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A Model to Predict Pre-Hospital Endotracheal Intubation Success

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by

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ABSTRACT

A MODEL TO PREDICT PRE-HOSPITAL ENDOTRACHEAL INTUBATION SUCCESS

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Background: Pre-hospital endotracheal intubation (ETI) is one of the most critical skills performed by paramedics and is considered the "gold standard" of airway management. Pre-hospital ETI success rates are variable, ranging from 33% to 100% across EMS systems in the U.S. Previous investigative efforts have identified factors associated with pre-hospital ETI success, but the generalizability of findings is limited. Few researchers have controlled for the concurrent effects of multiple factors when examining pre-hospital ETI success. **Methods:** In this retrospective exploratory study, we used national data from the National Emergency Medical Services Information System (NEMSIS) and data from a four state regional representation of the U.S. emergency medical services (EMS) system for 2013 to generate National and Comprehensive State models. Hierarchical logistic regression was used to evaluate what variables predicted pre-hospital ETI success. **Results:** Type of service requested, U.S. census region, EMS total call time, Center for Medicare and Medicaid Services service level, provider certification level, race, chief complaint organ system, and cardiac arrest were structure factors significantly associated with pre-hospital ETI success ($p \leq .001$). Number of pre-hospital ETI attempts and response mode to scene were process factors significantly associated with pre-hospital ETI success ($p < .001$). **Conclusion:** Future researchers should examine systems with the best patient outcomes and use Utstein-style templates to frame data collection for airway management. These approaches will help clarify the use of advanced airway management and help to develop evidence-based guidelines for EMS provider.

This thesis is dedicated to Mom, Dad, and Mike. Mom and Dad, thanks for always believing in me and teaching me responsibility and courage to face all of life's challenge and to shape my fondest dreams. Mike, thanks for being understanding and putting up with all the late nights and long hours spent at the computer. Nothing can measure the love I feel for you guys and how much I appreciate all you have done for me over the years. xoxoxo

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CHAPTER I

INTRODUCTION

The Institute of Medicine (IOM) considers patient safety “indistinguishable from the delivery of quality health care” (Aspden, Corrigan, Wolcott, & Erickson, 2004). The IOM defined quality as "the degree to which health services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge" (Lohr and Committee to Design a Strategy for Quality Review and Assurance in Medicare, 2003, p.21). Measuring quality in Emergency Medical Services (EMS) is important since EMS is pre-hospital medicine. Patient safety in EMS has been poorly studied. There is paucity of evidence in pre-hospital emergency medicine, and there have been very few experimental trials of interventions designed to make EMS safer. The IOM’s 1999 paper, To Err is Human: Building a Safer Heath Care System, identified three domains of quality in health care: 1) ensuring patient safety, 2) providing “best practices” consistent with current medical knowledge, and 3) having the ability to meet customer-specific expectations. The Agency for Healthcare Research and Quality (AHRQ) asserts that patient safety across the continuum of care is a national priority (AHRQ, 2015). Health care researchers and practitioners alike have worked toward understanding threats to patient safety, researching many factors that contribute to patient harm, and compiling evidence for best practices to reduce adverse events. Systematic weaknesses and individual behaviors are at the root of adverse events (Canadian Patient Safety Institute, 2009).

Unique environmental challenges exist in the pre-hospital setting due to the uncontrolled environment which may lead to adverse events. EMS personnel work in small, poor, dimly lit spaces. The pre-hospital environment is chaotic and challenging for emergency health care interventions. Most emergency pre-hospital scenes are loud, cluttered, and unfamiliar to the pre-hospital provider. Emotional stressors are also heightened by the presence of panicked family members, curious bystanders, and lack of medical and human resources. The time sensitive nature of EMS care further complicates these physical and emotional stressors. Opportunities for adverse events are numerous (Canadian Patient Safety Institute, 2009).

Pre-hospital ETI is a procedure associated with numerous opportunities for adverse events. ETI is the most prominent and invasive form of airway management. ETI is the insertion of a plastic breathing tube through the mouth, between the vocal cords, and into the trachea. Optimal and controlled delivery of oxygen is provided to the patient, as ETI provides a direct conduit to the lungs (Danzl, 2000). ETI facilitates oxygen delivery, helps prevent aspiration and gastric distension, and provides an alternate drug route. Positive pressure ventilation can be delivered, and tracheal suctioning is possible (Sanders, McKenna, Quick, & Lewis, 2007).

Despite its accepted role as standard pre-hospital clinical practice since the early 1970s, several recent studies question the safety and effectiveness of pre-hospital ETI (De Leo, 1977; Guss & Posluszny, 1984; Wang & Yealy, 2006b). For example, some studies have highlighted important procedural errors including multiple attempts, tube displacement or dislodgement, failed attempts, iatrogenic oxygen saturation, and bradycardia (Dunford, Davis, Ochs, Doney, & Hoyt, 2003; Katz & Falk, 2001; Wang, Kupas, Paris, Bates, Constantino, & Yealy, 2003; Wang, Lave, Sirio, & Yealy, 2006; Wang & Yealy, 2006a). Other studies have shown that ETI is not associated with clinical benefit and may be associated with increased harm (Davis, Peay, Sise, Vilke, Kennedy, Eastman, Velky, & Hoyt, 2005; Gausche, Lewis, Stratton, Haynes, Gunter, Goodrich, Poore, McCollough, Henderson, Pratt, & Seidel, 2000; Wang, Peitzman, Cassidy, Adelson & Yealy, 2004). Some have proposed abandoning the procedure (Bochicchio & Scalea, 2003; Nolan, 2001; Zink & Maio, 2004; Wang and Yealy, 2006b). Abandoning ETI in pre-hospital care would challenge the long-standing unsubstantiated belief in the U.S. that ETI is the optimum method for airway management (Wang, et al., 2006).

ETI procedural success is commonly used as a measure of intubation proficiency and can be used as a measure of quality in pre-hospital medicine (Prekker, Kwok, Shin, Carlbom, Grabinsky, & Rea, 2014). Pre-hospital ETI success rates are highly variable, ranging from 33% to 100% across EMS systems in the U.S. (Bulger, et al., 2007; Diggs, Yusuf, & De Leo, 2014; Hubble, Brown, Wilfong, Hertelendy, Benner, & Richards, 2010; Wang, Mann, Mears, Jacobson, & Yealy, 2011). This variability has been attributed to system factors, patient factors, and paramedic skill and experience (Warner, Carlbom, Cooke, Bulger, Copass, & Sharar, 2010). We seek a valid and reliable model predicting pre-hospital ETI success.

Donabedian's classic paradigm for assessing quality of care based on a three-component approach—structure, process, and outcome—frames the proposed research. Donabedian's model proposes that each component has a direct influence on the next: structure directly affects process which directly affects outcome (Donabedian, 1980). The background and significance, problem statement, purpose, theoretical framework, research questions, assumptions, and limitations are introduced in Chapter 1.

Problem Statement

ETI is one of the most critical skills performed by paramedics and has been advocated since the early 1970s as a method to improve the care of critically ill patients in the pre-hospital setting (Pepe, Copass, & Joyce, 1985). Pre-hospital ETI is attempted in 426/100,000 of 9-1-1 calls where EMS is activated (Diggs, et al., 2014). Pre-hospital ETI success rates are highly variable, ranging from 33% to 100% across EMS systems in the U.S. (Bulger, et al., 2007). This variability has been attributed to system factors, patient factors, and paramedic skill and experience (Warner, et al., 2010). Previous investigative efforts have identified factors associated with successful pre-hospital ETI. However, because the preponderance of evidence was generated by studies utilizing retrospective single-service designs, the generalizability of findings is limited. Furthermore, most researchers used univariate methods to examine possible predictors—they did not quantify or control for the concurrent effects of multiple factors (Carlson, Quitero, Guyette, Callaway, & Menegazzi, 2011; Davis, Peay, Sise, Vilke, Kennedy,Eastman, Vekly, & Hoyt, 2005; Denver Metro Study Group, 2008; Doran, Tortella, Drivet, & Lavery, 1995; Garza, Gratton, Coontz, Noble, & Ma, 2002; Helm, Hossfeld, Schafer, Hoitz, & Lampl, 2006; Tam, Maloney, Gaboury, Verdon, Trickett, Leduc, & Poirrier, 2009; Wang, O'Connor, Schnyder, Barnes, & Megargel, 2001). Thus, there is only a limited understanding of how multiple factors (considered in a single sample) affect pre-hospital ETI success. Concerns have been raised about pre-hospital ETI regarding both safety and efficacy. Some even advocate abandoning this procedure in favor of alternate methods of invasive or noninvasive respiratory support. A better understanding of factors associated with pre-hospital ETI success would help to determine where to target limited resources for purposes of enhancing paramedic performance and the quality of medical services provided to EMS patients.

Purpose

We constructed two valid and reliable models for purposes of predicting the factors associated with pre-hospital ETI success. One model incorporated data retrieved from the largest national aggregate of EMS data currently available—the National Emergency Medical Services Information System (NEMIS) 2013 data set. This model was called the National Model. A second model incorporated state-based EMS data. We used data from one state in each U.S. census region. Maine represented the Northeast census region. Virginia represented the South census region. Illinois represented the Midwest census region, and Utah represented the West census region. This model was called the Comprehensive State Model.

Background

Airway Management and ETI. Airway management is the process of delivering life-saving oxygen by establishing an open passage between the mouth and lungs (Wang, 2007). Critically ill individuals such as those suffering from cardiac arrest, major trauma, airway obstruction, respiratory failure, severely altered mental status, or decompensated shock often are unconscious and cannot maintain an open airway on their own (Abdullah, Smith, Biddinger, Kalenderian, & Schwamm, 2008; Gahan, Studnek, & Vandeventer, 2011; Pons & Markovchick, 2002; Silbergleit, Lowenstein, Durkalski, Conwit, & Neurological Emergency Treatment Trials (NETT) Investigators, 2011). Airway management is a priority in caring for the critically ill. Vital organs such as the brain begin to die without an adequate supply of oxygen (Wang, 2007). Airway management involves basic methods (e.g., mouth-to-mouth or bag-valve-mask ventilation) or more advanced techniques (e.g., ETI, Combitube, Laryngeal Mask Airway, King LT, cricothyroidotomy) (Diggs, et al., 2014).

Pre-hospital ETI, the insertion of a breathing tube into the trachea by EMS personnel prior to arrival at the emergency department, is regarded as one of the most important EMS procedures. Pre-hospital ETI has been used by EMS personnel in the U.S. for more than 40 years (Wang, et al., 2006). Performance of pre-hospital ETI is done to optimally oxygenate, ventilate, and protect critically ill patients from aspiration. Concerns have been raised about pre-hospital ETI due to concerns regarding both safety and efficacy (Prekker, et al., 2014).

