the analysis of miscommunication. A suggestion was made to include a concept for the operational task involved with miscommunication. There was much discussion about the “Why” and “How” and “What will this mean for me?” aspects of the project that consumed most of the meeting. Several members were concerned that these changes would result in the need to submit many more QA/Event Reports (i.e., increased sensitivity to communication issues). One member suggested that this researcher should just develop the ontology and let the team buy off on the final product. While limited progress was made at this meeting in developing the ontology, the team did agree to meet again in July.

To address the issues from meeting three, this researcher and the Adult Services medical director met again to plan for the July meeting. At the planning meeting it was decided to add another member on the team, the Adult Services nurse manager, and to have the medical director lead the next several meetings. To answer the concerns raised at meeting three, this researcher created a meeting summary with additional explanatory information that was emailed to the team. A copy of the summary is provided in Appendix G.

Meeting four of ontology development was held on July 9 and lasted 90 minutes. All team members were present with the addition of the Adult Service nurse manager. The meeting began with the Adult Services medical director explaining the importance of improving the existing ontology in the QSMS to better analyze communication issues. Next, the medical director described the process of quality improvement using Lean

Manufacturing principles and how the team will utilize those principles on this project. At this point, the previously developed materials from meeting two were brought out (i.e., concept list, concept map, competency questions) and the team worked on additions and refinements. In the last part of the meeting, the Adult Service QA nurse provided a summary of her review of a set of 2013 QA/Event Reports looking at miscommunication. Her findings were consistent with those of Study 2 with respect to the frequency of communication errors (20%) and proportions of errors by Communication Level (Level 1 = 50%, Level 4 = 43%). The meeting concluded with the team agreeing to meet again on July 30.

Meeting five for ontology development was held on July 30 and lasted 90 minutes. All team members were present. The meeting began with the medical director defining the organizational goal the project was supporting (i.e., reducing communication errors) and why the project was important to that goal. Next, the medical director explained the three key steps of Lean Manufacturing the team would use to accomplish the goal: 1) define the current state, 2) define the ideal or final state, and 3) utilize the PDCA cycle to move from the current state to the final state. The ontology development project was an important part of the PDCA cycle and key to having an efficient and reliable measurement system for communication errors. The last part of the meeting was used to review and refine the definitions for the four Levels of Communication. Table 16 provides the ontology concepts and definitions as of meeting five. Figure 9 shows the updated concept map.

The next three meetings for ontology development took place on Aug. 15, Sept. 17, and Oct. 29 of 2013. These were the sixth, seventh, and eighth meetings of ontology

Table 16. Communication ontology concepts - meeting 5

Concept	Description/definition
Communications	Similar to that used for Safety Concern on QA/Event report.
Communications Level	Levels 1-4 as described by Clark. Determined by trained QA nurse.
Involved persons	Those involved in miscommunication, identified by role.
Operational task	The task the person was involved with when the communication error occurred.
Level 1 - Channel	No contact made. Either did not attempt or attempted but could not contact (channel issue).
Level 2 - Signal	Garbled communication (unreadable, incomplete/cutoff – signal issue).
Level 3 - Semantics	Did not know definition of a word, phrase, acronym, or visual signal (semantics, difficulty with meaning).
Level 4 - Goals	Failure to achieve the desired outcome or goal of communication (‘not on the same page’, often a result of vague, ambiguous terms, or incomplete information – ‘I assumed you knew that!’).

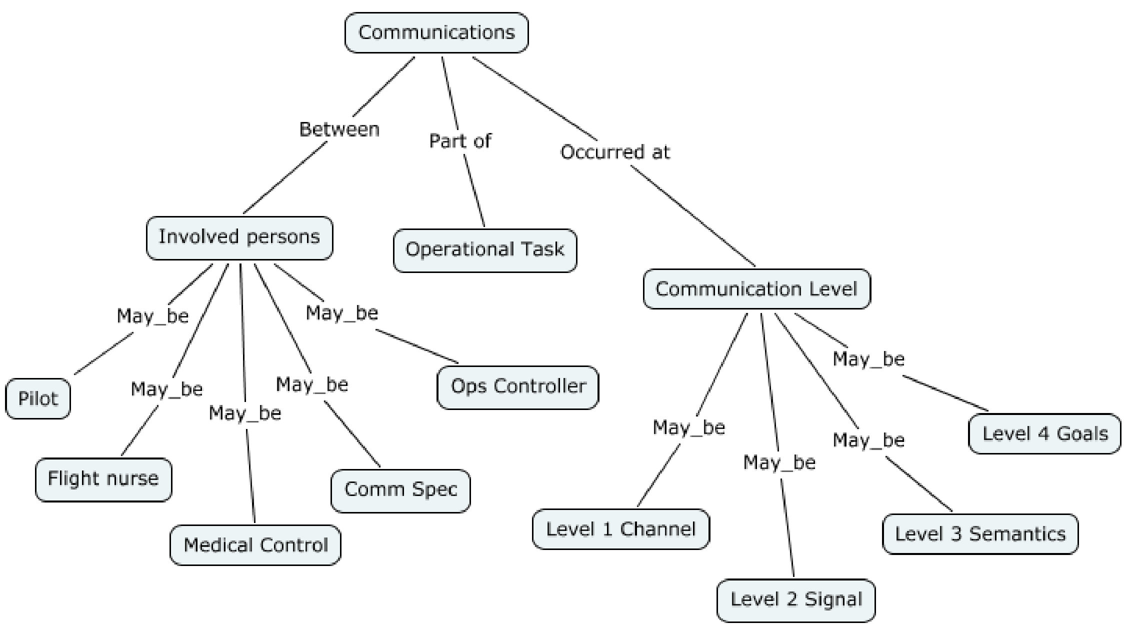


Figure 9. Concept map - meeting 5

development, respectively. Each meeting began with the Adult Services medical director going over the goals and purpose of the project and then reviewing the current concept map and definitions the team had developed. Over the course of these meetings, there was much discussion of the Communication Level concepts. The team had particular difficulty in coming up with workable operational definitions for Level 2 – Signal and Level 3 – Semantic concepts. The team realized they needed concepts with definitions that could be reliably understood and used by staff on the QA/Event Report. As a result, the team decided to create a simpler, custom concept called Communication Concern having three types or possibilities. Furthermore, due to time constraints on the project, the team decided to focus the ontology on a limited set of concepts that would answer two key competency questions while minimizing the change in workflow of staff using the QA/Event Report. This resulted in concepts such as 'involved persons' and 'operational task' being removed from the ontology. The competency questions, concepts, and concept map are shown in Tables 17, 18, and Figure 10, respectively. By the end of the eighth meeting of ontology development, the team felt the ontology was ready for reliability testing and finalization. The procedure agreed upon for reliability testing was that a subgroup of three persons from the team would independently review and code a sample of QA/Event Reports having communication errors using the newly developed ontology. Interrater reliability between subgroup members would be measured as in Study 2 using the Kappa statistic. If Kappa was less than 0.8, refinements would be made to the ontology and then additional rounds of coding would take place until a measure of 0.8 or greater was achieved. Once sufficient interrater reliability had been achieved, the subgroup would report back to the team with the final recommended ontology.

Table 17. Competency questions - meeting 8

How often do communication errors occur? (i.e., Communication Concern)
What type of Communication Concern occurred?

Table 18. Ontology concepts - meeting 8

Concept	Description/definition
Communication Concern	A noteworthy communication error, problem, or issue that causes a delay, a safety concern, or other indication as described in Appendix G.
Unable to contact or difficulty contacting	Communication Concern type 1 - Contact with other person was attempted but not achieved or contact took multiple attempts or longer than expected. Similar to Level 1 – Channel error of Joint Action Ladder.
Conversation misunderstood	Communication Concern type 2 – Contact was made, conversation took place, but goals, expectations, or objectives of communication were not fully achieved. Two persons ‘ *not on the same page.’* Similar to Level 4 – Conversation error of Joint Action Ladder.
Other	Communication Concern type 3 - Communication errors at Level 2 or 3 of Joint Action Ladder or otherwise not meeting definition of Communication Concern type 1 or 2 above.

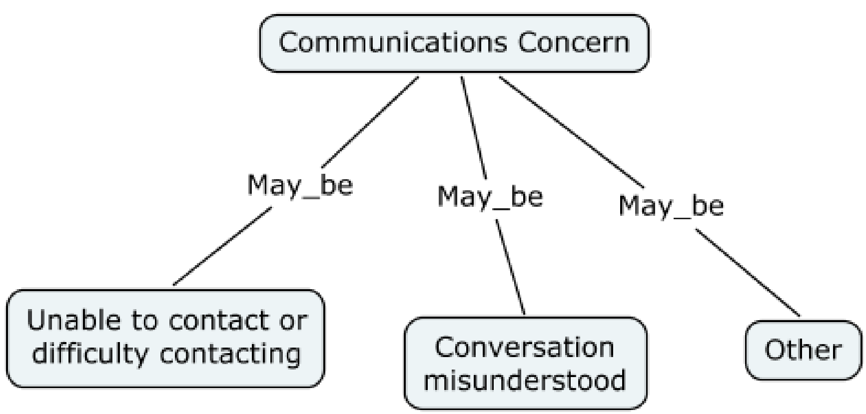


Figure 10. Concept map - meeting 8

The subgroup selected for reliability testing consisted of this researcher, a pilot, who is also the QSMS developer, and an operational controller. A set of 38 QA/Event Reports from Study 2 were randomly selected of which 10 were distributed to each rater to code. After the first round, a Kappa value of 0.42 was achieved. Since this did not meet the 0.8 minimum, the raters discussed differences and clarified each other's understanding. No concepts or definitions for the ontology were changed. However, the process for reviewing and coding was refined to require each rater to document the rational for their choices from the ontology. For the second round, a new set of 10 QA/Event Reports were given to the raters and the agreement measure of 0.73 was achieved.

While the second round was an improvement, it still did not meet the goal of 0.8 minimum. Detailed review by the raters revealed a gap between the ontology concepts and Communication Concern scenarios on the reports. That gap was due to scenarios where persons who should have been included in communications were not or where a person failed to recognize the need to communicate. Neither of these scenarios fit cleanly into the choices in the ontology for Communication Concern. This is because Clark's Joint Action Ladder, the underlying model for the ontology, assumes a person wants to communicate and is actively trying to communicate with some other person. The model does not address scenarios of a broader information-communication task space, described by Coiera[28], which is the context for operations at Life Flight. Failing to recognize the need to communicate is an important communication error at Life Flight that is not addressed by the Joint Action Ladder. To overcome this issue with the ontology, the raters created a new, additional type of Communication Concern called 'Information not forwarded' and provided a definition to cover the problem scenarios from round two. The updated types of Communication Concerns are shown in Table 19. Using the updated ontology, the raters conducted a third round of coding on another 10 QA/Event Reports. At the end of this round, agreement measured 0.87, thus meeting the reliability goal. Adding the new concept made an important difference in reliability of coding. At this point the work of the subgroup was completed and a final ontology development meeting was planned for Feb. of 2014.

The final ontology development meeting was held Feb 2, 2014 and included all participants on the team. The planned agenda included three items: 1) review results and recommendations from the subgroup, 2) finalize and approve the ontology, 3) plan implementation of the ontology. The meeting began with this researcher reviewing the findings and recommendations for ontology concepts and definitions from the subgroup.

Table 19. Types of Communication Concerns

Concept	Description/definition
Unable to contact or difficulty contacting	Communication with other person was attempted but not achieved or contacting took multiple attempts or longer than expected. Similar to Level 1 error of Joint Action Ladder.
Conversation misunderstood	Contact was made, a conversation took place, but goals, expectations, or objectives of communication were not fully achieved. Two persons *' not on the same page.'* Similar to Level 4 error of Joint Action Ladder.
Information not forwarded	Failure to recognize the need to communicate or failure to include a key person in communication. Example – not contacting medical control when there is a question about patient care.
Other	Communication errors at Level 2 or 3 of Joint Action Ladder or otherwise not meeting definition of Communication Concern type 1 or 2 above.

The development team agreed with the subgroup and had no further revisions for the ontology. The competency questions were reviewed and the team unanimously agreed that implementing the ontology on the QA/Event Report will enable the competency questions to be answered. The team's agreement provided final approval for the reliability and validity of the ontology. In the last part of the meeting, the team discussed possible approaches for implementing the ontology. The team recommended that the Communication Concern concept and its subtypes function similar to the Safety Concern concept on the current QA/Event Report. The team assigned the subgroup members to act as an implementation team. Going forward, implementation would be managed by the implementation team in consultation with the managers of impacted depts. With the goals of the ontology development project completed, the ontology development team was dissolved and implementation was handed over to the implementation team.

Results

The final communication ontology concepts, definitions, and concept map are provided in Table 20 and Figure 11. A screenshot of the communication ontology in WebProtégé is provided in Figure 12.

Discussion and Conclusions

The goal of this study was to develop an improved, theory-based ontology that enables more accurate and useful measurement of communication errors. Evaluation of that goal was based upon successful reliability testing and face validation using a set of competency questions. Both of those objectives were achieved with the final communication ontology. However, the ultimate success of the ontology will be determined in Study 4 that will quantitatively measure for improvement.

Table 20. Final communication ontology concepts and definitions

Concept	Description/definition
Communication Concern	A noteworthy communication error, problem, or issue that causes a delay, a safety concern, or other indication as described in Appendix G.
Unable to contact or difficulty contacting	A type of Communication Concern. Communication with other person was attempted but not achieved or contacting took multiple attempts or longer than expected. Similar to Level 1 error of Joint Action Ladder.
Conversation misunderstood	A type of Communication Concern. Contact was made, a conversation took place, but goals, expectations, or objectives of communication were not fully achieved. Two persons *' not on the same page.'* Similar to Level 4 error of Joint Action Ladder.
Information not forwarded	A type of Communication Concern. Failure to recognize the need to communicate or failure to include a key person in communication. Example – not contacting medical control when there is a question about patient care.
Other	A type of Communication Concern. Communication errors at Level 2 or 3 of Joint Action Ladder or otherwise not meeting definition of Communication Concern type 1 or 2 above.

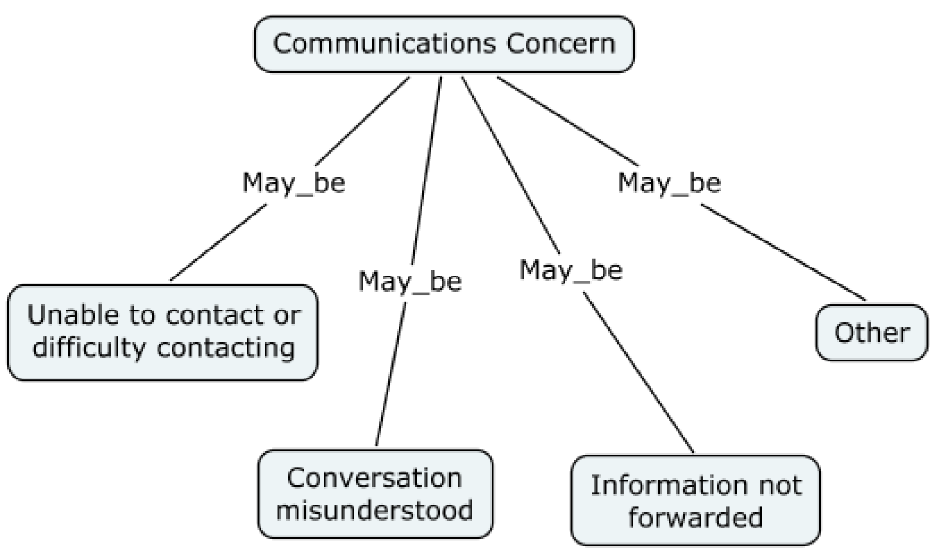


Figure 11. Final concept map of communication ontology

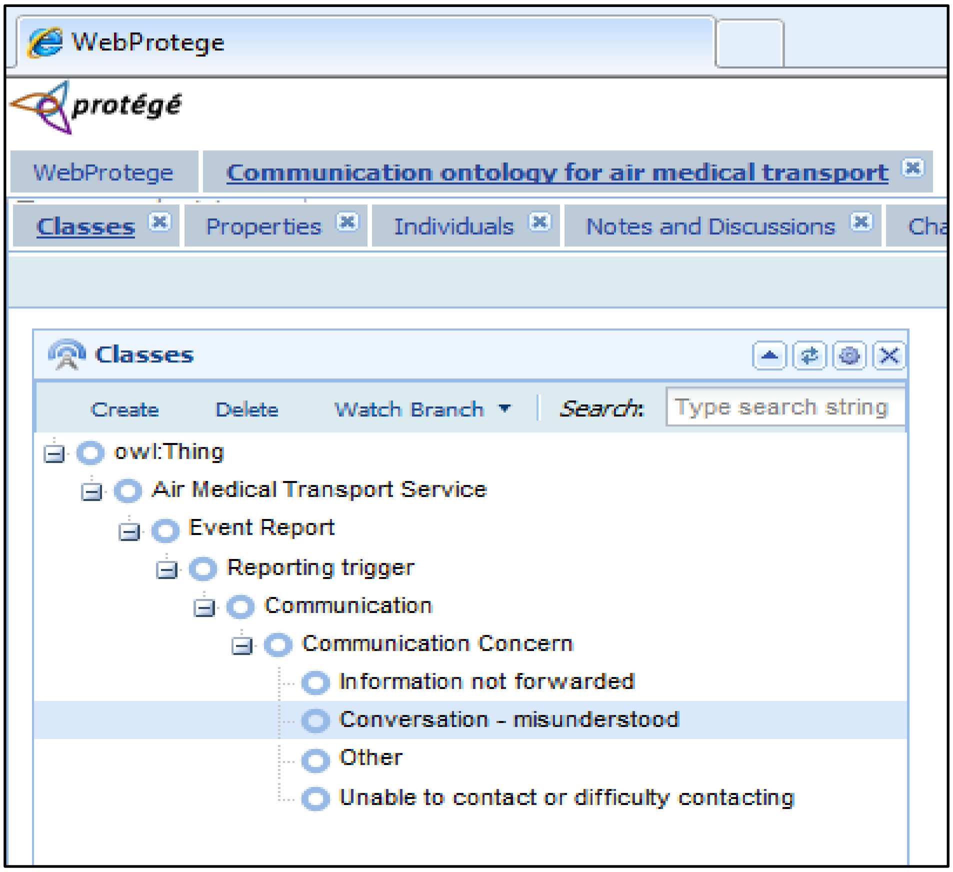


Figure 12. Screen shot of final communication ontology from WebProtégé

The underlying theoretical model for this ontology was Clark's Joint Action Ladder. The process of development revealed some difficulties and gaps between the model and the process to which the model was being applied (i.e., communication in AMT). Those difficulties were related to definitions in the model and the context for which the model was developed. Development of the new communication ontology began with adoption of the Joint Action Ladder. It became apparent early on that understanding and application of levels two and three of the Joint Action Ladder to miscommunication scenarios at Life Flight was problematic. The team struggled with identifying and explaining examples of those types of communication errors in their environment. The consistency among the team of assigning those two levels to various communication errors was poor. When it was pointed out that Study 2 found the vast majority of communication errors at levels one and four (99%) and virtually no communication errors at levels two and three, the team decided to combine levels two and three into a single concept called ‘Other’ that would capture all scenarios not identified as either level one or four.

The process of reliability testing revealed a difference between the underlying context for Clark’s Joint Action Ladder and the context to which it was being applied at Life Flight. The context of the Joint Action Ladder is within the occurrence of a single communication interaction. The underlying premise is that the decision to communicate has already been made by the initiator and progression of levels one to four proceeds in a sequential manner. The context for describing communication errors in the QA/Event Report is more broad than with interactions that have taken place, rather it is the information – communication space necessary for accomplishing a patient transport. In that space, the failure to attempt to communicate, either due to a lapse of memory or failure to recognize the need, is an important error not addressed by the Joint Action Ladder. This context issue was overcome by the addition of a new concept called ‘Information not forwarded’. Despite issues with using the Joint Action Ladder for the ontology, the combination of nominal group process and reliability testing enabled the transformation of the theoretical model into a useful operational model.

While the objectives of this study were met, the process was time consuming and fraught with opportunities for failure. Progress was floundering until key leadership from Life Flight became directly involved and led the project. As is often the case in research, the knowledge gained about the process can be as valuable as the knowledge gained by the results. The following discussion highlights key lessons learned from the project.

The overarching theme from the road bumps and pitfalls of this study is about conducting research in a live, operational environment. In a laboratory environment, the setting is contrived and, with the exception of the researcher, participants have little at stake. If a process fails or equipment breaks, it is the researcher who must deal with the problem while the participants go back to their normal lives until the experiment can resume. However, in an operational environment such as Life Flight, with staff as participants and equipment being the QSMS, the stakes are much higher for participants. In fact, the stakes likely feel higher to the participants than the researcher. This is because manipulation of an operational process, as part of research, may negatively alter workflow of the participants. This was evident from participant comments during the third meeting when several of the team expressed concern that the new ontology would lead to the need to report many more communication issues, thus increasing workload. While a great effort was made at the beginning of the project to explain the benefit to QI workflow of the new ontology, there was no reassurance given about the impact to daily workflow for submitting reports (i.e., impact to operational workflow). To assuage their concerns, a memo was sent out explaining that the goal of the new ontology was not to increase sensitivity of reporting communication issues, but rather when they are reported, it should be done in a consistent way that is easily retrieved by query (Appendix G).

Another issue with conducting research in an operational environment is the perceived authority of the researcher. In the lab environment, the participants depend on the plan and instructions of the researcher (i.e., authority). In a live, operational environment, participants may not accept the authority of the researcher, either consciously or unconsciously. Thus plans, goals, objectives, and timelines of the researcher may not seem as important to participants as with their normal leadership. The recognition of this issue led to the inclusion of the nurse manager as part of the team and having the medical director lead several meetings.

In summary, planning for successful research in an operational environment should address participant perceptions related to all aspects of workflow (e.g., operational, quality) as well as participant recognition of authority.

STUDY 4 – IMPLEMENTATION AND EVALUATION OF A COMMUNICATION ONTOLOGY

Study Purpose

The purpose of this study is two-fold; 1) implement the new ontology in the QA/Event Report and evaluate its performance for identifying reports with communication errors and 2) analyze communication errors using the new ontology combined with the Task Timeline Model of Communication from Study 1 (Appendix D, E). This study will answer the following questions:

1. Is the new ontology in the QA/Event Report utilized more frequently to indicate communication errors than the set of communication error triggers reported in Study 2?
2. Are there any patterns that emerge for communication errors using the Task Timeline model or Communication Concern type?

Methods

Implementation of communication ontology

Procedures. Life Flight has an established process for implementing changes to the QSMS that begins with an implementation plan to address the following steps:

1. Database and user interface design modifications
2. User training
3. System testing

4. Installation

The implementation team from Study 3 was assigned to create the plan and oversee the process. An implementation planning meeting was scheduled with key stakeholders for Feb 11, 2014. The key stakeholders included the medical director, nurse manager, and two QA nurses.

In preparation for the planning meeting, the implementation team met to create a mock-up of the new communication ontology implemented on the QA/Event Report. The ontology development team from Study 3 had recommended the new communication concepts be implemented similar to the Safety Concern dropdown box already on the QA/Event Report. A screenshot of the Safety Concern user interface (UI) is provided in Figure 13. The Communication Concern mock-up is provided in Figure 14. At the implementation planning meeting, the Communication Concern mock-up was reviewed with key stakeholders. The key stakeholders approved the mock-up and began discussing the tasks and timeline for the implementation plan. User training, system revision, system

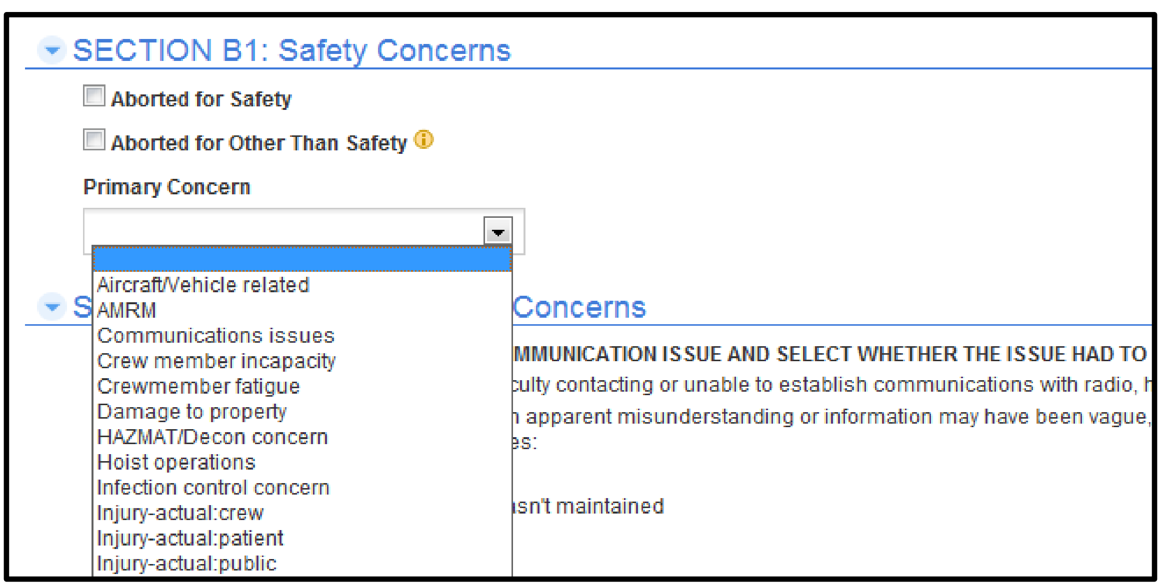


Figure 13. Screen shot of Safety Concern UI

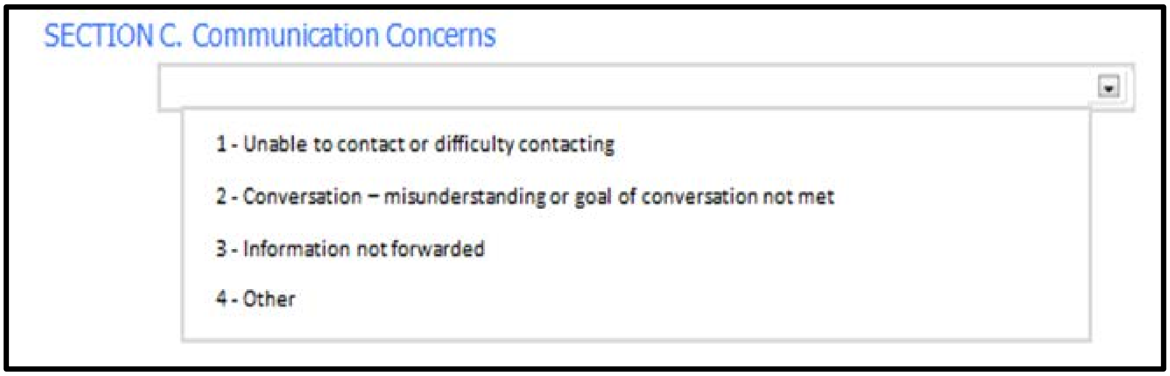


Figure 14. Mock-up of Communication Concern dropdown box

testing, and installation/roll out were discussed at length and dates were assigned. The final implementation plan called for user training to take place in March staff meetings for flight crew, pilots, and Communication Center staff. System development would take place in March with final implementation and testing on Sunday night March 24. Upon successful testing, the system would roll out for staff use on March 25. The following paragraphs detail the key steps of the implementation.