History of Pre-Hospital ETI. Paramedics first performed pre-hospital ETI in the early 1970s during an era of intense efforts to improve the pre-hospital care of patients suffering from cardiac arrest. Experts believed that oxygen delivery was a fundamental component of cardiac arrest. Most experts viewed ETI as the best way to deliver oxygen to the lungs in comatose individuals. ETI was performed on cardiac arrest patients in hospitals, and it seemed reasonable to train paramedics to perform ETI on cardiac arrest patients in the pre-hospital environment. Prior to this time, paramedics used older airway management methods such as bag-valve-mask and the esophageal-obturator airway. Neither of these methods was seen as adequate in this clinical context (Wang, 2007).

Scientific reports of paramedic, pre-hospital ETI were first seen in San Diego, Columbus (Ohio), Pittsburgh, and Boston. These paramedics received classroom and mannequin training as well as practice in the operating room on live patients. Anesthesiologists were active in training and mentoring these paramedics during these pilot efforts. These first studies received significant attention and spurred efforts to generalize pre-hospital ETI throughout the U.S. (Wang, 2007).

Today, clinicians view ETI as one of the interventions that distinguishes paramedic care. Pre-hospital ETI is a standard of paramedic care. Although this procedure is used by paramedics, there are many controversies surrounding pre-hospital ETI (Wang, 2007).

Controversies Surrounding Pre-Hospital ETI. Controversies surrounding pre-hospital ETI come in many forms. Researchers question whether pre-hospital ETI is lifesaving. Adverse events and errors occurring during pre-hospital ETI have been associated with less than optimal health outcomes. Paramedic skill and experience may be limited when compared to others who perform ETI such as emergency medical residents and anesthesiologists (Wang, 2007).

Is the Practice of Pre-Hospital ETI Lifesaving? Patient survival and other outcomes should be improved by resuscitation. Most have assumed that pre-hospital ETI is beneficial because it provides a protected conduit to the lungs. Recently, studies have found that pre-hospital ETI may in fact not improve survival or other outcomes and, in some cases, may even worsen outcomes (Davis, et al., 2003; Gausche, et al., 2000; Wang, Peitzman, Cassidy, Adelson, & Yealy, 2004).

A prospective pseudo-randomized control trial, comparing ETI to bag-valve-mask in children, found no difference in survival or neurological outcome (Gausche, et al., 2000). In a group of patients receiving rapid sequence intubation compared to a group of historical controls that did not receive ETI, the experimental ETI group exhibited a higher adjusted odds of death (Davis, et al., 2003). In a study that analyzed over 4,000 head-injured patients treated by paramedics in Pennsylvania, those patients intubated by paramedics had a four times higher adjusted odds of death than those intubated in the receiving hospital emergency department (Wang, et al., 2004).

Adverse Events and Errors Occurring During Pre-Hospital ETI. Previous studies have suggested that pre-hospital ETI may interfere with key aspects of resuscitation. ETI may lead to inadvertent hyperventilation which can adversely affect cerebral perfusion in traumatic brain injury or coronary perfusion during cardiopulmonary resuscitation (Aufderheide & Lurie, 2004; Aufderheide, Sigurdsson, Pirrallo, Yannopoulos, McKnite, vonBriesen, Sparks, Conrad, Provo, & Lurie, 2004; Davis, Dunford, Poste, Ochs, Holbrook, Fortlage, Size, Kennedy, & Hoyt, 2004). Other adverse events and errors associated with ETI include lacerated tongue and lips; dental trauma from the laryngoscope; lacerated pharyngeal and tracheal mucosa; tracheal puncture; avulsion of arytenoid cartilage; vocal cord injury; vomiting and aspiration of stomach contents; significant release of epinephrine or norepinephrine leading to hypertension; tachycardia, or cardiac rhythm disturbances; vagal stimulation leading to hypotension and bradycardia; increased intracranial pressure in patients with head injury; accidental intubation of esophagus; accidental intubation of bronchus; accidental extubation; and pneumothorax (Sanders, McKenna, Quick, & Lewis, 2007). A study that focused on reports of three error events: 1) ETI tube displacement or dislodgement, 2) multiple ETI attempts, and 3) failed ETI efforts, found one or more of these errors occurred in 1 in 4.5 ETI efforts when analyzing over 1,900 ETIs performed (Wang, et al., 2004).

Paramedic ETI Training and Experience. Given the complexity of ETI, one would expect that paramedics receive substantial training and practice in the ETI procedure. However, the current practices and ETI training standards may not afford adequate baseline or maintenance experience (Wang, 2007). An example of this can be seen in the entry level paramedic curriculum. Whereas anesthesiology and emergency medicine resident physicians must perform 35-50 ETIs prior to graduation, paramedic students are only required to perform five ETI procedures to graduate (Wang, Seits, Hostler, & Yealy, 2005). Most emergency medicine residents spend 160 hours in the operating room learning ETI under anesthesiologists while paramedic students spend only 16-32 hours in the operating room learning ETI (Johnston, Seitz, & Wang, 2006).

Paramedic clinical ETI experience falls below expected levels. A 2003 Pennsylvania statewide study found that the average paramedic performs one ETI annually. The minimum annual number of procedures is not defined, but the best air medical programs, which frequently treat severely injured patients in need of pre-hospital ETI, require paramedics to perform only twelve ETIs annually (Wayne & Friedland, 1999).

National Emergency Medical Services Information System (NEMSIS). NEMSIS is a standardized system of collecting, storing, and sharing EMS patient care data at the national, state, and local level. The National Highway Traffic and Safety Administration (NHTSA), in cooperation with the Health Resources and Services Administration (HRSA), have provided funding since 2001 to the National Association of EMS Directors to develop NEMSIS, which was launched in 2002. The purpose of NEMSIS is to have a standardized approach to the collection of both clinical and EMS resource information. NEMSIS provides a uniform data set with standard terms, definitions, and values. In 2005, NHTSA, in cooperation with HRSA and the Centers for Disease Control and Prevention, entered into a contract with the University of Utah's School of Medicine to operate the NEMSIS Technical Assistance Center (NEMSIS TAC, 2014). NEMSIS TAC provides assistance to state, territory, and local EMS agencies and to software vendors (Dawson, 2006).

Theoretical Model

Donabedian's conceptual model for assessing quality of medical care, as depicted in Figure 1, framed the proposed research. According to Donadedian, the information from which inferences about the quality of care can be drawn can be classified under three categories: structure, process, and outcome (Donabedian, 1966; Donabedian, 1980).

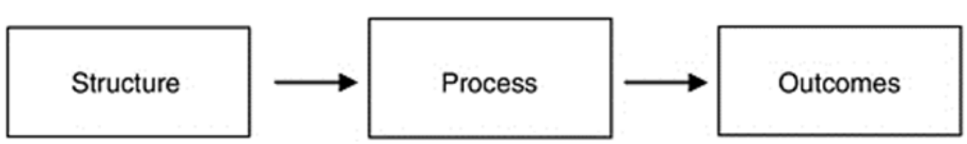


Figure 1. Donabedian's Classic Paradigm for Assessing Quality of Medical Care.

Structure denotes the setting where medical care takes place. Setting attributes include material resources, human resources, and organizational structure (Donabedian, 1988). System characteristics such as organization, personnel, access, facilities, and equipment; provider characteristics such as socio-demographics, specialty training, and preferences; and patient characteristics such as diagnosis, comorbidity, and severity of illness are elements of structure (Donabedian, 1980).

Process denotes what is done in giving and receiving care. It includes both practitioner and patient activities (Donabedian, 1988). Provider's technical style is included and refers to specific services used and the way providers manage the episode of care. Services include tests ordered, medications prescribed, and procedures performed (Donabedian, 1980).

Outcomes are the end result of medical care and denote the effects of care on patient status (Donabedian, 1988). Patient outcomes can include those representing an end result such as mortality or function. Intermediate outcomes such as physiologic or biochemical values that precede and may lead to longer-range end results are also included (Donabedian, 1980).

The conceptual model framing this research can be seen in Figure 2. In the depicted model, system, provider, and patient characteristics are proxies for structure. Process will be denoted by management of care. Pre-hospital ETI was the outcome. Variables included in the models can be found in Figure 3.

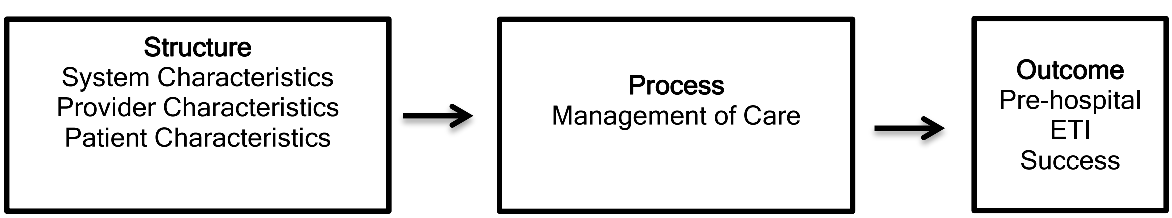


Figure 2. Conceptual Model of Pre-Hospital ETI Success.

System Characteristics	
E02_04	Type of Service Requested
E02_05	Primary Role of Unit
USCensusRegion	
Urbanicity	
EMSTotalCallTime	
Provider Characteristics	
D07_05	Personnel Level of Certification*
E07_34	CMS Service Level
Patient Characteristics	
E06_11	Gender
E06_12	Race
E06_13	Ethnicity
E06_14	Age
E09_04	Possible Injury
E09_12	Chief Complaint Organ System
E11_01	Cardiac Arrest
E11_02	Cardiac Arrest Etiology
E11_05	First Monitored Cardiac Rhythm of Patient*
E11_06	ROSC*
E14_04	Systolic Blood Pressure*
E14_07	Pulse Rate*
E14_09	Pulse Oximetry*
E14_11	Respiratory Rate*
E14_19	GCS (initial)*
E14_22	Level of Responsiveness*

↓

Process Variables	
E02_20	Response Mode to Scene
E19_05	Number of Procedure Attempts
E20_14	Transport Mode form Scene

↓

Outcome
E19_06 Procedure Successful
(Pre-hospital ETI Success)

Figure 3. Variables Representing Structure, Process, and Outcome.

Assumptions

The following are assumptions:

- All data provided to NEMSIS and states through patient care reports was complete and accurate and reported honestly by pre-hospital care providers.
- Since the final response measure considered was pre-hospital ETI success for each patient, there were only two outcomes considered: success or failure of pre-hospital ETI on each patient for a fixed number of patient records.
- Data utilized from each record was independent, meaning one patient record has no influence on another patient record.
- All pre-hospital care providers had met minimum eligibility and education requirements, had passed an acceptable certification exam, and had received approval by a physician to practice a specific scope of activities under his or her delegated authority (National Emergency Medical Services Advisory Council, 2012).

Significance of Study

Pre-hospital ETI success rates ranging from 33%-100% across EMS systems in the U.S. can be attributed to system factors, patient factors, and paramedic skill and experience (Bulger, et al., 2007; Warner, et al., 2010). Retrospective single-service designs have dominated the literature when identifying factors associated with pre-hospital ETI. Most of these studies did not quantify or control for the concurrent effects of multiple factors (Carlson, et al., 2011; Davis, et al., 2005; Denver Metro Study Group, 2008; Garza, et al., 2002; Helm, Hossfeld, Schafer, Hoitz, & Lampl, 2006; Tam, et al., 2009; Wang, et al., 2001).