Database and user interface design modifications. The implementation team, which included the QSMS developer, met several times prior to the planned system installation and roll out. Using the mock-up as a model, the developer wrote out a design plan detailing database fields and the UI objects to be added to the QA/Event Report. Since Life Flight does not have a test platform for development, system revisions and testing are done in the live environment at a time when users are least likely to utilize the system, typically at midnight on a Sunday. System revision and testing was planned for midnight March 24.

User training. User training took place over the first three weeks in March and consisted of a 15-minute presentation in staff meetings for the Adult Service, Children's Service, the pilots, and the Communication Center. Additional electronic content was distributed in the Daily Briefing newsletter. A copy of the Daily Briefing is provided in Appendix H. The staff meeting presentation was posted to Life Flight's online education portal for staff unable to attend the meetings.

System testing. Prior to system testing, the implementation team developed a set of test cases to exercise the new ontology on the QA/Event Report. The test plan also included running several queries and reports to ensure data entry, reporting, and overall functionality worked as planned. Test cases were selected from reports used in Study 2 and the queries were based upon the competency questions from Study 3.

Installation. Revision of the QSMS to add the changes to the database and QA/Event Report took place at 11pm on March 24 by the QSMS developer. Users were notified by email and by shift change briefings that the system would be unavailable from 11pm until after 1am. After making the revisions, the test cases were entered to create new QA/Event Reports. Data entry for the test reports worked as planned and also verified the UI. Queries of data from the test cases also worked as planned, verifying database elements and overall functionality. With system testing completed, communication was put out to the staff that the new Communication Concern trigger was live on the QA/Event Report. Data collection and Formative evaluation began on Mar. 25. Data collection concluded on June 30, 2014.

Formative evaluation. A formative evaluation period took place for three weeks following the installation. The purpose of this evaluation was to get feedback from staff on how the Communication Concern trigger was working. During this evaluation, QA/Event Reports were reviewed for cases where the submitter either used the Communication Concern trigger or where it appeared they should have used the trigger, but did not. For these cases, the submitter was interviewed by phone or email for feedback that could be used to improve performance of the ontology. Most of the staff who did not use the Communication Concern trigger when indicated stated they forgot about it, or didn't think to use it, or didn't know about it. Feedback from one flight nurse did lead the implementation team to add an additional sentence of explanation on the UI. A total of 10 staff were interviewed during the evaluation. A screenshot of the Communication Concern trigger on the QA/Event Report after the Formative Evaluation period is provided in Figure 15.

Aim 1 - Evaluation of new communication ontology in QA/Event Report

Design. This study was a prospective, quantitative design collecting data from key ontology variables on QA/Event Reports and comparing with data from Study 2.

Procedures. After implementation of the new communication ontology, data were collected on each QA/Event Report submitted by Life Flight staff. The following questions were used to evaluate the reports; 1) Was there evidence of a communication issue or communication error? 2) If so, what was the Communication Concern type selected by staff? If no Communication Concern type was selected, 'none' was assigned to the variable. In addition to answering the key questions, demographic data were collected for descriptive statistics. The variables collected are shown in Table 21.

Analysis. Descriptive statistics were used for reporting demographics, prevalence of communication errors, and classification categories. The two tailed Chi-squared test was performed to determine if there were differences in the submission rates of reports by service or mode and if there were differences in miscommunication reported by service or mode. When multiple, pairwise comparisons were made, Bonferroni adjusted and

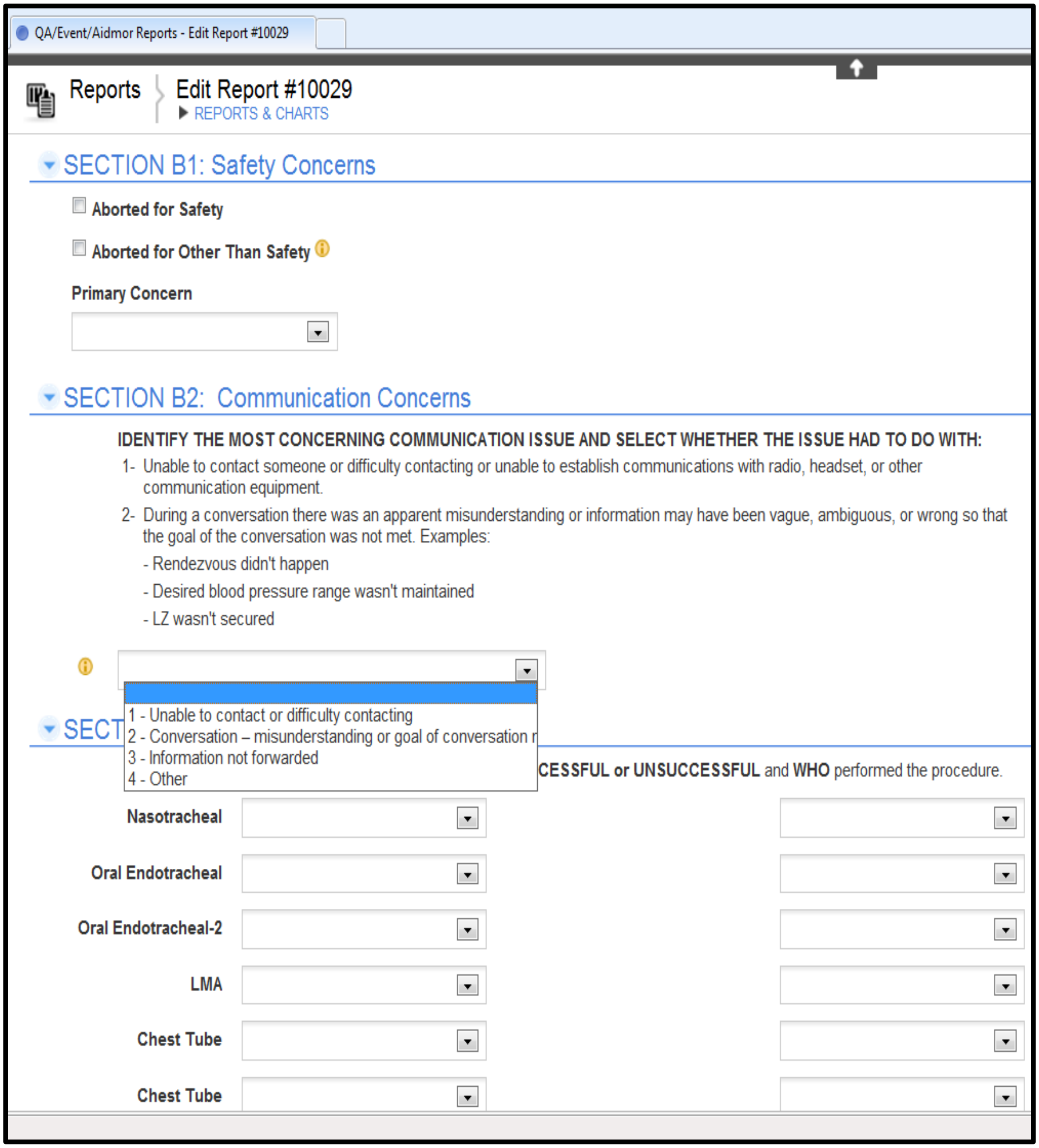


Figure 15. Communication Concern Trigger after Formative Evaluation

Table 21. Variables for Study 4 – Aim 1

Variable	Definition
Transports	Numeric, count of Life Flight patient transports during the study period. Same is in Study 2. Used for descriptive statistics.
QA reports	Numeric, count of QA/Event Reports filed during the study period. Used for descriptive statistics.
Service	Categorical, identifying the service submitting the QA/Event Report (e.g., Adult, Pediatric, Neonatal). Used for descriptive statistics.
Mode	Categorical, vehicle type indicated by the transport on the QA/Event Report (e.g., Rotor-wing, Fixed-wing, Ground). Used for descriptive statistics.
Communication error	Categorical, one of a set of 8 possible communication error categories that was indicated on the QA/Event Report. Same as in Study 2.
Reports with communication error	Numeric, count QA/Event Reports indicating a communication error occurred. Key analytic variable for answering Aim 1. Same as in Study 2.
Communication Concern	One of 4 possible types as defined by the communication ontology. Assigned by a report reviewer to a communication error on an event report. Key analytic variable for answering Aim 1.

p-values were calculated. A p-value of < 0.05 was considered statistically significant. Comparison of communication ontology performance with baseline (i.e., Study 2) used a 2 - sample test of proportions with alpha = 0.05 and sampling to achieve 90% power. The goal of the new ontology was to improve the proportion of QA/Event Reports having communication errors and being flagged by a communication error trigger by at least 100% from Study 2 (i.e., from 31% to ≥ 62%).

This study used a sequential adaptive approach for sampling. The sequential adaptive approach estimates sample sizes over a range of effect sizes so that data collection time can be reduced if the effect size is larger than the minimum planned. It was assumed the rate of communication errors on QA/Event Reports would remain roughly the same as with Study 2 (21%). Table 22 gives sample estimates for a power of 90% and effect sizes of 85%, 100%, and 115%.

The plan for sampling was to test for a significant difference with Study 2 when 50 reports with communication errors had been recorded. If the results were significant to $p < 0.05$, then data collection would stop. If not, data collection would continue and significance would be tested again at 64 reports having communication errors and then, if needed, at 75 reports.

Aim 2 – Analysis of communication errors using the new ontology combined with the Task Timeline model

This was a descriptive study looking at the frequency of communication errors from Studies 2 and 4 categorized by key elements of the Task Timeline model and types of communication concerns from the new ontology. Frequencies of errors were measured for key elements such as transport phase, communication task, participants, communication medium (e.g., radio, face-to-face), and Communication Concern. Elements from the model having disproportionately high frequencies of errors may provide insight for strategic areas to improve communications.

Procedures. There were at total 110 reports and 122 communication errors collected from QA/Event Reports from both Studies 2 and 4 of this research having

Table 22. Effect size and sample estimates for Study 4 – Aim 1

Effect Size	QA/ Event Reports with communication errors	QA/Event Report samples
85%	75	357
100%	53	252
115%	41	195

communication errors. Communication errors were coded with key elements of the Task Timeline model and also to types of Communication Concerns. Table 23 provides the variables for data collection.

Analysis. Analysis consisted of frequencies of occurrence for the variables.

Results

Reporting demographics

Over the study period, Life Flight conducted 811 transports from which 229 (28%) QA/Event Reports were submitted. Of the 229 QA/Event Reports, 52 (23%) had evidence of one or more communication errors. A total of 58 communication errors were detected as some reports had multiple errors. Table 24 provides the frequency of transports by service and mode. Tables 25 and 26 show the frequency of transport versus QA/Event Reports by service and mode, respectively. Table 27 provides the frequency of reports with communication errors by service and mode.

Table 23. Variables for Study 4 - Aim 2

Variable	Definition
Communication task	Categorical, brief text code of communication task during transport where error occurred. Similar to numeric sequence communications in Task Timeline model.
Participants	Categorical, persons involved in communication. Indicated by role such as pilot, flight nurse, medical control, Ops controller.
Communication medium	Categorical, type of medium used for communication such as cell phone, pager, radio, Land line, face-to-face.
Transport phase	Categorical, based upon Task Timeline references.
Communication Concern	One of 4 possible types as defined by the communication ontology (e.g., Unable to contact or difficulty contacting, Information not forwarded, Misunderstood, Other)

Table 24. Frequency of transports by service and mode – Study 4.

Service	Fixed-wing	Ground	Rotor-wing	Total
Adult	54	19	312	385
Neonatal	34	128	70	232
Pediatric	44	28	122	194
Total	132	175	504	811

Table 25. Frequency of transports and QA/Event Reports by service - Study 4.

Service	Transports	QA/Event Reports
Adult	385 (47%)	151 (66%)
Neonatal	232 (29%)	37 (16%)
Pediatric	194 (24%)	41 (18%)
Total	811(100%)	229(100%)

Table 26. Frequency of transports and QA/Event Reports by mode - Study 4.

Mode	Transports	QA/Event Reports
Fixed-wing	132 (16%)	40 (18%)
Ground	175 (22%)	33 (14%)
Rotor-wing	504 (62%)	156 (68%)
Total	811(100%)	229(100%)

Table 27. Frequency of reports with communication errors - Study 4.

Service	Fixed-wing	Ground	Rotor-wing	Total
Adult	4	2	26	32 (62%)
Neonatal	0	5	7	12 (23%)
Pediatric	1	2	5	8 (15%)
Total	5 (10%)	9 (17%)	38 (73%)	52 (100%)

Chi-squared analysis showed a statistically significant difference between the proportion of transports by service versus the proportion of reports submitted by service (Table 25, Chi-squared = 34.046, $p < 0.0001$, 2 degrees of freedom). There was also a statistically significant difference between the proportion of transports by mode versus the proportion of reports submitted by mode (Table 26, Chi-squared = 7.688, $p = 0.0214$, 2 degrees of freedom).

Chi-squared analysis showed no statistically significant differences between services (Chi-squared = 1.982, $p = 0.371$, 2 degrees of freedom) or mode of transport (Chi-squared = 2.634, $p = 0.268$, 2 degrees of freedom) when comparing the proportion of communication errors versus the proportion of reports submitted. Communication errors were evident in reports in about the same proportion for each service as well as for each mode.

<u>Research question 1 - Is the new ontology in the QA/Event Report utilized more frequently to indicate communication errors than the set of communication error triggers reported in Study 2?</u>

Table 28 provides the frequencies of QA/Event Reports with communication errors and those having communication errors flagged by triggers from Study 2 (pre) and this study (post).

Table 28. Frequency of QA/Event Reports with communication errors and reports having those errors flagged by communication error triggers.

Study	QA/Event Reports with comm. errors	Reports using comm. error triggers
2 (pre)	58	18 (31%)
4 (post)	52	37 (71%, $p < 0.001$)
Total	110	55

There was a significant difference between pre and post studies in use of communication error triggers ($p < 0.001$, 95% CI = -0.5907145, -0.2116727).

Research question 2 - Are there any patterns that emerge for communication errors using the Task Timeline model and Communication Concern types?

A total of 119 communication errors from Studies 2 and 4 were coded to the Task Timeline model and Communication Concern types. Three errors from Study 2 were excluded as their report descriptions were too vague to be adequately mapped to the models. Tables 29 through 33 provide the frequency of occurrence for transport phase, communication task, participants, communication medium, and Communication Concern type.

Table 29. Frequency of communication errors by transport phase.

Phase	Count
Triage/Prep	60 (50%)
Ref Facility	17 (14%)
Return - Enroute	11 (9%)
Liftoff - Enroute	10 (8%)
Scene	8 (7%)
Request	7 (6%)
Other	4 (<5%)
Receiving	2 (<5%)
Total	119

Table 30. Frequency of communication errors by communication task.

Communication task	Count
Triage/prep	25
Notify of Xport	19
Patient care report	17
Initial patient report	11
Scene communication	6
Patient care at bedside	6
Receiving notify	3
Referring instructions	3
Gnd Amb rendezvous	2
Liftoff - Enroute	2
Status update	2
Med supply restocking	1
Ambulance rendezvous	1
Request Gnd Amb	1
Scene coordination	1
LZ scene safety info	1
Fuel management	1
Referring notify - Team ETA	1
Info to family	1
Return Liftoff	1
Crew coordination/prep	1
Bed availability at Rec hosp	1
Status update - change in Rec facility	1
Status update - change in patient condition	1
Status update - Rec unit not ready yet	1
Status update - Rec unit needs report from FN	1
Status update - Team ETA	1
Team member accuracy	1
Team communication	1
Personnel status	1
Team transport	1
Prep status/instructions	1
Aircraft maintenance	1
Receiving instructions	1
Total	119

Table 31. Frequency of communication errors by participants.

Participants	Count
CS and FN	15
CS and medcrew	12
FN and MedControl	12
FN and RefStaff	12
Between Medcrew	8
FN and RecStaff	7
CS and RefStaff	7
CS and Amb	7
CS and RecStaff	6
CS and MedControl	5
Pilot and Medcrew	4
FN and PS/FR	3
OC and Pilot	2
Between RefStaff	2
Pilot and PS/FR	2
FN and Amb	2
CS and Pilot	2
CS and RT	1
Between Ref staff and family	1
CS and Xfer Center	1
CS and OC	1
MedControl and Rec/Ref MDs	1
CS and EMS	1
Pilot and ATC	1
Between CS staff	1
CS and Airport staff	1
Between Amb and family	1
CS and PS/FR	1
Total	119

Table 32. Frequency of communication errors by communication medium.

Medium	Count
Phone	62 (52%)
Radio	21 (18%)
Face-to-face	16 (13%)
Pager	9 (8%)
Sat phone	4 (<5%)
Helmet intercom	3 (<5%)
Cell	2 (<5%)
Other	2 (<5%)
Total	119

Table 33. Frequency of communication errors by Communication Concern type.

Communication Concern type	Count
Info not fwd	44 (37%)
Conversation	40 (34%)
Contact	29 (24%)
Other	6 (5%)
Total	119

Discussion

Reporting demographics

As with Study 2, there were differences in the proportion of QA/Event Reports submitted by service and mode compared with the proportion of transports. This was not surprising given the explanation from Study 2. These differences were likely due to the differences in service specific triggers on the report and the modes utilized by the various services. As with Study 2, there were no differences in the proportion of reports with communication errors compared with the proportion of reports submitted when analyzed by either service or mode. Overall for this study, noteworthy communication errors occurred on 23% of QA/Event Reports.

Research question 1 - Is the new ontology in the QA/Event Report utilized more frequently to indicate communication errors than the set of communication error triggers reported in Study 2?

Life Flight staff utilized the new ontology on the QA/Event Report, (i.e., Communication Concern) far more often for communication errors than the previous ontology having a variety of communication error triggers (71% vs. 31%, $p < 0.001$). While the new ontology was not utilized for all reports having communication errors, it now provides a practical tool for quality improvement because a single query of a database field in the QSMS will return a majority of reports having communication errors. Furthermore, the theory-based concepts associated with communication errors in the new ontology (e.g., Contact, Conversation, Information not forwarded) provide clues to the underlying nature of the error.

A follow-up analysis was done on the 15 reports having communication errors and not utilizing the Communication Concern trigger. The largest portion of these was due to lack of staff awareness about the trigger and its definitions. This finding was seen in the Formative Evaluation period and revealed gaps in the thoroughness of the education plan. This has been a common finding with updates to the QSMS. Comments from a QA nurse indicated that some updates take six months or more before the staff are consistently utilizing the changes.

Research question 2 - Are there any patterns that emerge for communication errors using the Task Timeline model or Communication Concern type?

Analysis of communication errors using the Task Timeline Model of Communication indicated that half of the errors occur in the early Triage/Prep phase of transports, equaling the sum of errors across all other phases combined. This is not surprising since only a limited amount of information has been received at this time and much communication is required to select the vehicle, transport team, equipment, and coordinate external resources that are often needed. Correspondingly, the tasks having the most frequent communication errors occurred during the Triage/Prep phase. Those tasks were triage/prep, notification of transport, and patient care reports. While it may not be surprising that most communication errors occur in the early phases of a transport, it does reflect an opportunity for improvement. The standard approach for targeting areas for quality improvement are those having either a high frequency of defects (e.g., errors) or those where there is a high consequence for failure. The frequency of communication errors in the Triage/Prep phase implies a reasonable return on investment for applying costly resources towards improvement.

Task Timeline analysis showed that the most frequent participants associated with communication errors are communication specialists and flight nurses. This also is an expected result since these roles have the greatest frequency of communication tasks indicted by the model. The next most frequent participants were medical control, medical crew, and referring staff. These also seem reasonable based upon their frequency of communication tasks on transports.

The medium associated with the most frequent communication errors was the telephone. This is likely due to the frequency of tasks utilizing the telephone and because most errors are not due to signal quality issues, but the failure to recognize the need to communicate (i.e., information not forwarded) or misunderstanding in conversation.

Analysis by Communication Concern types indicated that communication errors were most often associated with Information not forwarded (n=44/119, 37%) followed closely by Conversation – misunderstood (n=40/119, 34%). The occurrence of errors related to Information not forwarded was a surprise because these scenarios were not uniquely articulated until late in the ontology development process. This result highlights the nature of AMT where new information is constantly flowing into the system from the beginning of the transport and creates a great burden on distribution of that information between key participants. While there are numerous redundant technologies to ensure communication can be established (e.g., radio, cell phone, satellite phone, landline), there are no elegant and redundant mechanisms to ensure key information is distributed to the all the right persons at the right time.

The frequency of errors that occurred at the conversation level is consistent with data from Study 2. These errors result from speech practices that are influenced by individual mental models and assumptions of understanding. Communication errors of this type are often due to vague or ambiguous phrasing, the lack of shared mental models, and the failure to synchronize each other's mental model.

Limitations

There are several limitations with this study. First, this study collects data from one QSMS in one AMT service and the results may have limited usefulness for other services and scenarios. Second, there was measurement error associated with coding data from QA/Event Reports. Data from these reports often had limited and cryptic descriptions of the communication scenarios. Therefore, some assignment of categories relied on knowledge of roles and operational tasks. Coding of these reports could not be done accurately without familiarity with Life Flight processes. Third, data are self-reported so that counts and types of communication errors are biased by individual perceptions of benefits or consequences of reporting, self-image, cultural norms, and organizational expectations. Lastly, this research was conducted in an operational setting, which placed constraints on the study design and possible changes to the ontology and to the QA/Event Report. Only modest, incremental changes were tolerated for the ontology and the QA/Event Report. As a result, bold and potentially innovative solutions that involved significant changes were not practically considered.

CONCLUSIONS

The goal of air medical transport is the safe and timely transport of a patient to the most appropriate care. The communication required to transport a patient in a safe and timely manner is a complex process that varies by the patient location, patient condition, and the aircraft or vehicle required. Analysis shows there are typically 17 communication interactions often involving at least 8 different people for an uneventful scene transport and typically 28 interactions involving at least 10 different people for an interfacility transport. Furthermore, there are a plethora of technologies needed to ensure communication. The transport team carries at least three different communication devices with them at all times (i.e., pager, cell phone, 800 Mhz radio). During the course of a complex scene transport, they may utilize as many as six different communication devices. In the Life Flight Communication Center, the communication specialists utilize sophisticated paging, radio, and telephone systems having dozens of channels each, along with a state-of-the-art, computer-based dispatch center application and satellite-based flight tracking systems. Achieving the goal of a safe and timely transport requires the focused attention of all involved, with the support of much technology.

Communication errors are ubiquitous in daily life. They occur frequently and are usually repaired immediately with little or no consequence. Likewise in AMT, communication errors occur frequently and are often repaired immediately. In AMT however, the consequences of miscommunication can be much higher due to the critical nature of patients and risks of air transport. Some communication errors cause delays, safety concerns, procedure errors, and adverse events. It is these noteworthy communication errors that are reported by staff in Life Flight's QSMS using their QA/Event Report.

Combining data from pre and post studies, this research found that communication errors are evident in 22% of all QA/Event Reports (n=110/507). Furthermore, Life Flight staff submit QA/Event Reports on about 24% of all transports (n=1054/4399), so that noteworthy communication errors are being reported on about 5.2% of transports.

Historically, the ontology of the QA/Event Report evolved in an ad hoc manner. The primary motivation for concepts was to identify transports needing further review as part of a quality assurance program. These concepts are known as triggers. That approach has led to a patchwork of concepts that are highly specific to an undesired outcome such as; 'Equipment failure-paging' or 'Delay > 15 min - ambulance not notified.'

This research showed that Life Flight's legacy ontology, implemented on the QA/Event Report, was inadequate for analysis of communication errors for quality improvement purposes. Only 31% of reports having communication errors were able to be retrieved by simple query. The only way to do meaningful analysis of communication errors was to manually read every report and look for communication errors.

To facilitate quality improvement of communication, this research undertook development of a new communication ontology. That process led to a theory-based ontology, implemented on the QA/Event Report, that increased retrieval of reports with communication errors from 31% to 71%. Life Flight's new ontology now enables practical measurement and analysis of communication errors.

Significance to the Field

This research makes a unique and foundational contribution to AMT as well as important contributions to the fields of biomedical informatics and human factors. According to Warner, “Medical informatics is the study, invention, and implementation of structures and algorithms to improve communication, understanding, and management of medical information”[68]. This mixed-methods research, combining qualitative and quantitative data, provides the most thorough understanding of communication and miscommunication in AMT to date. The utilization of theoretical models for both communication and human factors created a rich conceptual framework for description and analysis. This framework is a useful tool for informatics with generalized applicability to many other domains that are communication intensive beyond the specialty of AMT. The concept map in Appendix A provides a generalized ontology of communication in AMT combining knowledge and elements from other related domains.

Reliable measurement is a cornerstone of quality improvement theory. This research contributes the most comprehensive measurement and analysis of communication errors in AMT to date. The Task Timeline Model of Communication provides a novel approach for visualizing and analyzing the complex process of communication from a human factors perspective. The new theory-based communication ontology enables analysis that can isolate errors to distinct, underlying causal mechanisms. The combination of Task Timeline model and communication ontology provides a powerful tool for improving communications in AMT.

In AMT as with many other industries, communication is frequent and ubiquitous.

It can seem daunting to identify which areas of communication to target for improvement. The new communication ontology coupled with analysis from the Task Timeline model provides Life Flight with a systematic approach and better information for prioritizing quality improvement efforts.

Future Directions

By establishing a useful and reliable measure for communication errors, this research has laid the foundation for improving performance in AMT. The next step for quality improvement is to target opportunities to reduce communication errors. Analysis from this research has identified two key scenarios of the communication–information space of AMT that need research and solutions. Those areas are *information not forwarded* and *misunderstanding in conversation*. Each area reveals unique factors and underlying causes. The issue of *information not forwarded* is rooted in the continuous influx of information that occurs during a transport, the need to share information with key persons, and factors such as workflow bottlenecks, memory failures, and lack of situational awareness. The issue of *misunderstanding in conversation* is rooted in how individuals talk with each other and synchronize understanding. Future research should investigate and analyze causal factors for *information not forwarded* and *misunderstanding in conversation* so that solutions could be developed.