Few multivariate studies have been conducted looking at pre-hospital ETI (Freund, Dachateau, Devaud, Ricard-Hibon, Juvin, & Mantz, 2012; Wang, et al., 2003). Most studies conducted on pre-hospital ETI focused on difficult pre-hospital ETI. A 2012 study examined variables associated with difficult pre-hospital ETI. The logistic regression performed in this study showed that airway obstruction, intubation on the floor, and a hyoid-mental distance less than three fingers were independent predictors of difficult pre-hospital ETI (Freund, et al., 2012). Wang, et al. (2003) performed a multivariate logistic regression using prospective data from The Pre-hospital Airway Collaborative Evaluation, a multi-centered observational study involving advanced life support (ALS) EMS systems in the Commonwealth of Pennsylvania, and found presence of clenched jaw/trismus, increased weight, electrocardiograph monitoring established prior to pre-hospital ETI attempt, inability to pass the endotracheal tube through the vocal cords, inability to visualize the vocal cords, intact gag reflex, and intravenous access prior to pre-hospital ETI attempt to be associated with pre-hospital ETI failure.

Due to the complexity of the ETI procedure, Wang and Katz (2007) used the skills-rules-knowledge model of cognitive control to explain how the procedure is learned. Thomas, Abo, and Wang (2007) used a qualitative analysis to look at ETI performance and found EMS education, organization, retention, and professionalism linked to ETI performance. No studies have used a theoretical framework that considers system factors, patient factors, and paramedic skill and experience to predict ETI success.

Donabedian's conceptual model was used to frame analysis of predictors of pre-hospital ETI success. Data from the largest national aggregate of EMS data, NEMSIS data set, and state data from one state in each of the four US census regions, was used to create the National and Comprehensive State Models for purposes of examining predictors of pre-hospital ETI success.

Multivariate modeling was used to quantify and control for the concurrent effects of multiple factors leading to pre-hospital ETI success. These models allowed us to determine which structure and process variables were significant predictors of pre-hospital ETI success and helped to determine where to target limited resources for purposes of enhancing paramedic performance and the quality of medical services provided to EMS patients.

Research Questions

RQ1. What variables representing structural factors predict pre-hospital ETI success? Answering this question provides information necessary to see if system, provider, or patient characteristics contribute to ETI success and will help determine where to target limited resources for purposes of enhancing paramedic performance and the quality of medical services provided to EMS patients.

RQ2. What variables representing process factors predict pre-hospital ETI success? Answering this question will help determine how to best manage patient care during pre-hospital ETI.

RQ3. Does the combination of structure variables and process variables add strength to the prediction of pre-hospital ETI success? Answering this question will help to determine if Donabedian's Quality of Care Model can aid in the prediction of pre-hospital ETI success.

Operational Definitions

The following operational definitions were used:

1. ETI: A medical procedure in which a tube is placed through the mouth into the windpipe
2. Pre-hospital ETI: ETI performed in all environments outside an emergency department resuscitation room or a place specifically designed for resuscitation and/or critical care in a healthcare setting. It usually relates to an incident scene, but it includes the ambulance

environment. Implicit in this term is the universal need, by this specific group of patients, for transfer to hospital.

3. Predictive Modeling: The process of developing a model in a way that we can quantify and understand the model's prediction accuracy on future data.

4. Pre-hospital ETI success: Whether the pre-hospital ETI performed on the patient was successful.

CHAPTER II

LITERATURE REVIEW

The purpose of this study was to construct a valid a reliable model that predicts pre-hospital ETI success. According to Donabedian, quality of care is best described as a linear model consisting of structure, process, and outcome (Donabedian, 1988). This chapter presents an overview of Donabedian's conceptual framework followed by an introduction to the concepts of quality measurement in EMS with a focus on clinical performance indicators used by EMS agencies in the United States. An Utstein-style template for uniform reporting of pre-hospital airway management is described. The only study that uses Donabedian's conceptual model to frame quality improvement of medical care for patients receiving ETI in the pre-hospital setting is highlighted. Studies on pre-hospital ETI are then reviewed. The chapter concludes with a summary of the strengths and limitations of the current body of evidence.

Conceptual Model

The Institute of Medicine (IOM) described six dimensions of quality care: care that is effective, safe, patient centered, timely, efficient, and equitable. When applied to EMS, the IOM concepts of quality care require system design with a specific arrangement of facilities, personnel, and equipment that function to ensure effective and coordinated delivery of health care services under emergency conditions but also high quality appropriate care. This ideal design is not often seen in pre-hospital emergency care because most EMS systems evolved as a reactive response to the communities' needs for emergency health care services (major highway trauma, non-traumatic cardiac arrest, military conflicts) rather than as an apriori designed EMS infrastructure. There is great heterogeneity among EMS system designs, making EMS difficult to evaluate and compare (El Sayed, 2011). Performance indicators are measurement tools that should be “specific, measurable, action-oriented, relevant, and timely” (Dunford, Domeier, Blackwell, Mears, Overton, Rivera-Rivera, & Swor, 2002).

Donabedian’s conceptual model provides a framework for assessing quality of medical care. Process of health care is meant to achieve certain objectives related to the promotion, preservation, and restoration of health (Donabedian, 1988). Moreover, health care should be conducted in a way that is acceptable, pleasing, and rewarding to patients and clients. Health care should be provided in settings that take into account clients’ needs (Donabedian, 1985). The information from which inferences about the quality of care can be drawn can be classified under three categories: structure, process, and outcome (Donabedian, 1966, 1980; El Sayed, 2011).

Structure describes the setting in which medical care takes place. Setting attributes include material resources (facilities, equipment, and money), human resources (number of qualified personnel), and organizational structure (medical staff organization) (Donadedian, 1988). Setting also denotes geographic factors such as distance, isolation, and geographic accessibility of services and facilities. System arrangements and population characteristics are also included in the concept of setting (Donabedian, 1980).

Process of medical care is what is done while giving care to patients. Provider’s technical style refers to the specific services used and the way providers manage an episode of care. Services include tests ordered, medications prescribed, and procedures performed (Donabedian, 1980).

Outcome is the ultimate test of effectiveness of medical care and denotes the effects of care on patient health status (Donabedian, 1988). Patient outcomes can include clinical endpoints such as mortality and functional ability. Intermediate outcomes such as physiologic or biochemical values which precede and may lead to longer-range end results are also included. Proxies used to indicate an outcome such as hospital readmission can be included as outcome measures (Donabedian, 1980).

EMS System Performance Indicators

Structure, process, and outcome indicators can all be used to measure the quality of EMS patient care. Structural data refers to the characteristics of the different components of an EMS system including equipment, facilities, staffing, knowledge base of providers, credentialing, and deployment. Structure indicators reflect standards developed at the local, regional, or national level through consensus building or by EMS authority. These indicators generally provide an indirect measure of quality and are difficult to relate to outcomes in patient care (Moore, 1999). These indicators may not be applicable to all EMS systems due to system design diversity. EMS response time standard is the most widely used structure measure of quality (Fitch, 2005).

Process data is another type of measure. Process data reflect the components of the encounter between the EMS professional and the patient. It is an evaluation of the steps of care provided. Compared to structure, process measures are more sensitive to differences in quality of care (Rubin, Pronovost, & Diette, 2001). Process measures allow a direct assessment of quality of care (Mant, 2001). Process measures can become complex due to the increased clinical sophistication of the medical services provided in the pre-hospital setting. Many EMS interventions are not yet evidence based (Mant, 2001; McLean, Maio, Spaite, & Garrison, 2002; Koenig, 1995). Thus, adherence to standard protocols by EMS providers is often an indirect measure of the quality of processes (Mant, 2001).

Outcome data evaluate the change in the subsequent health status of the patient in response to a clinical intervention. Outcome data are more easily interpreted and easily understood by different stakeholders. Clinical outcome data must have accurate risk adjustment, standardization of definitions, and development of research models for each measured outcome (Spaite, Maio, Garrison, Desmond, Gregor, Stiell, & O'Malley, 2001; Rubin, et al., 2001; Mant, 2001). The US National Highway Traffic Safety Administration (NHTSA) launched the EMS Outcomes Project (EMSOP) in 1994 in an effort to overcome the barriers to outcome research and the adoption of outcome data as performance indicators for EMS systems. They defined six outcome categories: survival (death), impaired physiology (disease), limit disability (disability), alleviate discomfort (discomfort), satisfaction (dissatisfaction), and cost-effectiveness (destitution) (Maio, Garrison, Spaite, Desmond, Gregor, Cayten, & Miller, 1999). The "Episode of Care Model," for high priority conditions to measure long term outcomes, and the "Out-of-Hospital Unit of Service Model," for lower priority conditions to measure intermediate outcomes, were developed (Spaite, et al., 2001). Examples of core risk adjustment measures (RAMS) common to all EMS conditions (e.g., age, gender, vital signs) and specific RAMS (e.g., peak flow measurement for asthma exacerbations) were also included (Garrison, Maio, Spaite, Desmond, Gregor, O'Malley, & Miller, 2002). The purpose was to facilitate outcome research and the adoption of outcome measures to evaluate quality in EMS.

On the Road to EMS Clinical Performance Indicators

The complexity of EMS systems requires a more comprehensive evaluation of the different components of the system. Relying on only one type of performance measure whether it be structure, process, or outcome can yield a narrow perspective on EMS quality of care. Hence, comprehensive sets of indicators have been proposed by different stakeholders (El Sayed, 2011).

One set of standards was proposed by the International Association of Firefighters in the National Fire Protection Association (NFPA). They proposed standards for emergency medical operations (NFPA 1710), criteria for response times (NFPA 1720), and dispatch standards (NFPA 1221) (National Fire Protection Association, 2015). In 2007, the National Association of EMS Officials (NAEMSO) also proposed 35 consensus-based indicators at the conclusion of the EMS Performance Measures Project in an effort to identify a common set of specifically designed measures of EMS system performance (O'Meara, 2012). The practical application and validity of the indicators developed by NAEMSO are yet to be tested.

Evidence-based treatment bundles were proposed by the United States Consortium of Metropolitan Municipalities EMS directors. Six priority EMS conditions were selected based on evidence of an effective pre-hospital treatment and on a consensus of EMS experts. Similarity in infrastructure and clinical sophistication of the prehospital services and standardized data collection are prerequisites for the use of these bundles for performance comparison between EMS systems (Myers, Slovis, Eckstein, Goodloe, Isaacs, Loflin, & Pepe, 2008).