These communication problems are not unique to AMT and solutions may be emerging from industries such as transportation and shipping as well as research from the air traffic control domain (ATC). Since the timely sharing of information is an important goal in AMT, as with many other industries, the concept of a shared awareness display provides a natural solution. A shared awareness display is one that collates and presents information from different sources on a common screen, accessible to persons collaborating on a particular task. One common example is the arrival/departure displays at airports. This display combines information from airline traffic and airport terminals to keep travelers and airport personnel informed and able to make timely decisions when needed. Another example is shipping control center displays that integrate GPS, traffic, vehicle information, and messaging to enable visualization and optimization of daily shipping tasks. A shared awareness display for AMT would be one that integrates information about aircraft/vehicle location, transport crew status, patient status, and receiving facility status on displays available to the transport crew, the communication center, and receiving center personnel. DriverTech[69], a Salt Lake City-based mobile computer solutions company for the transportation industry has partnered with EMS dispatch application vendor Zoll[70] to provide a mobile, on-board computing solution for the EMS/medical transport industry. This system enables EMS crews and dispatch center staff to share call information, real-time vehicle location, vehicle status, traffic information, patient physiologic monitor data, along with 2-way data messaging over a secure network combining satellite, cell phone, and Wi-Fi technologies[71].

Research in ATC may also yield a solution to communication problems in AMT. One of the difficulties of information distribution in ATC is related to communication bottlenecks and the challenges of synchronous communication. To address this problem, the Federal Aviation Administration (FAA) is conducting research on the use of a data link messaging system for nonurgent information to supplement voice communication[72]. The data link is an asynchronous messaging system that provides certain communication advantages because flight crews can respond to the messages at a time that fits their workflow and the messages persist in the system until they can be reviewed and rechecked if needed. A data link for AMT could enable the distribution of information between transport crew and the communication center in a manner more suitable to workflows of each setting.

Misunderstanding in conversation is a well-known communication error in ATC[73]. That is particularly true with international operations. Although English has been established as the universal language of ATC, air crew and ATC personnel can have difficulties understanding each other when each has limited skill with English as a second language[10]. To address this problem the International Civil Aviation Organization (ICAO) recommends a four-step technique known as *confirmation/correction closed-loop*:

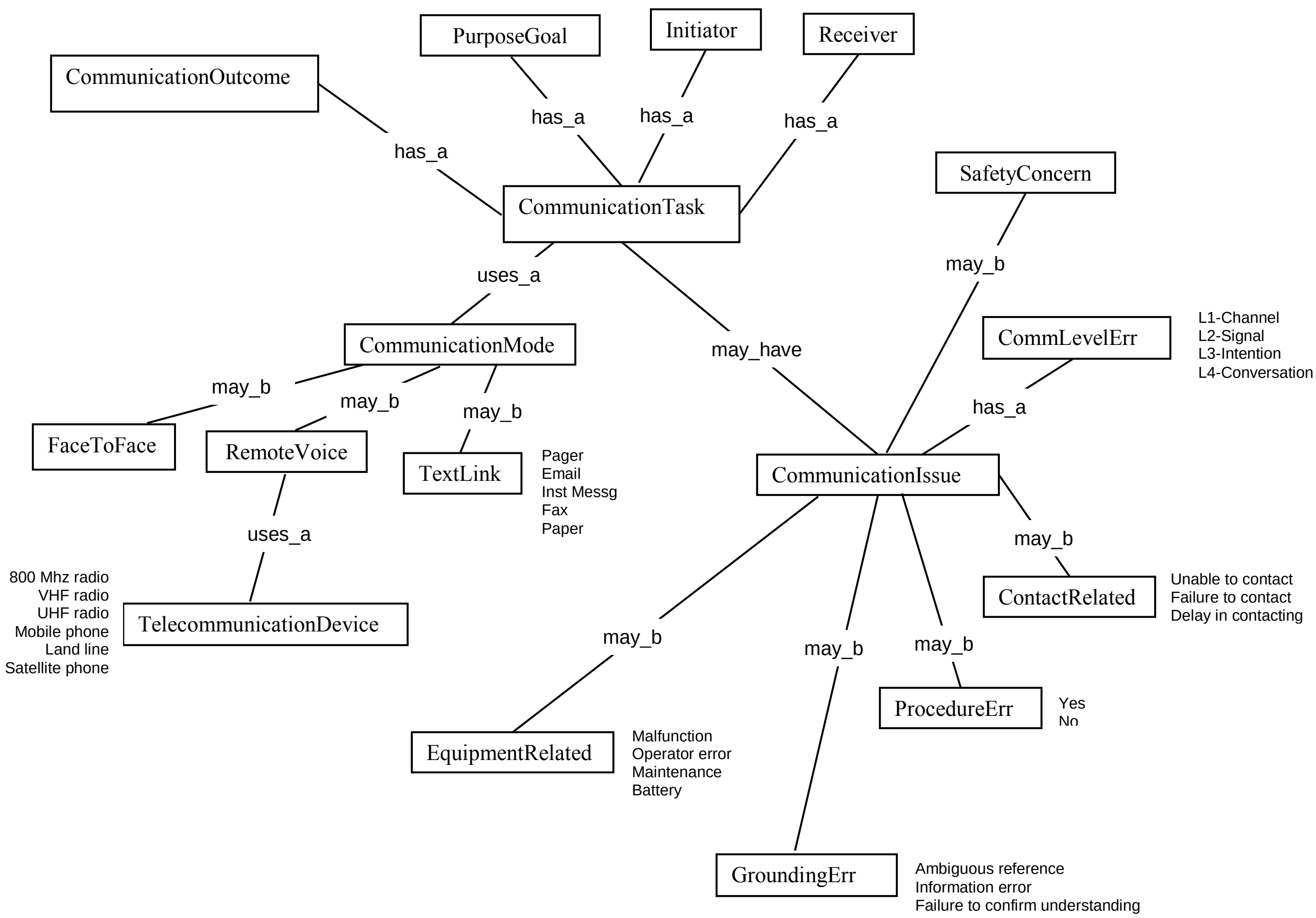
1. The sender transmits a message
2. The receiver actively listens to the message
3. The receiver repeats the message back to the sender
4. The sender actively listens for the correct readback

Success of this approach depends on all steps being performed correctly. Unfortunately, this standardized approach is not widely utilized, even in ATC. Future research should be done to identify barriers to this standardized approach and how the closed-loop elements could be implemented or adapted for AMT.

APPENDIX A

CONCEPT MAP OF COMMUNICATION ONTOLOGY

Communication Ontology



Ontology Concepts and Relationships - In the graphic above, boxes are concepts and connections between boxes are relationships. Possible values for concepts are next to box containing concept

APPENDIX B

INTERVIEW GUIDE

Interview/Focus Group Guide

Date: Place: Interviewer:
Interviewee role:
Context notes (gender, age range, etc.):

Questions	Reflections
1. Describe the various communication activities you are involved with in order to transport a patient at Life Flight? (What are they and how do you perform them? You may go in chronological order) **Probe questions:**	
2. What types of equipment/technology (e.g., systems, devices) are used for communication during a transport? **Probe questions:** How well does the communication equipment/technology work for it's purpose?	

How proficient are you with the communication equipment/technology, systems, or devices? Are there issues with the communication equipment/technology, systems, or devices?	
3. What training or education do you receive related to the communication necessary to transport a patient? (all communication related training, not necessarily technology or equipment training)	
4. Can you recall any communication issue or problem that gave you concern during a transport? (Please describe)	

Probe questions: What impact did the communication issue cause? If there was a potential impact, what was it? What did you or others at Life Flight do to reconcile the problem?	
5. Are there certain types of communication issues that are more frequent or problematic?	
6. What does Life Flight do to prevent or reduce communication related issues?	

APPENDIX C

OBSERVATION GUIDE

Observation Guide

Date/Start Time: Place: Observer:

Date/Stop Time:

Context notes (# of persons, gender, age, equipment, layout/dimensions, weather, etc.):

Time	**Observations**	**Reflections**

APPENDIX D

TASK TIMELINE MODEL OF COMMUNICATION FOR A SCENE TRANSPORT

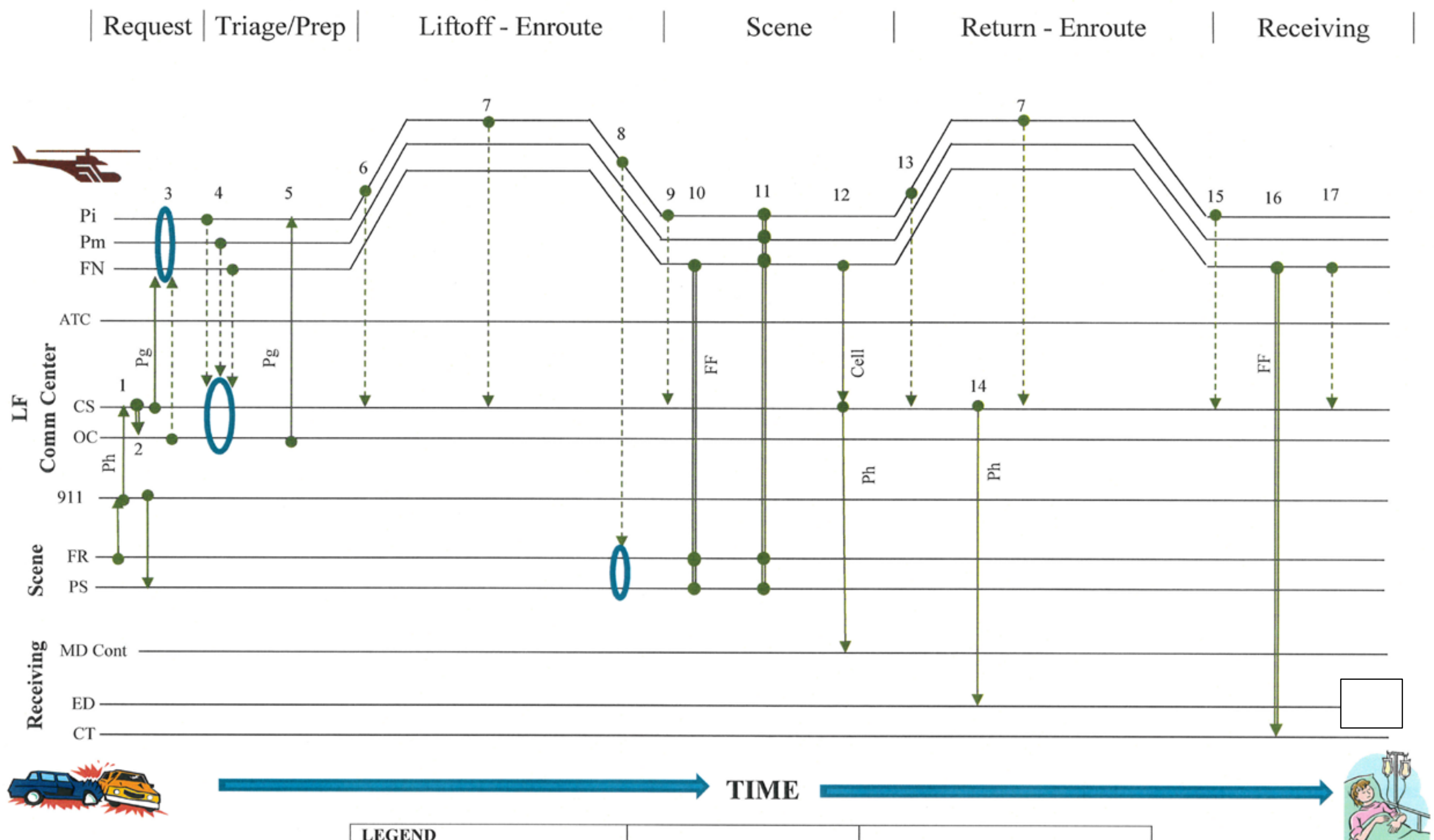
Nominal Communication Process for a SCENE Transport.

Vehicle involved is usually helicopter [RW], but may be ground [GND] if weather or unusual conditions

1. EMS Dispatcher (EMS-D) telephones Life Flight Communication Center (LFCC) to request transport
    a. Information Sending (I-SND): EMS-D provides location of patient, demographics and medical condition of victim, contact information of first responder at scene.
    b. Information from EMS-D has been relayed/forwarded by a human (I-HFWD_1+) from source near scene and may not be accurate. Sometimes initial information is radically different from subsequent information
    c. Accuracy and completeness of information from scene usually improves as time goes by in subsequent messaging compared with original message
2. Communication Specialist (CS) discusses with Operational Controller (OC) the most appropriate resource (i.e., vehicle/team) to send, using face-to-face communication. Information Exchange (I-EX)
    a. Vehicle/team decision is based on distance to patient, patient demographics/condition, weather conditions, equipment needed or available
    b. [RW] OC prepares initial flight plan (FP) for pilot
    c. [GND] If GND is chosen as mode, transport team does not include pilot
3. OC contacts transport team (XT) using 800Mhz radio CS contacts XT using paging system to provide transport information: (I-SND)
    a. Transport teams are alerted by a tone on the 800 Mhz radio
    b. Minimum information: Location of patient, demographics and medical condition of patient, contact information of first responder at scene. At this point information has been relayed at least 2 times (I-HFWD_2+): EMS-D to CS and CS to XT. Radio info from OC relayed additional time (CS to OC, face-to-face)
    c. Use of two systems for communication provides redundancy
    d. Paging system can be considered a data relay/forwarding system (I-DFWD_1)
    e. Both human information forwarding and data forwarding is subject to errors, distortions, and transmission loss from each forwarding source. Degradation is cumulative with multiple episodes of forwarding.
4. XT uses 800 Mhz radio to acknowledge receipt of transport request and seek or confirm transport information: (I-SEEK)
5. [RW] OC pages flight plan info to pilot: I-SND. Information has been forwarded by human 2+ times (I-HFWD_2+)
6. XT contacts LFCC to indicate they have lifted off/left base and gives report: (I-SND, I-SRC).
    a. [RW] Typically done by pilot using UHF/VHF radio onboard aircraft
    b. [GND] FN uses cell phone
    c. Information is ETA, '# of souls onboard', fuel remaining
    d. LFCC gives liftoff/departure time
7. (Optional) If time en route > 15 minutes, XT will contact LFCC by UHF/VHF radio to provide current location/status every 15 min: I-SND, I-SRC
    a. If XT does not radio in, LFCC will contact helicopter/ambulance by radio to seek status I-SEEK
8. [RW] XT radios first responder (FR) at scene, prior to arrival, to give ETA, instructions for landing zone, and get local info/patient status. I-EX, I-SRC
    a. Usually done when aircraft is about 15 min from arrival.
    b. Typically done by pilot
9. XT contacts LFCC that aircraft/ambulance has landed/arrived and gets landing time. (I-EX, I-SRC)
    a. [RW] Typically done by pilot using UHF/VHF radio onboard aircraft
    b. [GND] FN uses cell phone
10. Flight nurse takes report on patient from first responder(s) at scene in face-to-face communication (I-FF), (I-SND, I-SRC)
11. Flight nurse (FN), pilot, and other crew may communicate by radio to coordinate scene activities (I-EX, I-SRC)

12. FN cell phones LFCC to be connected/linked (I-LNK1)with medical control at receiving facility to give report on patient I-SND, I-SRC, I-LNK
    a. If no cell service is available, FN will use satellite phone or radio
    b. Report includes patient condition, treatments, support needed at arrival
13. XT contacts LFCC to indicate they have lifted off/left scene and gives report (I-SND, I-SRC)
    a. [RW] Typically done by pilot using UHF/VHF radio onboard aircraft
    b. [GND] FN uses cell phone
    c. Information is ETA, '# of souls onboard', fuel remaining
    d. LFCC will provide departure time
14. CS telephones receiving facility ED to give XT ETA (I-SND, I-HFWD1+)
    a. May request additional support at arrival by medical and security personnel
    b. [RW] requires gurney and support at landing zone (LZ)
    c. [RW] Planned to occur 5 minutes from expected time of arrival of XT
15. XT contacts LFCC that aircraft/ambulance has landed/arrived and gets landing time. I-EX, I-SRC
    a. [RW] Typically done by pilot using UHF/VHF radio onboard aircraft
    b. [GND] FN uses cell phone
16. FN gives report on patient to receiving facility care team (CT) (I-FF, I-SND, I-SRC)
17. XT contacts LFCC, typically by UHF/VHF radio, that team and aircraft is back in service. (I-SND, I-SRC)

Model of Nominal Communication Interactions – Scene Transport (RW) – Life Flight AMT



LEGEND		
CS – Communication Specialist	FR – First responder	Pg – pager
OC – Operational Controller	PS – Public Safety	Rad – 800 Mhz/VHS radio - - - - - -
Pi – Pilot	911 – EMS Dispatch	Cell – cell phone
Pm – Paramedic	ATC – Air Traffic Control	Ph – Land line
FN – Flight nurse	ED – ED staff	Sat – Satellite phone - + - + - +
MD Cont – Medical Control MD	CT – Care team	FF – Face to Face ═══════

APPENDIX E

TASK TIMELINE MODEL OF COMMUNICATION FOR

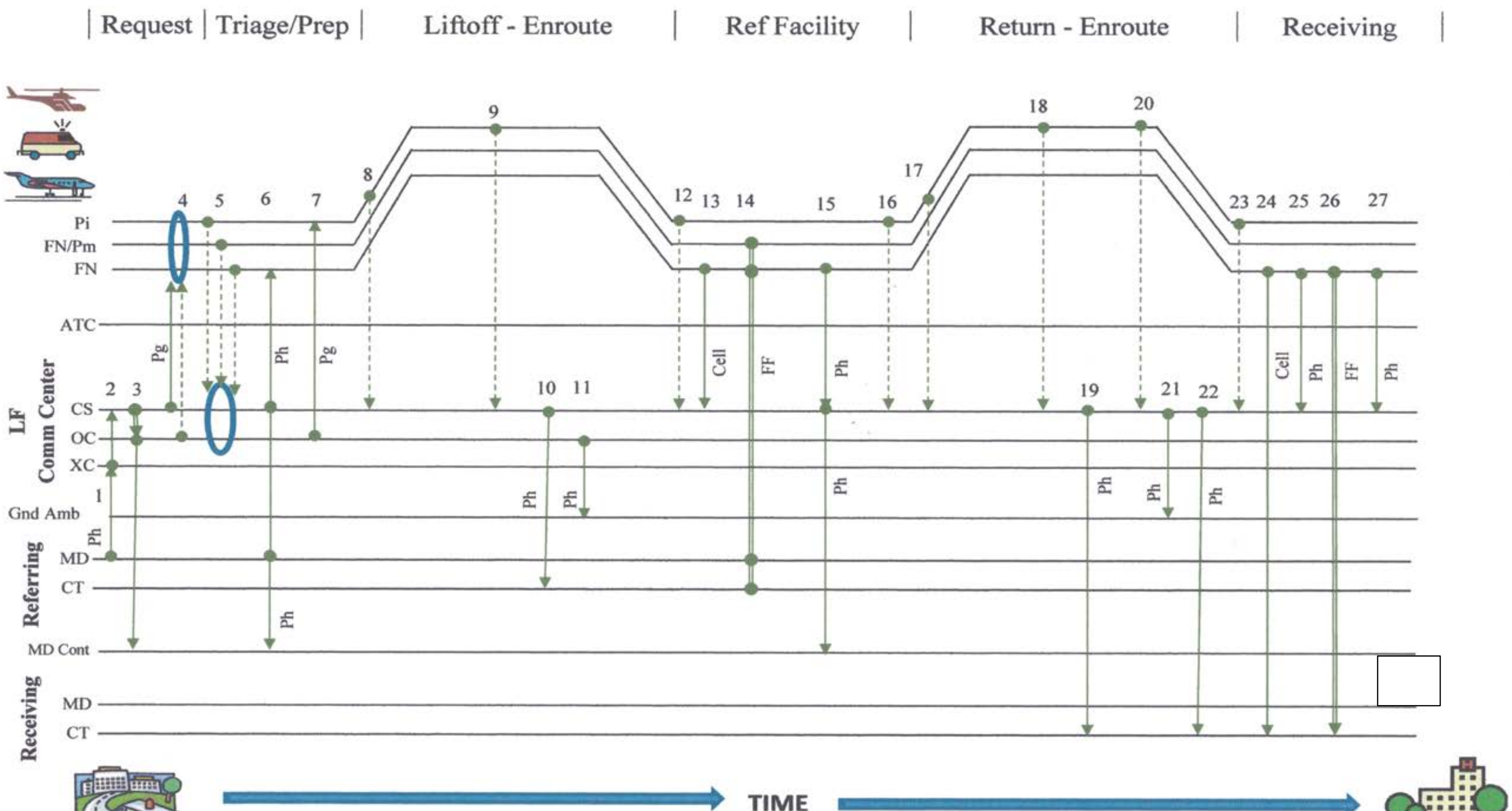
AN INTERFACILITY TRANSPORT

Nominal Communication Process for an INTERFACILITY Transport.

1. Referring physician telephones Receiving physician, or medical control physician, or LF Transfer Center requesting to transfer their patient by air transport (I-SND, I-SRC)
    a. Receiving physician or LF transfer Center takes information to forward to LF Communication Center
    b. Minimum information: contact information of referring physician, patient demographics, patient condition, facility and unit where patient is located, urgency of transport need (e.g., scheduled or immediate)
    c. Receiving physicians that take a request for transfer are notoriously inconsistent in what information they gather.
2. Receiving physician, or medical control physician (MC), or LF Transfer Center telephones Life Flight Communication Center (LFCC) to request transport (I-SND, I-HFWD_1+)
    a. Receiving physician/MC/LF Transfer Center provides contact information of referring physician, patient demographics, patient condition, facility and unit where patient is located, urgency of transport need (e.g., scheduled or immediate)
    b. Information that has been relayed/forwarded by a human (I-HFWD_1+) and may not be accurate.
    c. Information from Receiving physician is notoriously suspect, often incomplete and sometimes erroneous, such as patient location
3. Communication Specialist (CS) discusses with Operational Controller (OC) using face-to-face communication and MC by telephone, if indicated, to determine what vehicle to use, what team, what equipment to take, how quickly to launch.
    a. Vehicle may be fixed-wing airplane, rotor-wing helicopter, or ground ambulance depending upon distance, weather conditions, patient demographics/condition, and equipment needed.
    b. [FW, RW] OC prepares initial flight plan (FP) for pilot
    c. [GND] If GND is chosen as mode, XT does not include pilot
4. Communication Specialist (CS) uses paging system to contact on-call transport team to notify about transport and provide initial information: (I-SND). If on-call team is already on another transport, CS pages available team at base, OC contacts team by radio
    a. Minimum information: Location of patient, demographics and medical condition of patient, contact information of referring physician.
    b. Paging system can be considered a data relay/forwarding system (I-DFWD_1)
    c. Both human information forwarding and data forwarding is subject to errors, distortions, and transmission loss from each forwarding episode. Degradation is cumulative with multiple episodes of forwarding.
5. Transport team (XT) telephones/radios LFCC to acknowledge receipt of transport request and seek transport information: (I-SEEK)
6. CS telephones and connects/links medical control physician (MC), XT flight nurse, and if available, referring physician together on conference call for report about patient. (I-EX, I-LNK2)
    a. Information exchange is use to confirm what vehicle to use, what team, what equipment to take, how quickly to launch.
    b. If call includes referring physician, the information is direct (I-EX, I-LNK2), otherwise it is indirect/forwarded by MC (I-LNK, I-EX, I-HFWD_1)
    c. Conference call is notoriously difficult to do in a timely manner as CS often has pager numbers for referring physician and for MC.
    d. Frequently requires multiple calls to physicians to establish telephone conference
    e. This is the most problematic communication on this type of transport.
7. [FW, RW] OC pages flight plan info to pilot: I-SND. Information has been forwarded by human 2+ times (I-HFWD_2+)
8. XT contacts LFCC to indicate they have lifted off/left base and gives report: (I-SND, I-SRC).
    a. [FW] Typically done by FN using UHF/VHF radio onboard aircraft
    b. [RW] Typically done by pilot using UHF/VHF radio onboard aircraft
    c. [GND] FN uses cell phone
    d. Information is ETA, '# of souls onboard', fuel remaining
    e. LFCC gives liftoff/departure time

9. [FW, RW] If time en route > 15 minutes, XT will contact LFCC by UHF/VHF radio to provide current location/status every 15 min (I-SND, I-SRC). If XT does not radio in, LFCC will contact aircraft/ambulance by radio to seek status (I-SEEK)
10. CS telephones charge nurse of unit where patient is located to give ETA of XT. (I-SND)
11. [FW] OC telephones ambulance service at patient location to give ETA of transport team and location of where to meet them. (I-SND)
    a. Rendezvous takes place at the airport.
    b. Usually done when airplane is about 45-60 min from arrival.
12. XT contacts LFCC that aircraft/ambulance has landed/arrived and gets landing time. I-EX, I-SRC
    a. [FW, RW] Typically done by pilot using UHF/VHF radio onboard aircraft
    b. [GND] FN uses cell phone
13. [FW] Flight nurse uses cell phone to call CS and let them know medical team (XT excluding pilot) is in ambulance, en route to patients facility I-SND, I-SRC
    a. Done regularly by Neo team and Dixie. Not done by Adult Team
14. Flight nurse takes report on patient from patient care nurse or MD in face-to-face communication (I-FF, I-SND, I-SRC)
15. FN telephones CS to be connected/linked (I-LNK) with medical control at receiving facility to give report on patient (I-SND, I-SRC, I-LNK)
    a. Report includes patient condition, treatments, support needed at arrival
    b. FN sometimes delegates this to referring care nurse to give report to receiving facility ICU or ED in effort to save transport time. Is this an issue? Are reports from referring nurse consistent, timely, and complete? Speed vs. accuracy tradeoff. (I-SvA)
    c. Omitted communication link through LFCC may reduce situational awareness
16. [FW] Pilot contacts LFCC to indicate they are preparing to lift off: I-SND, I-SRC.
17. XT contacts LFCC to indicate they have lifted off/left location and gives report: I-SND, I-SRC.
    a. [FW] Typically done by FN using UHF/VHF radio onboard aircraft
    b. [RW] Typically done by pilot using UHF/VHF radio onboard aircraft
    c. [GND] FN uses cell phone
    d. Information is ETA, '# of souls onboard', fuel remaining
    e. LFCC will provide departure time
18. FW, RW] If time en route > 15 minutes, XT will contact LFCC by UHF/VHF radio to provide current location/status every 15 min (I-SND, I-SRC). If XT does not radio in, LFCC will contact aircraft/ambulance by radio to seek status (I-SEEK)
19. CS telephones charge nurse of unit of receiving facility to give XT ETA (I-SND, I-HFWD1+)
20. [FW] XT radios LFCC to let them know they will be arriving shortly (ie.. about 30 min) and notify ambulance for rendezvous
21. [FW] CS telephones ambulance service at receiving location to give ETA of transport team and location of where to meet them. (I-SND)
    a. Rendezvous takes place at the airport
    b. Usually done when airplane is about 25-45 min from arrival.
22. [RW] CS telephones receiving facility to give XT ETA, request gurney and support at landing zone. (I-SND, I-HFWD1+)
    a. This may involve calling security and/or ED at receiving facility
    b. Planned to occur 5 minutes from expected time of arrival of XT
23. XT contacts LFCC that aircraft/ambulance has landed/arrived and gets landing time. I-EX, I-SRC
    a. [FW, RW] Typically done by pilot using UHF/VHF radio onboard aircraft
    b. [GND] FN uses cell phone
24. [FW] Flight nurse uses cell phone to call receiving facility and let them know medical team (XT excluding pilot) is in ambulance, en route to receiving facility (I-SND, I-SRC)
    a. Information includes updated ETA, vital signs, vent settings, IV meds (I-SND, I-SRC)
25. Flight nurse uses telephone to call CS and let them know medical team has arrived at receiving unit (I-SND, I-SRC)
26. FN gives report to receiving facility care team (I-FF, I-SND, I-SRC)
27. [FW] FN calls CS to request cab for return to airport. (I-SND, I-SRC)
28. [FW] CS telephones taxi service to pick up medical team from receiving facility (I-SND, I-SRC)