Different stakeholders have unique perspectives on quality care. The Institute for Healthcare Improvement (IHI) recommended "Whole System Measures," defined as a "balanced set of system level measures which are aligned with the Institute of Medicine's (IOM's) six dimensions of quality and are not disease or condition specific." A transition toward these "Whole System Measures" can help overcome some of the challenges of evaluating quality in EMS (Martin, Nelson, Lloyd, & Nolan, 2007). Examples of the "Whole System Measures" include patient satisfaction with care, rate of adverse events, health care cost per capita, and incidence of occupational injuries and illnesses. These measures would include specific goals and a dashboard for benchmarking that could be communicated across all levels of the EMS system from prehospital care providers to leadership and policy makers. A system of measures such as these could help to answer the questions regarding what value the EMS system is adding to patient care and what quality of services are being provided to EMS patients (El Sayed, 2011)

Utstein-Style Template

Pre-hospital advanced airway management is a critical intervention carried out regularly on the most severely ill and injured patients. Yet, limited evidence exists regarding its benefit. There is a need for standardization of pre-hospital airway management guidelines. In addition, there is a need for standardization of EMS training and for ways to ensure that advanced airway management skills are maintained. The Utstein-style template (See Appendix A) for uniform reporting of pre-hospital airway management is a useful template for framing standardization. The call for Utstein-style for standard reporting of EMS care emerged in 1991 when a major international meeting was held in Utstein Abbey, Norway to establish a common set of definitions and core data points to be collected for cardiac arrest (Cummins, Chamberlain, Abramson, Allen, Baskett, Becker, & Eisenberg, 1991). The Utstein core data elements for EMS reported are reviewed because it provides a framework of the criteria that should be measured to assure high-quality airway management. This template provides a common platform for comparing data and evaluating the implementation of new guidelines or methods. The Utstein system recommends that two types of variables should be collected during advanced airway management: fixed system variables and core variables (Sollid, Lockey, Lossius, & Pre-hospital Advanced Airway Management Expert Group, 2009).

Fixed system variables are regarded as fixed within the system and do not change between patients. Fixed system variables provide a picture of the population, area covered by the EMS system, and information on how the EMS system is organized. These variables include population, area, urbanicity, tiered response, time intervals collected, service mission types (trauma or mixed-patient), established airway management protocols, airway management techniques available, type of EMS provider training in airway management, type of tracheal tube confirmation technique, and type of available ventilator (Sollid, et al., 2009).

Core data are divided into three groups based on their relationship to the intervention, advanced airway management: “system variables,” “patient variables,” and “post intervention-variables” (Sollid, et al., 2009). These divisions are similar to components of Donabedian’s structure-process-outcome model. Utstein core system airway variables include highest level of EMS provider on scene, airway devices available on scene, drugs available for airway management, main type of transportation, and response time. Core patient variables include co-morbidity, age, gender, patient category, indication for airway intervention, initial respiratory rate, initial heart rate, initial Glasgow Coma Score, initial systolic blood pressure, and SpO_2 (arterial oxygen saturation). Core post-intervention variables include post-intervention ventilation, post-intervention systolic blood pressure, post- intervention SpO_2, post-intervention end-tidal carbon dioxide level ($EtCO_2$), post-intervention heart rate, survival status, number of intubation attempts, intubation success, post-intervention systolic blood pressure on arrival at hospital, post-intervention SpO_2 on arrival, post-intervention $EtCO_2$ on arrival, survival status, complications, drugs used to facilitate airway procedure, and device used in successful airway management (Sollid, et al., 2009). The constructs of the Donabedian quality care model and the Utstein guidelines for standardized collection of data related to airway management were used to guide parameters for the literature review.

Using Donabedian's Model to Assess Quality of Care

Prekker and colleagues (2014) conducted the only study found in the literature that mentions Donabedian's conceptual model. They retrospectively reviewed data on 7,523 pre-hospital ETIs which had been prospectively collected from September 2006 to November 2011 in a large metropolitan EMS system. The organizational structure was a two-tier emergency response: firefighter-EMTs which provided basic life support, and paramedics, who worked in teams of two, and provided advanced life support including advanced airway management. One hundred and fifty paramedics served a population of 1.3 million. They assessed structural variables (provider training and experience) and process variables (patient management) in relation to the outcome of pre-hospital ETI success.

Provider characteristics included paramedic students who had completed an airway management curriculum, which involved lectures, skill laboratories, simulation, and clinical training in the emergency room and operating room. As part of regional certification requirements, paramedics had to successfully intubate at least 12 times annually or returne to the operating room to obtain the necessary number of intubations. Paramedics were permitted to intubate patients in cardiac arrest prior to physician consultation, with or without the use of paralytics. Medical direction was required for patients not in cardiac arrest. Children, younger than 12, were excluded from the study. (Prekker, Kwok, Shin, Carlbom, Grabinsky, & Rea, 2014).

Donabedian (1980) suggests the process of medical care is what is done in giving care to patients including: a) management of patients, b) procedures performed, and c) complications and challenges occurring during procedures. Airway management of patients during emergent medical situations can be fraught with challenges that limit ETI success. Prekker, et al. (2014)

assessed the airway management of patients. Their purpose was to describe the challenges and corrective measures taken by EMS providers during pre-hospital ETI. They analyzed the pre-hospital ETI in 7,523 patients 13 years and older via an EMS patient registry for a large urban area. They found that at least one advanced airway attempt occurred in 1.4% of EMS activations (6.2% of paramedic responses). Multiple challenges to successful pre-hospital airway management were identified by paramedics including bodily fluids obstructing the laryngeal view (i.e., blood, emesis, or secretions), obesity, patient positioning, and facial or spinal trauma. Critical adjustments were made in one of each four patient encounters. Critical adjustments included airway suctioning, repositioning of the patient, adjunctive bougie use, blade change, operator change, and rapid sequence induction (Prekker, et al., 2014).

Donabedian (1988) stated outcomes are the ultimate test of effectiveness of medical care. Outcome can include intermediate outcomes such as pre-hospital ETI procedural success. Prekker (2014) and colleagues reported that the first attempt pre-hospital ETI success rate was 77%, and ultimate pre-hospital ETI success rate was 99%. The primary objective of the study was to describe the process of pre-hospital advanced airway management and to highlight the challenges and corrective actions that enable paramedic ETI.

Literature Search Strategy

A thorough search of the literature was conducted to identify all reports concerning pre-hospital ETI, from which papers regarding variables related to pre-hospital ETI success could be isolated. Studies were identified through a comprehensive search of PubMed, MEDLINE, CINAHL, and the Cochrane Library. Terms were mapped to the appropriate MeSH EMTREE subject headings and "exploded:" ("ambulance" OR "emergency medical services" OR "pre-hospital care") AND ("intubation" OR "ETI"). The search was limited to English-language articles from the year 2000 forward, and only studies conducted in the U.S. were included. The bibliographies of selected studies were also reviewed to identify any additional relevant studies. The literature review takes into account variables related to structure (system characteristics, provider characteristics, patient characteristics) and process.

Structure variables. Structure variables include system, provider, and patient characteristics. Type of device and difficult intubation are also explored.

System Characteristics. Several studies have assessed system characteristics when describing pre-hospital ETI success. Bulger, et al. (2007) conducted a retrospective analysis of trauma care in the U.S. and found great variability in pre-hospital ETI success rates across census regions. The analysis included 3,357 trauma patients representing a weighted sample of 9,929 patients. The median ETI success rate was 75% and ranged from 33% to 100% across census regions.

Wang, Lave, Sirio, & Yealy (2006) examined the relationship between the population setting and system characteristics (number of EMS services, median number of personnel, and staffing configuration [career, volunteer, mixed]), median patient contacts, and ETI errors (N=1,953). Error rates were lower for EMS services that performed more intubations annually (more than 50 ETIs per year) but higher for services with a greater number of patient contacts (more than 5,000 per year). ETI errors were not associated with system configuration (ground versus air medical), personnel patterns (mixed career/volunteer), or the number of paramedic-level rescuers.

Provider Characteristics. Provider characteristics are also structure variables (Donabedian, 1980). Pre-hospital ETI is a complex skill. Hence, provider characteristics such as education, training, skill, and experience with ETI in the pre-hospital setting may be important.

At the federal level, the National Highway Traffic and Safety Administration (NHTSA) developed training requirements (National Standard Curriculum) for pre-hospital care providers that all states must meet (NHTSA, 1998). In addition, NHTSA developed the National EMS Scope of Practice Model. This model details the minimum psychomotor set of skills that each pre-hospital care provider should possess (NHTSA, 2007, p. 2-27). However, licensing and scope of practice of pre-hospital EMS providers are governed at the state level and can vary significantly between states and even within different regions of the same state. The National Registry of Emergency Medical Technicians (NREMT) developed certification tests for most emergency responder levels, and at this time 46 states use the NREMT certification for one or more certification levels (NREMT, 2014).

Wang, Seitz, Hostler, & Yealy (2005) in a retrospective review of longitudinal data from 60 paramedic training programs over a two-year period, found that the more ETIs a paramedic student performed, the greater their success rate. Between one and 74 ETIs (median 7; IQR 4-12) were performed by each of 802 paramedic students. Of 7,635 ETIs, 6,464 (87.4%) were successful. Stratified by clinical setting, 6,311 (82.7%) ETIs were performed in the operating room, 271 (3.6%) in the emergency department, 64 (0.8%) in the intensive care unit (ICU), 86 (1.1%) in other hospital settings, and 903 (11.8%) in the pre-hospital setting. For the 7,398 ETIs included in the multivariate analysis, a cumulative number of ETI was associated with an increased odds ratio of ETI success (OR 1.067 per ETI, 95% CI 1.044-1.091). ETI learning curves were steepest for the pre-hospital and ICU settings. Paramedic experience is another provider characteristic. Many researchers have found a positive association has been found between paramedic experience and successful pre-hospital ETI (Garza, Gratton, Coontz, Noble, & Ma, 2003; Gerbeaux, 2005; Pointer, 1988; Wang, Seitz, Hostler, & Yealy, 2005).

Wang, Kupas, Hostler, Cooney, Yealy, & Lave (2005) reviewed 11,484 ETIs performed by 5,245 out-of-hospital providers, calculated individual rescuer ETI frequency and opportunity, and concluded that ETI is an uncommon event for most rescuers. The median ETI frequency was one (interquartile range, 0-3; range, 0-23). Of 5,245 rescuers, more than 67% (3,551) performed two or fewer ETIs, and more than 39% (2,054) rescuers did not perform any ETIs. The median number of ETI opportunities was three (interquartile range, 0-6; range 0-76). ETI frequency was associated with patient volume (Spearman's rho = 0.67) and was higher for air medical (p=.006) and urban (p = < .001) rescuers.

Garza, et al. (2003) conducted a retrospective review to determine the effect of paramedic experience on ETI success in pre-hospital adult non-traumatic cardiac arrest patients in an urban advanced life support (ALS) setting. They reviewed procedures performed by 98 paramedics. These paramedics performed 909 intubations on 1,066 cardiac arrest patients. They found there was significant correlation between the number of patients in whom ETI was attempted and intubation success rate (p < .001, R=0.32). No correlation was found between months of paramedic experience and pre-hospital ETI success (p = .241, R = 0.120).