Model of Nominal Communication Interactions – Interfacility Transport (FW) – Life Flight AMT

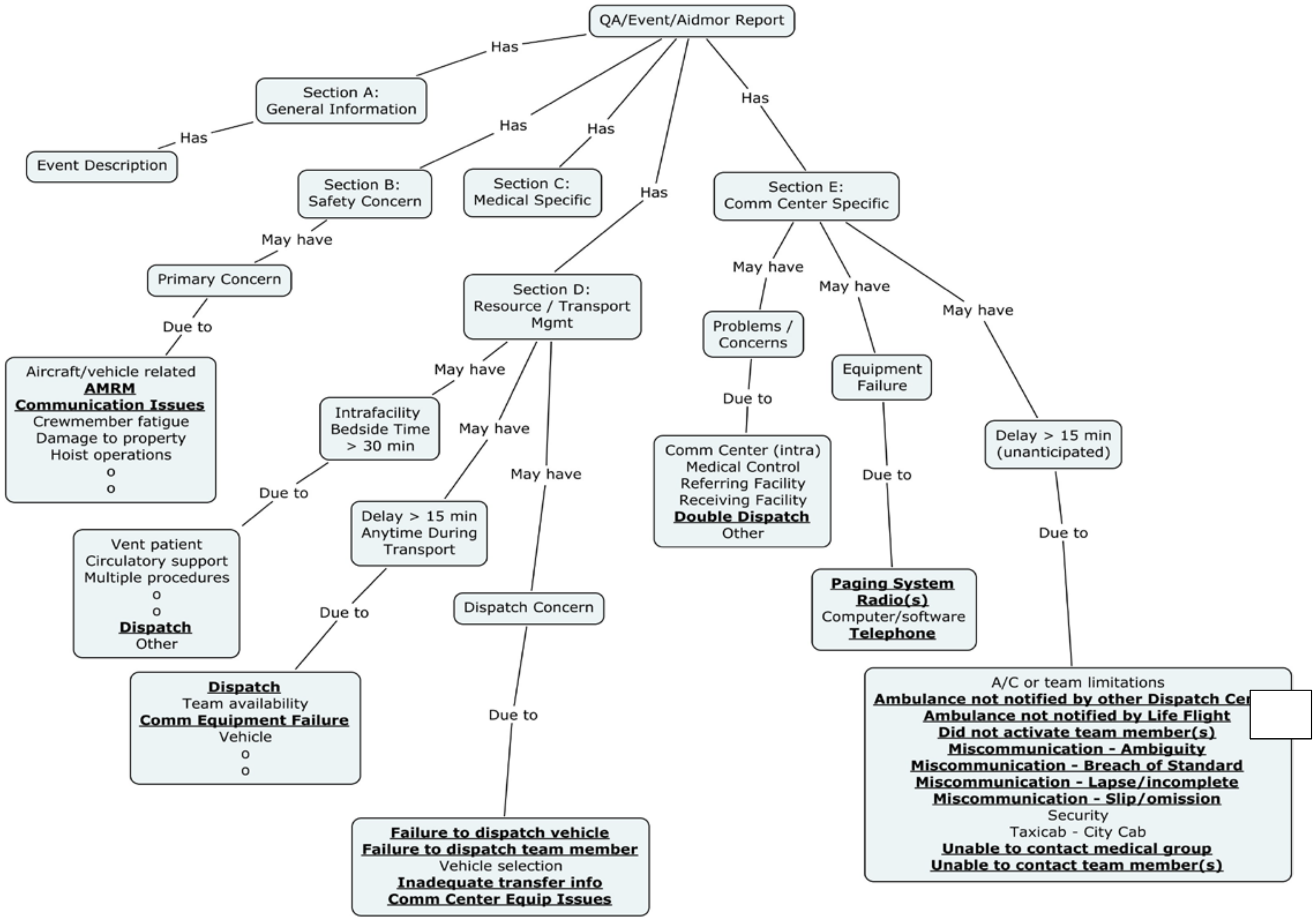


LEGEND		
CS – Communication Specialist	FR – First responder	Pg – pager
OC – Operational Controller	PS – Public Safety	Rad – 800 Mhz/VHS radio - - - - - -
Pi – Pilot	911 – EMS Dispatch	Cell – cell phone
Pm – Paramedic	ATC – Air Traffic Control	Ph – Land line
FN – Flight nurse	ED – ED staff	Sat – Satellite phone - + - + - +
MD Cont – Medical Control MD	CT – Care team	FF – Face to Face ══════

APPENDIX F

CONCEPT MAP OF ONTOLOGY IN QA/EVENT REPORT

Concept Map of QA/Event Report – Communication Issue



Note: Communication triggers in **bold underline**

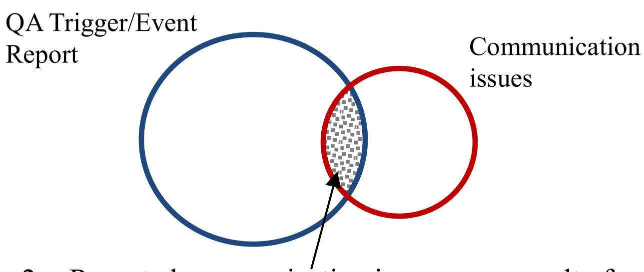
APPENDIX G

ONTOLOGY DEVELOPMENT MEETING SUMMARY

Notes from Communication Error Ontology Development Meeting - 6/18/13

Characteristics of current reporting of communication issues in LF QA Trigger/Event system:

1. Not all communication issues are reported in QA Trigger/Event system



2. Reported communication issues are a result of:
    - Safety concern
    - Bedside delay > 30
    - Delay > 15 min (any)
    - Scene ground time > 20
    - Dispatch concern (both medical and comm center types)
    - Problems/Concerns (e.g., customer complaint or crewmember concern)
    - Equipment (issue or failure)
    - Search & rescue
    - Otherwise noteworthy (Interesting case, Variation from protocol, Peds Xport by adult)

Guidelines for reporting communication issues (something one would say to a new hire)

Report communication issues if they:

1. cause
    - Safety concern
    - Delay (i.e., bedside > 30 min, scene > 20 min, any delay > 15 min)
    - Dispatch concern (either medical or Comm Center types)
    - Problems/Concerns (e.g., customer complaint or crewmember concern)
2. result from an Equipment issue (e.g., comm equipment failure or operator difficulty)
3. impact Search & rescue
4. are otherwise noteworthy (i.e., communication issues that affect the quality or safety of the transport or task you are involved with AND you feel it should be documented)

Goals for improving the QA Trigger/Event System to better analyze communication issues

1. Not to substantially increase or decrease frequency of reporting communication issues (i.e., maintain current sensitivity)
2. Increase the identification of communication issues by triggers rather than free text event narrative (i.e., more queryable)
3. Make reports more useful for understanding communication issues and identifying causes and remedies

Key questions that queries of QA Event Report will be able answer:

1. How often are communication issues being reported?
   Based upon our current process, these are noteworthy communication issues that affect safety, delays, search & rescue, etc.)

2. Who is involved in communication issues? (i.e. participants)

3. During which process step or operational task are communication issues occurring?

4. At which level of communication did the issue occur? (e.g., level 1 – contacting, level 3 – understanding meaning of words, level 4 – goals/purpose of conversation between participants)

Terms or concepts being considered for QA Event Report for answering key questions above:

1. ***Communication issue*** – (Possibly a dropdown box with choices like ***safety, delay, equipment***, etc.)
   Should we use a dropdown box? If so, what categories do we need? If not, what other way can we use to determine which reports have communication issues?

2. ***Participants - What choices or terms for participants do we need?***
   Pilot, Flight nurse, Comm Spec, Ops Controller, Referring MD, Receiving MD, Medical Control, etc.

3. ***Operational task*** – (Possibly a dropdown box with choices like ***request, team notification, triage, patient care, flight following, scene coordination, rendezvous, others?***)

   What choices or terms for operational task do we need?

4. ***Communication level*** – (Possibly a dropdown box with choices like ***failure/inability to contact, goals of conversation not achieved, others?***)

   What choices or terms for communication level do we need?

APPENDIX H

DAILY BRIEFING NEWSLETTER

CRM Topic

Oh, . . . I assumed you knew that !

Background

On January 25, 1990, when Colombia's Avianca Airlines Boeing 707 was approaching its destination, New York's Kennedy International Airport, the plane was required to remain in a holding pattern due to bad weather conditions. However, the plane did not have sufficient fuel left to do so, and the pilots attempted to tell the controller that. The first officer, who was communicating with the controller, used ambiguous expressions like "need for priority," instead of clearly declaring "an emergency" (National Transport Safety Board, 1991: 56-7). As a result, the New York controller never realized the airplane was in an emergency situation and never gave an emergency clearance for it to land prior to others. The airplane eventually ran out of fuel and crashed near the airport, killing 72. If the pilots had explicitly declared an emergency, they would have been given a priority to land.

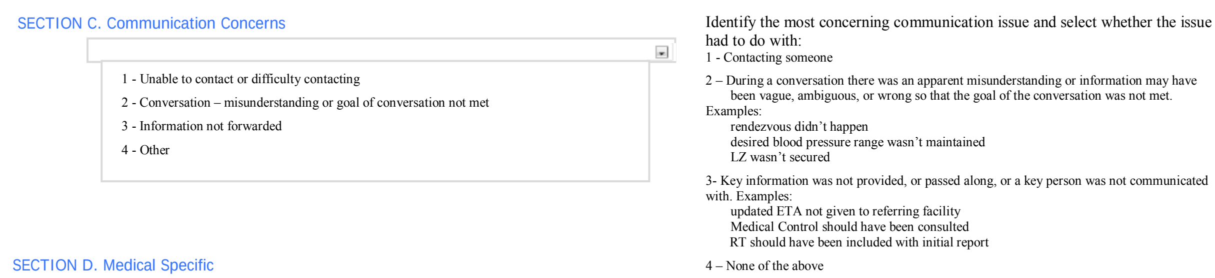
On June 29, 2008, about 3:47 pm MST, two Bell 407 EMS helicopters, operated by Air Methods Corporation, and Classic Helicopter Services, collided in midair while approaching the Flagstaff Medical Center (FMC) helipad in Flagstaff, Arizona. All 7 persons aboard the two helicopters were killed and both helicopters were destroyed. The National Transportation Safety Board determined that the probable cause of the midair collision was that both pilots failed to see and avoid the other helicopter on approach to the helipad. Contributing to the accident were the failure of one pilot to follow arrival and noise abatement guidelines and the failure of the other pilot to follow communication guidelines.

Because of its crucial role, miscommunication in aviation accidents has been studied extensively. A Boeing study about the prevention of aircraft accidents found that miscommunication between pilot and controller contributed to at least 11 percent of fatal airplane crashes worldwide in the period of 1982-91 (Ritter, 1996). More broadly, another analysis has claimed, "over 70% of aviation accidents result from crew coordination and communication as opposed to lack of individual technical skills" (Lautman et al, 1993).

Improving Communication at Life Flight

Many of us have experienced communication issues during a transport. Some of those posed a safety risk, some caused delays, and many others affected the quality of the transport in one manner or another. In order to improve communication at Life Flight, we are adding a new trigger to the QA Trigger/Event form to better analyze communication issues, and ultimately, reduce their occurrence.

The new trigger will be a drop down box called ***Communication Concern*** and will provide 4 choices to categorize the nature of the miscommunication. The following figure provides a screenshot of the new trigger:


SECTION C. Communication Concerns

1 - Unable to contact or difficulty contacting
2 - Conversation – misunderstanding or goal of conversation not met
3 - Information not forwarded
4 - Other

SECTION D. Medical Specific

Identify the most concerning communication issue and select whether the issue had to do with:
1 - Contacting someone
2 – During a conversation there was an apparent misunderstanding or information may have been vague, ambiguous, or wrong so that the goal of the conversation was not met.
Examples:
rendezvous didn't happen
desired blood pressure range wasn't maintained
LZ wasn't secured
3- Key information was not provided, or passed along, or a key person was not communicated with. Examples:
updated ETA not given to referring facility
Medical Control should have been consulted
RT should have been included with initial report
4 – None of the above

While miscommunication occurs frequently in our daily activities, most is of little consequence and is 'repaired' by the parties involved in short order. These nuisance and sometimes humorous gaffes ***are not*** intended to be captured by this new trigger. Rather, the new trigger is intended to better classify those ***noteworthy communication issues*** that affect the quality of the transport or the activity we are involved in. Historically, staff at Life Flight have flagged communication issues on the QA Trigger/Event form when they cause a safety concern, a delay, or a problem or concern for the crew, the referring facility, receiving facility, etc. Please continue to write up and flag communication issues on the QA Trigger/Event form as you have in the past, but also select one of the four categories in Communication Concerns that best describes the nature of the issue. NOTE: If there are multiple communication issues, describe them as always in your event narrative and use the drop down box to select the category for the communication issue you were most concerned with.

Discussion Points

What types of communication issues are worthy of writing up and flagging on a QA Trigger/Event form?

What was the nature of the communication issue?

Was it a problem with trying to contact someone? (Selection 1)

Did it result from of a conversation between parties where one of the parties did not do what was expected by the other? (i.e., *parties were 'not on the same page'*) (Selection 2)

Was it because new information or changing status was not forwarded to someone who needs or would benefit from the information? (Selection 3)

Was it because somebody should have been informed or consulted, but wasn't? (Selection 3)

Was it none of the above? (Selection 4)

REFERENCES

1. Atlas and Database of Air Medical Services – 12th Edition National Air Medical Services GIS Database. 2014. (Accessed Oct 10, 2014, at http://www.adamsairmed.org/pubs/ADAMS_Intro.pdf.)

2. FAQ's from the Association of Air Medical Services. Association of Air Medical Services, 2014. (Accessed Oct 18, 2014, at http://aams.org/member-services/fact-sheet-faqs/.)

3. Alvarez G, Coiera E. Interdisciplinary communication: an uncharted source of medical error? J Crit Care 2006;21:236-42; discussion 42.

4. Bhasale AL, Miller GC, Reid SE, Britt HC. Analysing potential harm in Australian general practice: an incident-monitoring study. Med J Aust 1998;169:73-6.

5. Sentinel Event Statistics. 2011. (Accessed Jan. 23, 2012, at http://www.jointcommission.org/SentinelEvents/Statistics/.)

6. Kohn LT, Corrigan J, Donaldson MS, Institute of Medicine (U.S.). Committee on Quality of Health Care in America. To err is human : building a safer health system. Washington, D.C.: National Academy Press; 2000.

7. Kanki BG. Communication as a group process mediator of crew performance. Aviat Space Environ Med 1989;60:402-10.

8. Orasanu J. Team Decision Making in Complex Environments. In: Klein GA, ed. Decision making in action : models and methods. Norwood, N.J.: Ablex Pub.; 1993:327-45.

9. Orasanu J, Fischer U. Cross-cultural barriers to effective communication in aviation. In: Granrose CS, Oskamp S, eds. Cross-cultural workgroups. Thousand Oaks, CA: Sage Publications; 1997:134-62.

10. Tajima A. Fatal miscommunication: English in aviation safety. World Englishes 2004;23:451-70.

11. MacDonald RD, Banks BA, Morrison M. Epidemiology of adverse events in air medical transport. Acad Emerg Med 2008;15:923-31.

12. DEN08MA116B. 2009. (Accessed Jan. 23, 2012, at http://www.ntsb.gov/aviationquery/brief.aspx?ev_id=20080715X01051&key=2.)

13. Arndt KA. Information excess in medicine. Overview, relevance to dermatology, and strategies for coping. Archives of dermatology 1992;128:1249-56.

14. McDonald CJ. Protocol-based computer reminders, the quality of care and the non-perfectability of man. The New England journal of medicine 1976;295:1351-5.

15. Intermountain Life Flight 2014. (Accessed Oct. 10, 2014, at http://intermountainhealthcare.org/services/lifeflight/Pages/home.aspx.)

16. Commission on Accreditation of Air Medical Transport Systems (CAMTS). 2014. (Accessed Oct. 11, 2014, at http://www.camts.org/.)

17. Cancio LC. Airplane crash in Guam, August 6, 1997: the aeromedical evacuation response. J Burn Care Res 2006;27:642-8.

18. Honey G, Bleak T, Karp T, MacRitchie A, Null D, Jr. Use of the Duotron transporter high frequency ventilator during neonatal transport. Neonatal Netw 2007;26:167-74.

19. Lastilla M, Bisetti R, Autore A, Aragonese F, Di Stefano M, Sarlo O. [Aero-transport of a MDR-TB affected patient with bio-containment systems]. Infez Med 2007;Suppl 1:43-6.

20. Svenson JE, O'Connor JE, Lindsay MB. Is air transport faster? A comparison of air versus ground transport times for interfacility transfers in a regional referral system. Air Med J 2006;25:170-2.

21. Thomas SH. Helicopter emergency medical services transport outcomes literature: annotated review of articles published 2000-2003. Prehosp Emerg Care 2004;8:322-33.

22. Thomas SH. Helicopter EMS transport outcomes literature: annotated review of articles published 2004-2006. Prehosp Emerg Care 2007;11:477-88.

23. Baker SP, Grabowski JG, Dodd RS, Shanahan DF, Lamb MW, Li GH. EMS helicopter crashes: what influences fatal outcome? Ann Emerg Med 2006;47:351-6.

24. Dery M, Hustuit J, Boschert G, Wish J. Results and recommendations from the helicopter EMS pilot safety survey 2005. Air Med J 2007;26:38-44.

25. Hinkelbein J, Dambier M, Viergutz T, Genzwurker H. A 6-year analysis of German emergency medical services helicopter crashes. J Trauma 2008;64:204-10.

26. Dalto JD, Weir C, Thomas F. Analyzing communication errors in an air medical transport service. Air Med J 2013;32:129-37.

27. Vilensky D, MacDonald RD. Communication errors in dispatch of air medical transport. Prehosp Emerg Care 2011;15:39-43.

28. Coiera E. When conversation is better than computation. J Am Med Inform Assoc 2000;7:277-86.

29. Shewhart WA, Deming WE. Statistical method from the viewpoint of quality control. Washington,: The Graduate school, the Department of agriculture; 1939.

30. Deming WE. Out of the crisis. Cambridge, Mass.: Massachusetts Institute of Technology, Center for Advanced Engineering Study; 1986.

31. Juran JM. Quality-control handbook. 1st ed. New York,: McGraw-Hill; 1951.

32. Juran JM, De Feo JA. Juran's quality handbook : the complete guide to performance excellence. 6th ed. New York: McGraw Hill; 2010.

33. Juran Institute. Total quality management : a practical guide. 1st ed. Wilton, Conn., USA (11 River Rd., Wilton 06897-0811): Juran Institute; 1991.

34. Feld WM. Lean manufacturing : tools, techniques, and how to use them. Boca Raton, FL; Alexandria, VA: St. Lucie Press ; APICS; 2001.

35. Pande PS, Holpp L. What is six sigma? New York: McGraw-Hill; 2002.

36. Vietze J. PDCA Cycle / CC BY-SA 3.0. 2013.

37. Shannon C, Weaver W. The Mathematical Theory of Communication. Urbana, Illinois: University of Illinois Press; 1949.

38. Littlejohn SW. Information Theory. Theories of human communication. Columbus, Ohio: Merrill; 1978:147-57.

39. Clark HH. Grounding in communication. In: Resnick L, Levine R, Teasley S, eds. Perspectives on socially shared cognition. Washington, DC: APA Press; 1991:127-49.

40. Clark HH. Using Language. New York: Cambridge University Press; 1996:146-54.

41. Paek T. Toward a Taxonomy of Communication Errors. Microsoft Research, One Microsoft Way, Redmond, WA 98052; 2003.

42. Patterson ES, Roth EM, Woods DD, Chow R, Gomes JO. Handoff strategies in settings with high consequences for failure: lessons for health care operations. Int J Qual Health Care 2004;16:125-32.

43. Patterson ES, Woods DD. Shift changes, updates, and the on-call architecture in space shuttle mission control. Comput Support Coop Work 2001;10:317-46.

44. Patterson JM, Shappell SA. Operator error and system deficiencies: analysis of 508 mining incidents and accidents from Queensland, Australia using HFACS. Accident; analysis and prevention 2010;42:1379-85.

45. Shappell SA, Wiegmann DA. U.S. naval aviation mishaps, 1977-92: differences between single- and dual-piloted aircraft. Aviat Space Environ Med 1996;67:65-9.

46. Reason JT. Managing the risks of organizational accidents. Aldershot, Hants, England ; Brookfield, Vt., USA: Ashgate; 1997.

47. Shappell S, Detwiler C, Holcomb K, Hackworth C, Boquet A, Wiegmann DA. Human error and commercial aviation accidents: an analysis using the human factors analysis and classification system. Hum Factors 2007;49:227-42.

48. Reason JT. Human Error. New York, New York: Cambridge University Press; 1990.

49. Maojo V, Crespo J, Garcia-Remesal M, de la Iglesia D, Perez-Rey D, Kulikowski C. Biomedical ontologies: toward scientific debate. Methods Inf Med 2011;50:203-16.

50. Castro AG, Rocca-Serra P, Stevens R, et al. The use of concept maps during knowledge elicitation in ontology development processes--the nutrigenomics use case. BMC bioinformatics 2006;7:267.

51. A C, DB L, DC W. Managing, Mapping and Maniuplating Conceptual Knowledge, AAAI Workshop Technical Report WS-99-10. Exploring the Synergies of Knowledge Management and Case-Based Reasoning; 1999; Menlo, California: AAAI Press.

52. Stetson PD, McKnight LK, Bakken S, Curran C, Kubose TT, Cimino JJ. Development of an ontology to model medical errors, information needs, and the clinical communication space. Proceedings / AMIA Annual Symposium AMIA Symposium 2001:672-6.

53. Gong Y, Zhu M, Li J, Turley JP, Zhang J. Clinical communication ontology for medical errors. Studies in health technology and informatics 2007;129:1007-11.

54. Horan T, Kaplancali U, Burkhard R, Schooley B. Inductive Design and Testing of a Performance Ontology for Mobile Emergency Medical Services. In: Sharman R, Kishore R, Ramesh R, eds. Ontology Handbook: Springer US; 2007:823-39.

55. Wiegmann DA, United States. Office of Aerospace Medicine., United States. Federal Aviation Administration., Civil Aerospace Medical Institute., University of Illinois (Urbana-Champaign campus). Institute of Aviation. Human error and general aviation accidents : a comprehensive, fine-grained analysis using HFACS. Washington, D.C.: Federal Aviation Administration; 2005.

56. Shorrock ST, Kirwan B. Development and application of a human error identification tool for air traffic control. Applied Ergonomics 2002;33:319-36.

57. Thomadsen B, Lin SW. Taxonometric guidance for developing quality assurance. International journal of radiation oncology, biology, physics 2008;71:S204-9.

58. Hall AL, Rist RC. Integrating Multiple Qualitative Research Methods (or Avoiding the Precaroiusness of a One -Legged Stool)*. Psychology and Marketing 1999;16:291-304.

59. Lindlof TR, Taylor BC. Qualitative communication research methods. 2nd ed. Thousand Oaks, Calif.: Sage Publications; 2002.

60. Creswell JW. Qualitative inquiry & research design : choosing among five approaches. 2nd ed. Thousand Oaks: Sage Publications; 2007.

61. Strauss AL, Corbin JM. Basics of qualitative research : grounded theory procedures and techniques. Newbury Park, Calif.: Sage Publications; 1990.

62. Quickbase. Intuit, 2014. (Accessed Oct. 13, 2014, at http://quickbase.intuit.com/.)

63. Fleiss JL. Measuring Nominal Scale Agreement Among Many Raters. Psychological Bulletin 1971;76:378-82.

64. Thomas F, Allen C, Butts W, Rhoades C, Brandon C, Handrahan DL. Does wearing a surgical facemask or N95-respirator impair radio communication? Air Med J 2011;30:97-102.

65. Gruber TR. A translation approach to portable ontologies. Knowledge Acquisition 1993;5:199-220.

66. IHMC CmapTools. (Accessed Nov. 24, 2014, at http://cmap.ihmc.us/.)

67. Protege. Stanford University, 2013. (Accessed Nov. 24, 2014, at http://protege.stanford.edu/products.php#web-protege.)

68. Warner HR. Medical informatics: a real discipline? J Am Med Inform Assoc 1995;2:207-14.

69. DriverTech. 2015. (Accessed Mar. 09, 2015, at https://www.drivertech.com.)

70. Zoll Dispatch Software Solutions. Zoll Medical Corporation, 2015. (Accessed Mar. 9, 2015, at http://www.zolldata.com/.)

71. MCHD Improves EMS Operation with Integrated Data Management Technology and Attains Measurable Process and Quality Improvements. Zoll Data Systems, 2004. (Accessed Mar. 9, 2015, at https:www.drivertech.com/docs/MCHD-casestudy.pdf.)

72. Wickens CD, National Research Council (U.S.). Panel on Human Factors in Air Traffic Control Automation. The future of air traffic control : human operators and automation. Washington, D.C.: National Academy Press; 1998.

73. McMillan D. Miscommunications in Air Traffic Control [Masters]: Queensland University of Technology; 1988.