Another retrospective review of 62,586 patients who received successful pre-hospital ETIs was conducted to determine if provider experience with ETI was associated with patient survival to hospital discharge. They reported that cumulative EMS ETI procedural experience was associated with improved patient survival after pre-hospital ETI for those patients who suffered cardiac arrest and medical patients who did not suffer arrests but was not associated with survival of those patients who were victims of trauma but who did not suffer cardiac arrest (Wang, Balasubramani, Cook, Lave, & Yealy 2010). Among 21,753 of those patients who had cardiac arrests, adjusted odds of survival were higher for patients intubated by providers with very high experience; adjusted odds ratio (OR) versus low tracheal intubation experience: very high 1.48 (95% CI 1.15 to 1.89), high 1.13 (95% CI 0.98-1.31), and medium 1.02 (95% CI 0.91 to 1.15). Among the 8,162 with medical non-arrests, adjusted odds ratio of survival was higher for patients intubated by providers with high and very high amounts of pre-hospital ETI experience: the odds ratios when compared to low experience with ETI: very high 1.55 (95% CI 1.08 to 2.22), high 1.29 (95% CI 1.04 to 1.59), and medium 1.16 (95% CI 0.97 to 1.38). Among the 3,202 patients with trauma who did not arrest, survival was not associated with provider experiences: adjusted odds ratio versus low tracheal intubation experience: very high 1.84 (95% CI 0.89 to 3.81), high 1.25 (95% CI 0.85 to 1.85), and medium 0.92 (95% CI 0.67-1.26). Doran and colleagues (1995) studied pre-hospital ETI in 236 patients who were intubated during EMS incidents. They also concluded that provider experiences and seniority were not associated with pre-hospital success ($p = .04$)

Warner, Sharar, Copass, & Bulger (2009), conducted a prospective cohort study of 4,091 patients who experienced attempted pre-hospital ETI over a four-year period in a large urban area. The purpose of the study was to evaluate ETI management in an ALS system and describe airway management outcomes of difficult intubation patients. Data was collected via questionnaires that were completed by EMS providers at the conclusion of the patient's pre-hospital care. Data from these questionnaires were then merged with data from an electronic database of pre-hospital patient encounters maintained by the fire department. They found a high success rate among experienced ALS providers, a provider characteristic and structure variable.

A prospective study on provider characteristics was designed to evaluate the effectiveness of a training module and special waiver project where EMT-Bs were trained to perform ETI in a rural community, found that acceptable pre-hospital ETI success rates can be achieved by EMT-Bs who are highly motivated and intensely trained. Thirty-two intubations were performed by EMT-Bs. Thirty attempts were successful and two unsuccessful (94%, 95% CI [80-98%]). Unsuccessful ETIs were managed with accepted basic life support airway standards. There were no unrecognized esophageal endotracheal tube misplacements (0%, 95% CI [0-11%]) (Pratt and Hirshberg, 2005).

Patient Characteristics. Patient characteristics are part of the structure component of Donabedian's (1980) model. Patient characteristics have also been associated with pre-hospital ETI success.

Wang, Lave, Sirio, and Yealy (2006) retrospectivly analyzed the association between ETI errors and patient characteristics among 1,953 patients. Error rates in pediatric patients were most pronounced for patients younger than six; with an odds ratio of 4.0, 95% CI [2.1-7.9] compared to patients greater than 70. Ages 18 to 39, with an odds ratio of 2.9, 95% CI [2.1-4.0] and 40 to 69 with an odds ratio of 1.6, 95% CI [1.3-2.1], were also found to be significant. Patient sex was insignificant when modeling error rates. Patient clinical status was significant when examining error rates. Patients who had not arrested (i.e. had a pulse) had more errors with an odds ratio of 2.6 (95% CI 0.7-1.1) when compared to patients in cardiac arrest.

Davis, Fisher, Buono, Brainard, Smith, Ochs, Holbrook, & Dunford (2006) reviewed records of 703 patients who underwent pre-hospital ETI as part of prospective observational study to examine: a) the association between intubation success and perfusion status, Glasgow Coma Scale (GCS) score, and end-tidal carbon dioxide (EtCO2); b) to document the frequency of unrecognized esophageal intubations with use of continuous capnometry; and c) to highlight the incremental benefit of invasive versus noninvasive airway management techniques in correcting hypoxemia. They found a relationship between intubation success and patient factors such as perfusion status, Glasgow Coma Score (GCS), and initial EtCO2. The use of capnometry was effective in eliminating unrecognized esophageal intubations. First attempt pre-hospital ETI success was 61%; overall success was 81%; invasive airway management was unsuccessful in 11% of patients. Initial EtCO2 was the only variable independently associated with intubation success ($p = .003$) after adjusting for hemodynamics (nonperfusion, hypoperfusion, and normoperfusion) and initial Glasgow Coma Score.

Wang, O'Connor, Schnyder, Barnes, & Megarel (2001) reviewed paramedic clinical charts on 893 ETI attempts for purposes of exploring the association between patient clinical status (cardiac-arrest vs. non-arrest) and pre-hospital ETI success rates. They found pre-hospital ETI success rates to be significantly higher ($p < .001$) for patient with cardiac arrest (551 of 591, 93.2%) when compared to those who had not arrested (220 of 302, 72.9%). They concluded that pre-hospital ETI data should be segregated and reported according to patient clinical status.

Garza, Algren, Gratton, & Ma (2005), in a retrospective observational study of 2,669 pre-hospital ETIs, found a significant difference in pre-hospital ETI failures between combined pediatric cardiac arrest and adult traumatic arrest groups compared with those adults who had experienced cardiac arrest without concurrent trauma (RR = 2.33, 95% CI [1.93-2.83] for intubation failure).

Hubble, Brown, Wilfong, Hertendly, Benner, & Richards (2010) performed a meta-analysis of orotracheal and nasotracheal intubation success rates. They found the highest success rates for pre-hospital orotracheal intubation performed by a mix of clinicians to be among cardiac arrest patients (91%) compared to trauma (73%) and non-arrest patients (70%).

Type of Device. Cady & Pirallo (2009) conducted a before-and-after study exploring pre-hospital ETI rates before and after the implementation of Combitube (i.e. esophageal tracheal airway device) use in a large urban/suburban EMS system. The Combitube is a dual lumen airway device that is blindly inserted without visualization of the oropharynx. They reported that pre-hospital ETI success rates decreased after Combitube implementation (91.6%) when compared to rates of success before implementation (93.5%). This decrease was statistically significant (p=.007).

Cady, Weaver, Pirallo, & Wang (2009) retrospectively reviewed 5,822 events of cardiopulmonary arrests. They looked at process variables including cardiac arrest status, ECG rhythm, and return of spontaneous circulation. They also observed outcome variables including survival to admission and survival to discharge. Of the 5,822 cardiopulmonary arrests, 4,335 (74%) received initial paramedic ETI and 1,437 (26%) received initial EMT-B Combitube insertion. They found that compared to pre-hospital ETI, initial EMT-B placement of Combitubes was not associated with patient survival after out-of-hospital cardiac arrest. Compared with paramedic ETI, EMT-B Combitube placement was not associated with return of spontaneous circulation (ROSC) (adjusted OR 0.93, 95% CI [0.82-1.05]), survival to hospital admission (adjusted OR 0.99; 95% CI 0.86-1.13), or survival to hospital discharge (adjusted OR 1.02, 95% CI [0.79-1.30]).

Difficult Intubation. Variables used in studies examining difficult airway are also related to Donabedian’s (1980) model. Difficult airway is often subjectively reported by EMS providers and includes patient characteristics such as “anatomic abnormalities, traumatic injuries, foreign bodies, inability to open the jaw, or inadequate muscle relaxation” (Warner, Sharar, Copass, & Bulger, 2009, p. 258).

Wang, Kupas, Paris, Bates, Costantino, & Yealy (2003), in a prospective study of 663 ETIs with 89 cases of failed intubation, applied logistic regression to identify a set of factors associated with failed pre-hospital ETI. Of 61 factors potentially related to ETI failure, presence of clenched jaw, or trismus; inability to pass endotracheal tube through vocal cords; inability to visualize the vocal cords; intact gag reflex; intravenous access established prior to ETI; and increased weight (ordinal scale) were found to be significant covariates.

Warner, Sharar, Copass, & Bulger (2009), conducted a prospective cohort study of 4,091 patients who underwent attempted pre-hospital ETIs over a four-year period in a large urban area. The purpose of the study was to evaluate ETI management in an ALS system and describe airway management outcomes of difficult intubation patients. They operationally defined difficult airway as "one requiring four or more ETI attempts" (p. 263). ALS providers subjectively reported that the most common reasons for difficulty with ETI were patient anatomic characteristics such as anterior trachea (39%) and small mouth (30%). Overall mortality when difficult airway was encountered was 44%.

Process. Process is what is done while caring for patients including the way a provider manages care (Donabedian, 1980). Tests ordered, medications prescribed, and procedures performed are also measures of process. Numerous studies have linked process variables to ETI success (Shy, Rea, Becker, & Eisenberg, 2004; Wang, O'Connor, Schnyder, Barnes, & Megarel, 2001, Wang & Yealy, 2006).

Wang, et al. (2001) reviewed paramedic charts and reviewed 893 ETI attempts. They found that route of ETI (nasotracheal versus orotracheal) was associated with time to intubation (TTI). TTI was calculated as the amount of time that elapsed from the point that paramedics arrived on the scene to the time that the endotracheal tube was securely in place. Median TTI was longer when ETI was attempted via the nasotracheal route (25 minutes) when compared to ETI attempts via the orotracheal route (15 minutes) (p =. 002).

Shy, Rea, Becker, &Eisenberg (2004) conducted a retrospective cohort study of 693 patients who were intubated due to pre-hospital cardiac arrest. They explored the association between quick TTI (less than or equal to 12 minutes) when compared to slow TTI (greater than or equal to 13 minutes). They reported that quick TTI was associated with higher survival rates for patients who had experienced pre-hospital cardiac arrest (46%) when compared to slow TTI (23%). Hence, successful pre-hospital ETI may save lives.

The number of ETI attempts performed before ETI is achieved is another process variable. Wang & Yealy (2006), in a prospective study of 1,941 pre-hospital ETI patients, found that it takes numerous attempts before success can be achieved in more than 30% of patients who received ETI in their study. For 1,272 ETIs placed after patient cardiac arrest, the cumulative success for the first three attempts was 69.9%, 84.9%, and 89.9%, respectively. Cumulative success approached overall success (91.8%) after three attempts (OR 0.79, 95% CI [0.61-1.04]). For 463 conventional non-arrest ETIs, cumulative success for the first three attempts was 57.6%, 69.2%, and 72.7%. Cumulative success approached overall success (73.7%) after two attempts (OR 0.95, 95% CI 0.71-1.28). They recommended that a protocol limiting paramedics to three attempts should be implemented in all EMS systems.

Outcomes Post ETI. Outcomes are the ultimate test of effectiveness of medical care and denote the effects of care on patient status (Donabedian, 1988). Outcomes of interest in emergency medicine include intermediate outcomes and long-term outcomes. The literature is replete with evidence that supports that successful pre-hospital ETI is associated with better intermediate and long term outcomes and abounding with contrary evidence. Successful pre-hospital ETI is associated with enhanced intermediate outcomes such as more optimal physiologic or biochemical values like better tissue perfusion, enhanced oxygenation, which lead to longer-range end results such as hospital discharge, and mortality rates (Bernard, Nguyen, Cameron, Masci, Fitzgerald, Cooper, & Smith, 2010; Davis, Peay, Sise, Vilke, Kennedy, Eastman, & Hoyt, 2005; Eckstein, Chan, Schneir, & Palmer, 2000; Lecky, Bryden, Little, Tong, & Moulton, 2008; Stockinger & McSwain, 2004).

Summary of Literature

The necessity of definitive airway control in the pre-hospital setting unquestionably has been established with ETI being universally accepted as the "gold standard" of care for pre-hospital airway management in the U.S. Yet, very little is known about which structural and process factors are associated with successful pre-hospital intubation of patients needing airway management.

Previously described factors affecting the success of pre-hospital ETI include structural measures such as age of the patient, gender of the patient, type of training received by the paramedic, paramedic pre-hospital ETI experience, underlying mechanism, Glasgow Coma Score (GCS), blood pressure, pulse rate, and respiratory rate. Yet, most of the studies found during an extensive search were exploratory retrospective analyses (Bulger, et al., 2007; Cady, et al, 2009; Garza, Algren, Gratton, & Ma, 2005; Prekker, et al., 2014; Shy, et al., 2004; Wang, et al., 2001; Wang et al., 2005; Wang, et al., 2006). The body of evidence generated by prospective and/or interventional research was quite limited (Cady, et al., 2009; Davis, et al., 2006; Pratt and Hirshberg, 2005; Wang, et al., 2003; Wang and Yealy, 2006). Therefore, which specific variables (i.e. system, structural, process) or combination of variables most accurately predict pre-hospital ETI success have not yet been clearly established. Hence, the purpose of the proposed study was to add to the body of evidence by identifying which structural and process factors may predict pre-hospital success by analyzing data from the largest sample of pre-hospital data available, the National Emergency Medical Services Information System (NEMSIS).

Generally, paramedic curricula require five intubations prior to graduation. It is not known if this standard is sufficient to prepare providers for the difficulties they may experience in the pre-hospital environment. Another consideration beyond initial pre-hospital ETI training is the maintenance of proficiency. The body of evidence highlights that many providers perform pre-hospital ETI on an infrequent basis. Wang, et al. (2006) showed that some paramedics may intubate as infrequently as once per year.

Wide variation was reported for pre-hospital ETI success rates ranging from 33% to 100% (Bulger, et al., 2007; Prekker, et al., 2014; Wang, et al., 2001; Wang, et al., 2006; Warner, et al., 2009). This may be explained in part by structure and process measures. Unfortunately, most studies that have researched pre-hospital ETI include heterogeneous populations, settings, and clinicians, obscuring the true pre-hospital ETI success rates for these subgroups. Many of the pre-hospital ETI studies are also small and underpowered, which may be especially problematic when the relatively small difference in success rates may be clinically relevant. As a complex intervention performed by operators with many different skill levels in different ways on different patient groups, the effect of pre-hospital ETI on outcomes of patients is difficult to assess.

Another limitation found in the literature was that most studies are conducted in single-service agencies. Data is not representative of an entire EMS system due to certain hospital being selected in a region. This prevents extrapolating results to other agencies and populations of patients. Information on post-intubation oxygenation, ventilation, circulation, and ultimate hospital outcomes are unfortunately lacking due to no linkages existing between pre-hospital and hospital data.

Most studies examining variables related to ETI success have done so in a descriptive manner or univariate fashion without quantifying or controlling for the effects of multiple factors. Another weakness in the literature is the use of self-reported data. In the context of retrospective and subjective reporting, paramedics may underreport adverse events and medical errors due to recall bias or for fear of getting into trouble.

Another challenge presented by the current body of evidence is the diversity of measures used to describe what constitutes high quality airway management. There is very little standardization among measures. Only one study reported the use of multiple imputation to handle the weakness of missing data (Bulger, et al., 2007). The proposed study will use multiple imputation to help reduce bias of the sample in the study.

Prekker, et al. 2014 used Donabedian's quality of care model to frame data collection and analysis. This study had many of the limitations inherent in the other studies including; a) retrospective design, b) lack of data about airway and ventilation management after ETI , c) lack of data about potential downstream complications of pre-hospital ETI and airway management, and d) no data about hospital-based patient outcomes post pre-hospital ETI. It is apparent that the optimal set of pre-hospital and hospital measures needed for assessing if high-quality airway management has been achieved has yet to be fully defined.

The current study contributes to the literature by being the first to use a national data set in the prediction of pre-hospital ETI. This study will be among the few studies that use Donabedian's quality of care model to frame the construction of research questions, data collection, and data analysis to assess which structural and process variables are most predictive of pre-hospital ETI success. A secondary outcome will be to determine if the data being collected by states and from states by NEMSIS is uniform, standardized, and of good quality.

CHAPTER III

METHODS

A detailed view of research methodology used in this retrospective exploratory study will be provided in this chapter. The purpose of this study was to construct a valid and reliable model that predicts pre-hospital ETI success. The research questions were:

RQ1. What variables representing structural factors (system characteristics, provider characteristics, and patient characteristics) predict pre-hospital ETI success?

RQ2. What variables representing process factors predict pre-hospital ETI success?

RQ3. Does the combination of structural measures and process measures add strength to the prediction of pre-hospital ETI success?

Research Design

A retrospective exploratory research design was used. The researchers collected data from existing databases, including NEMSIS and state EMS collection systems (Maine, Virginia, Illinois, and Utah), for purposes of constructing two predictive models. The Donabedian Quality of Care Model (1988), a conceptual model for assessing quality of care, was used to guide the selection of variables entered into the model.

A retrospective review of existing data was an appropriate approach for the conducted research. A retrospective study design uses an existing database and allows the researcher to formulate hypotheses about possible associations between an outcome and an exposure and to further investigate potential relationships. Preliminary measures of association are obtained to inform future studies and interventions (Hess, 2004). Exploratory research is the initial research used to learn more about little-known phenomena. It is an attempt to determine if what is being observed might be explained by currently existing theory (Davies, 2006). Causal statements of association should not be made as the result of conducting retrospective exploratory research.

Protection of Human Subjects

Before implementing any study related procedures, approval from Old Dominion University's College of Health Sciences Human Subjects Committee was sought and obtained. Exempt status was granted due to the retrospective nature of the study and the planned collection of de-identified human subjects' data.

Sampling

The sample was drawn from the 2013 NEMSIS Public Release Research Data Set, as well as, from state EMS data collection systems for Illinois, Maine, Virginia, and Utah. NEMSIS is a national repository that stores EMS data from participating states and U.S. territories. Participating state agencies submitting data to NEMSIS can be found in Table 1. Figure 4 shows states and territories that are submitting data to NEMSIS, actively working with NEMSIS, addressing barriers to NEMSIS, and states and territories who have limited progress with NEMSIS. Over 95% of states have some form of state EMS data collection system, with varying levels of sophistication in place. The sampling frame consisted of data retrieved from the NEMSIS database for all EMS patients who experienced pre-hospital ETI during the period of January 1, 2013 to December 31, 2013. The collected data was used for purposes of constructing a National Model. The state level sample was retrieved from Illinois, Maine, Virginia, and Utah and consisted of data for all patients who experienced pre-hospital ETI during January 1, 2013 to December 31, 2013. The collected data was used for purposes of constructing a Comprehensive State Model.

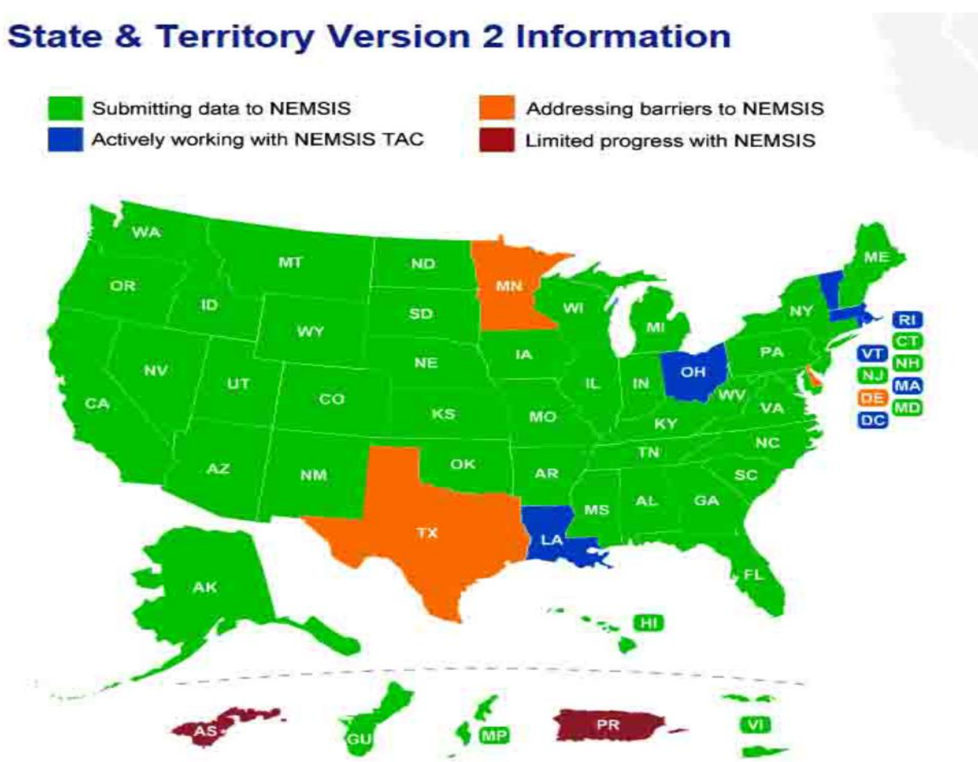
Table 1

Participating State EMS Agencies Submitting Data to NEMSIS

U.S. Census Region	State	% EMS Agencies in the State that Provide Data	Among Participating Agencies, What % of EMS Runs is Submitted?
Midwest	Illinois	52%	100%
Northeast	Maine	100%	100%
South	Virginia	100%	100%
West	Utah	100%	100%

Retrieved on October 20, 2014 from: http://www.nemsis.org/support/stateProgressReports/index.html

Figure 4. NEMSIS State and Territory Version 2 Information.



National Model Variables

Dependent Variable. The Donabedian Quality of Care Model allows for intermediate outcomes such as physiologic or biochemical values that precede and may lead to longer-range end result outcomes such as return to resumption of a) pre-event functional ability, b) recovery, and c) morbidity (Donabedian, 1980). Pre-hospital ETI success was the dependent variable or variable of interest. Pre-hospital ETI success was operationalized as whether the pre-hospital ETI performed on the patient was successful. Pre-hospital ETI success was measured as no success (0) and success (1).

Independent Variables

Structure Variables. The independent variables were derived from Donabedian's structural factors of a) system characteristics, b) provider characteristics, and c) patient characteristics (Donabedian, 1980). System characteristics include resources, accessibility, care design, geographic factors, administrative and staff organization, physical facilities, and equipment. Provider characteristics include demographics, education, and preferences (Donabedian, 1980). Patient characteristics are conceptualized as demographic characteristics such as gender, ethnicity, and diagnosis (Donabedian, 1980).

System Characteristics. System characteristics constructs were conceptualized as: a) type of service requested, b) primary role of unit, c) United States census region, d) urbanicity, and e) EMS total call time. The type of service requested was defined as the category of service requested of the EMS service responding for the specific EMS event (nominal variable). Type of service requested was measured by a) 911 response (30), b) intercept (35), c) interfacility transfer (40), d) medical transport (45), e) mutual aid (50), and f) standby (55). Primary role of unit was defined as the primary role of the EMS service requested for the specific EMS incident (nominal variable). Primary role of unit was measured as a) non-transport (60), b) rescue (65), c) supervisor (70), and d) transport (75). U.S. census region was defined as sub-national areas composed of states as defined by NEMSIS (nominal variable). U.S. census region was measured as a) Midwest (1), b) Northeast (2), c) South (3), d) West (4), and e) island areas (5). Urbanicity was defined as the degree to which qualities characterize a geographic area as a city (nominal variable) as defined by the United States Department of Agriculture (USDA) and Office of Management and Budget (OMB). Urbanicity was measured as a) urban (counties with large [more than 1 million residents] or small [less than 1 million residents] metropolitan areas) (1), b) suburban (micropolitan [with an urban core of at least 10,000 residents] counties adjacent to a large or small metropolitan area) (2), c) rural (non-urban core counties adjacent to large or small metropolitan area with or without a town (3), and d) wilderness (non-core counties that are adjacent to micropolitan counties with or without a town (4). EMS total call time was defined as total amount of time required for the EMS call in minutes (nominal variable). EMS total call time was recoded to include the following categories: a) 0-15 minutes (1), b) 16-30 minutes (2), c) 31-45minutes (3), d) 46-60 minutes (4), e) 61-90 minutes (5), f) 91-120 minutes (6), g) 121-150 minutes (7), h) 151-180 minutes (8), i) 181-210 minutes (9), j) 211-240 minutes (10), and k) 241+ minutes (11).

Provider Characteristics. Provider characteristics were conceptualized by the Center for Medicare and Medicaid Services (CMS) as defined by NEMSIS. CMS service levels were defined as CMS designated service levels for the specific EMS encounter (nominal variable. CMS service levels were defined as CMS designated service levels for the specific EMS encounter (nominal variable). CMS service levels were measured as: a) basic life support (1), b) advanced life support (2), c) paramedic intercept (3), d) specialty care transport (4), e) fixed wing airplane (5), and f) rotary wing helicopter (6).

Patient Characteristics. Data were collected on the following patient characteristics: a) gender, b) race, c) ethnicity, d) age, e) possible injury, f) chief complaint organ system, g) cardiac arrest, and h) cardiac arrest etiology. Gender was defined as the sex of the EMS patient (nominal variable). Gender was measured as male (1) and female (2). Race was defined as the patient's race as categorized by the OMB (nominal variable). Race was measured as a) American Indian or Alaskan Native (660), b) Asian (665), c) Black or African American (670), d) Native Hawaiian or other Pacific Islander (675), e) White (680), and f) other (685). Ethnicity was categorized by the OMB (nominal variable). Ethnicity was measured as Hispanic or Latino (690) and not Hispanic or Latino (695). Age was defined as patient's age calculated from date of birth or best approximation measured in years (nominal variable). Age was recoded to the following categories: a) 0-9 years of age (1), b) 10-19 years of age (2), c) 20-29 years of age (3), d) 30-39 years of age (4), e) 40-49 years of age (5), f) 50-59 years of age (6), g) 60-69 years of age (7), h) 70-79 years of age (8), i) 80-89 years of age (9), j) 90-99 years of age (10), k) 100+ years of age (11). Possible injury was defined as an indication of whether the EMS encounter was related to injury or traumatic event (nominal variable). Possible injury was measured as no injury (0) and injury (1). Chief complaint organ system was defined as the primary organ system of the patient injured or medically affected (nominal variable). Chief complaint organ system was measured as a) cardiovascular (1), b) CNS/neurological (2), c) global (3), d) other (4), and e) pulmonary (5). Cardiac arrest was defined as indication of cardiac arrest (heart attack) (nominal variable). Cardiac arrest was measured as a) no (0); b) yes, prior to EMS arrival (1); and c) yes, after EMS arrival (2). Cardiac arrest etiology was defined as etiology of the cardiac arrest (nominal variable). Cardiac arrest etiology was measured as a) presumed cardiac (1), b) trauma (2), c) drowning (3), d) respiratory (4), e) electrocution (5), and f) other (6).

Process Variables. Data for process variables were conceptualized by the following constructs: a) response mode to scene, b) transport mode from the scene, and c) the number of attempts required to perform pre-hospital ETI. Response mode to scene was defined as whether lights and sirens were used in route to the incident scene (nominal variable). Response mode to scene was measured as lights and sirens (1) and no lights and sirens (2). Transport mode from the scene was defined as whether lights and sirens were used in route from the incident scene to the emergency room (nominal variable). Transport mode from scene was measured as lights and sirens (1) and no lights and sirens (2). Number of attempts was defined as the number of attempts taken to complete a pre-hospital ETI regardless of success (nominal variable). Number of attempts was measured as a) one (1), b) two (2), and c) three or more attempts (3).

Comprehensive State Model Variables

Dependent Variable. Pre-hospital ETI success was the dependent variable or variable of interest. Pre-hospital ETI success was again operationalized as whether the pre-hospital ETI performed on the patient was successful. Pre-hospital ETI was measured as no success (0) and success (1).

Independent Variables

Structure Variables. The independent variables were derived from Donabedian's structural factors of a) system characteristics, b) provider characteristics, and c) patient characteristics (Donabedian, 1980).

System Characteristics. System characteristics included the following constructs: a) type of service requested, b) primary role of unit, and c) U.S. census region. The type of service requested was defined as the category of service requested of the EMS service responding for the specific EMS event (nominal variable). Type of service requested was measured by a) emergency response (30), b) interfacility transfer (40), c) intercept (35), d) medical transport (45), and e) mutual aid (50). Primary role of unit was defined as the primary role of the EMS service requested for the specific EMS incident (nominal variable). Primary role of unit was measured as a) non-transport (60), b) rescue (65), c) supervisor, and d) transport. U.S. census region was defined as sub-national areas represented by the location of the states (nominal variable). U.S. census region was measured as a) Midwest, b) Northeast, c) South, and d) West.

Provider Characteristics. Provider characteristics were guided by the Center for Medicare and Medicaid Services (CMS) service levels and provider certification levels as defined by NEMSIS. CMS service levels were defined as CMS designated service levels for the specific EMS encounter (nominal variable). CMS service levels were measured as a) advanced life support (1000, 1005, and 1010), b) basic life support (990 and 995), c) fixed wing (airplane) (1025), d) paramedic intercept (1015), e) rotary wing (helicopter) (1030), and f) specialty care transport (1020). Provider certification levels were defined as the licensing level of the prehospital care provider as defined by the state. Provider certification levels were measured by a) EMT-Basic (2), b) EMT-Advanced/Enhanced (1), c) EMT-Intermediate (3), d) EMT-Paramedic (4), and e) registered nurse/medical doctor/other (5).

Patient Characteristics. Additional data on patient characteristics were collected from the state datasets. Patient characteristics included a) gender, b) race, c) ethnicity, d) age, e) possible injury, f) chief complaint organ system, g) cardiac arrest, f) cardiac arrest etiology, g) first monitored cardiac rhythm of the patient, h) return of spontaneous circulation, i) systolic blood pressure, j) pulse rate, k) pulse oximetry, l) respiratory rate, and m) total Glasgow coma score. Gender was defined as the sex of the EMS patient (nominal variable). Gender was measured as a) male (1) or b) female (2). Race was defined as the patient's race as defined by the (OMB (nominal variable). Race was measured as a) Black or African American (670), b) Asian (665), c) other race (685), and d) White (680). Ethnicity was categorized by the OMB (nominal variable). Ethnicity was measured as Hispanic or Latino (690) and not Hispanic or Latino (695). Age was defined as the patient's age calculated from the date of birth in years (nominal variable). Age was recoded to the following categories: a) 0-9 years of age (1), b) 10-19 years of age (2), c) 20-29 years of age (3), d) 30-39 years of age (4), e) 40-49 years of age (5), f) 50-59 years of age (6), g) 60-69 years of age (7), h) 70-79 years of age (8), i) 80-89 years of age (9), j) 90-99 years of age (10), k) 100+ years of age (11).

Possible injury was defined as an indication of whether the EMS encounter was related to injury or traumatic event (nominal variable). Possible injury was measured as no injury (0) and injury (1). Chief complaint organ system was defined as the primary organ system of the patient injured or medically affected (nominal variable). Chief complaint organ system was measured as a) central nervous system/neurological (1355), b) cardiovascular (1350), c) global (1370), d) other (1405), and e) pulmonary (1390). Cardiac arrest was defined as indication of cardiac arrest (heart attack) (nominal variable). Cardiac arrest was measured as a) no (0), b) yes, prior to EMS arrival (2240), and c) yes, after EMS arrival (2245). Cardiac arrest etiology was defined as the cause of the cardiac arrest (nominal variable). Cardiac arrest etiology was measured as a) not applicable (0), b) other (2275), c) presumed cardiac (2250), d) respiratory (2285), and e) trauma (2255). First monitored cardiac rhythm was defined as the first cardiac rhythm present when a monitor or defibrillator was attached to the patient (nominal variable). First monitored cardiac rhythm of the patient was measured as a) asystole (1), b) bradycardia (2), c) normal sinus rhythm (3), d) other (4), e) paced rhythm (5), f) pulseless electrical activity (PEA) (6), g) unknown AED non-shockable rhythm (7), h) unknown AED shockable rhythm (8), i) ventricular fibrillation (9),

j) ventricular tachycardia (10). Return of spontaneous circulation was defined as a brief evidence of restored circulation (nominal variable). Return of spontaneous circulation was measured as a) no (0), b) yes, prior to EMS arrival (1), and c) yes, prior to EMS arrival and at the ED (2).

Patient vitals included as patient characteristics included systolic blood pressure, pulse rate, pulse oximetry, respiratory rate, and total Glasgow Coma Score. Systolic blood pressure was defined as the initial pressure in the patient's arteries recorded after placing a sphygmomanometer and measuring blood pressure (nominal variable). Systolic blood pressure was measured in millimeters of mercury (mmHG) and recoded to the following ranges: a) zero mmHG (0), b) < 5 mmHG (1), c) 50-75 mmHG (2), d) 76-119 mmHG (3), e) 120-139 mmHG (4), f) 140-189 mmHG (5), g) 190-219 mmHG (6), and h) 220+ mmHG (7). Pulse rate was defined as the patient's initial heart rate or pulse obtained from palpation or auscultation (nominal variable). Pulse rate was measured as the EMS patient's pulse rate per minute and recoded to the following ranges: a) zero (0), b) 1-59 (1), c) 60-99 (2), d) 100-149 (3), e) 150-199 (4), and f) 200+ (5). Pulse oximetry was defined as the patient's initial oxygen saturation (nominal variable). Pulse oximetry was measured as the EMS patient's oxygen saturation expressed as a percent and recoded to the following categories a) zero (0), b) 1-49 (1), c) 51-69 (2), d) 70-79 (3), e) 80-89 (4), and f) 90-100 (5). Respiratory rate was defined as the patient's initial ventilation rate (nominal variable). Respiratory rate was measured as the EMS patient's respiratory rate expressed as respirations per minute and recoded to the following ranges: a) zero (0), b) <5 (1), c) 5-11 (2), d) 12-20 (3), e) 21-30 (4), f) 31-40 (5), g) 41-50 (6), h) 51-60 (7), and i) 60+ (8). Total Glasgow coma score was defined as the patient's initial neurological state scored between three and 15, three being the worst, and 15 the best (nominal variable). Total

Glasgow Coma Score was measured on a scale of three to 15 and recoded to the following ranges: a) 3 (1), b) 4-5 (2), c) 6-8 (3), d) 9-12 (4), and e) 13-15 (5).

Process Variables. Data for process variables were conceptualized by the following constructs: a) response mode to scene, b) transport mode from the scene, and c) the number of attempts required to perform pre-hospital ETI. Response mode to scene was defined as whether lights and sirens were used in route to the incident scene (nominal variable). Response mode to scene was measured as lights and sirens (1) and no lights and sirens (2). Transport mode from the scene was defined as whether lights and sirens were used in route from the incident scene to the emergency room (nominal variable). Transport mode from scene was measured as lights and sirens (1) and no lights and sirens (2). Number of attempts was defined as the number of attempts taken to complete a pre-hospital ETI regardless of success (nominal variable). Number of attempts was measured as a) one (1), b) two (2), and c) three or more attempts (3).

Pilot Study

A pilot study was conducted to test a model designed to predict the probability of success of pre-hospital, non-drug assisted ETI performed by Virginia pre-hospital care providers (Diggs, et al., 2014). The retrospective observational study evaluated the success of pre-hospital, non-drug assisted ETI (N = 4002) performed by Virginia pre-hospital care providers, from January 1, 2012 to December 31, 2012. Data for the pilot study was obtained from the Virginia Department of Health Office of Emergency Medical Services.

For the pilot study, descriptive statistics were used to quantify structure variables, including system, provider, and patient characteristics. Pre-hospital ETI success rates were calculated by provider certification level and number of ETI attempts. Procedural complications were evaluated for the entire cohort. Variables were recoded for modeling purposes. Univariate analyses using chi-square tests were performed to identify candidate parameters to be included in the model. A backward stepwise logistic regression was performed to predict ETI success.

Community type (system characteristic), provider certification level (provider characteristic), and gender, age group, myocardial infarction, and ethnicity (patient characteristics) were all found to be significant predictors of pre-hospital ETI success ($p < 0.05$) in the model. The final model had a -2 log-likelihood value of 3705.574. This was the most parsimonious model evaluated. The final model demonstrated good fit (Hosmer-Lemeshow test $p = 0.646$) but poor discrimination (area under ROC curve = 0.595). The only modifiable factor in the pilot model was provider certification level suggesting that more advanced training of EMS personnel may improve the success rate. Equation 1 was derived from the model:

$$Logit\ (p) = .903 + .075\ ProviderCertification(1) - .189\ ProviderCertification(2) - .934\ ProviderCertification(3) - .011\ ProciderCertifcation(4) + .063\ AgeGroup(1) - .276\ AgeGroup(2) - .085\ AgeGroup(3) + .212\ AgeGroup(4) - .216\ Gender(1) - .068\ MyocardialInfarction(1) - .243\ MyocardialInfarction(2) + .634\ Ethnicity(1) + .418\ CommunityType(1) + .362\ CommunityType(2) + .469\ CommunityType(3) + .360\ CommunityType(4) \qquad (1)$$

Because this study was exploratory in nature, data were not split and internal model validation was not attempted. However, the model appeared to be statistically valid. The model was also adequately powered as there are more than 20 cases of intubation success for each of the six predictors in the final model. The results obtained via the pilot study led to the conclusion that a more sophisticated model could be built with a larger, more sophisticated data set, such as NEMSIS.

Data Management for the National Model

The National EMS Research Database is a set of relational tables. The database consists of 19 data files. STATA format was provided. All of the single-entry elements contained in the NEMSIS standard that have been approved for release are listed in the “Events” Table. The other 18 tables include elements for which multiple entry values are possible. The unique key in the database is the data element “EventID”, and it is used to match elements for each record contained in all of the other tables. The “Primary Key” (i.e., EventID) is the unique ID for each record contained in each table and can be used to match elements across the tables associated with the same EMS event.

Data from the following NEMSIS tables were needed for the current study: “Events Table,” “Procedures Table,” “Derived Table,” and “Geocodes Table.” Data reduction was performed to create a working data set. The orotracheal intubation procedure (ICD-9 Code 96.040) was extracted from the “Procedures Table.” There were 39,523,969 total procedure observations. The 89,034 orotracheal intubation observations were extracted. The data containing only orotracheal intubation observations was then searched for duplicates and sorted across all variables. The 4,566 duplicate observations were removed from the data resulting in 84,468 unduplicated observations of orotracheal intubation. One-hundred-eleven observations of attempts (e19_05) greater than four were deleted, resulting in 84,357 observations of orotracheal intubation. Data were then sorted by the variable eventID. A wide data set was created because some patients had more than one attempt of orotracheal intubation performed. The wide data contained 79,453 unique orotracheal intubation observations.

Attempts and successes were added across the three wide variables generating two new variables “attempts” and “success.” “Success” contains the total number of successes and non-successes for orotracheal intubations. "Attempts" contains the total number of attempts for each orotracheal intubation. Most orotracheal intubations were performed in six or fewer attempts. Three observations that required more than six attempts were removed from the dataset, leaving 79,450 orotracheal intubation observations. This will prevent the presence of blank cells in future calculations. The "Events Table," "Derived Table," and "Geocodes Table" were checked for duplicate observations. After removing duplicate observations, three 1:1 merges were performed with the new data set and each of the tables. All observations were matched. The final data set contained information for a total of 79,450 unique orotracheal intubation observations. Data was transferred to the Turing Cluster and RStudio in R version 3.2.0, "Full of Ingredients," statistical software for performing complex statistical analyses due to the size of the data set.

The imputation of missing values is especially important when pre-processing multivariate data. The naïve approach, namely omitting all observations that include at least one missing cell, is not attractive because a lot of valuable information may still be contained in these observations. When all observations that included at least one missing cell in the NEMSIS data were omitted, only 6,261 of 79,450 observations were left in the data set. The non-missing and original data were compared and showed great differences. Thus, imputation of the NEMSIS data set was necessary. Table 2 shows the number of missing values for each variable in the NEMSIS data set. Appendix B contains the descriptive statistics for the original non-imputed NEMSIS data set. Appendix C contains the descriptive statistics for the imputed NEMSIS data set.

Table 2

Number of Missing Observations in the NEMSIS Data Set

Variable	Class	# Missing
Type of Service Requested	Factor	0
Primary Role of Unit	Factor	0
Urbanicity	Factor	2,047
EMS Total Call Time	Numeric	197
US Census Region	Factor	0
CMS Service Level	Factor	32,063
Gender	Factor	692
Race	Factor	15,054
Ethnicity	Factor	22,226
Possible Injury	Factor	12,043
Chief Complaint Organ System	Factor	29,421
Cardiac Arrest	Factor	13,094
Cardiac Arrest Etiology	Factor	43,588
Age	Numeric	1,105
Attempts	Factor	5,518
Response to Scene	Factor	0
Transport from Scene	Factor	10,516
Success	Factor	12,580

Note: N=79,450

Imputation of National NEMSIS Data Set. A software tool in the R statistical software known as **irmi** was used to impute the national NEMSIS data set. Many challenges existed when imputing the NEMSIS data set including mixed types of variables in the data, both categorical and continuous variables, the large size of the data set, and that the data was far from a normal distribution. The algorithm called **irmi** for Iterative Robust Model-based Imputation has been implemented as function **irmi**( ) in the R package **VIM** and was used to impute the NEMSIS data set.

It was assumed that the data in the NEMSIS data set was missing at random, meaning that any systematic difference between the missing values and the observed values can be explained by difference in the observed data. **irmi** has several improvements over other imputation methods including improvements with respect to the stability of initialized values, or the robustness of imputed values. The algorithm does not require at least one fully observable variable. In each step of the iteration, one variable is used as a response variable and the remaining variables serve as the regressors, thus, the “whole” multivariable information was used for imputation in the response variable. The algorithm usually converges in a few iterations (Templ, Kowarik, & Filsmoser, 2011).

Data Management for the Comprehensive State Model

Data for the Comprehensive State Model was received in either STATA (.dta) or Excel (.xls) format. Data in .xls format was transferred into .dta format. Data was checked and rid of duplicates by the variable EventID. Categorical variables were converted to string and continuous variables were converted to float. Variables in each of the state data sets were placed in the same order. The data sets were then appended. There were 286 pre-hospital ETI observations from Maine (Northeast census region); 3,342 observations from Illinois (Midwest); 3,595 observations from Virginia (South), and 959 observations from Utah (West). This created a data set with a total of 8,182 non-drug facilitated pre-hospital ETIs. Variable categories were tabulated and recoded to the same values. The data set was then transferred to the Turing Cluster and RStudio in R version 3.2.0, “Full of Ingredients.” When all observations that included at least one missing cell in the state data were omitted, only 47 of 8,182 observations were left in the data set. The non-missing and original data were compared and showed great differences. Thus, imputation of the state data set was necessary. Table 3 shows the number of missing values for each variable in the state data set used for the Comprehensive State Model. Appendix D and Appendix E contain descriptive statistics for the original and imputed data sets.

Table 3

Number of Missing Observations in the Comprehensive State Data Set

Variable	Class	# Missing
Type of Service Requested	Factor	0
Primary Role of Unit	Factor	368
US Census Region	Factor	0
CMS Service Level	Factor	5,429
Provider's Certification Level	factor	977
Gender	factor	37
Race	factor	1,250
Ethnicity	factor	1,779
Possible Injury	factor	574
Chief Complaint Organ System	factor	2,529
Cardiac Arrest	factor	309
Cardiac Arrest Etiology	factor	2,513
First Monitored Cardiac Rhythm	factor	3,472
Response Level	factor	5,340
Return of Spontaneous Circulation	factor	2,833
Age	numeric	796
Systolic Blood Pressure	numeric	4,837
Pulse Rate	numeric	3,069
Pulse Ox	numeric	4,083
Respiratory Rate	numeric	3,271
Glasgow Coma Score	numeric	3,046
Attempts	factor	39
Response to Scene	factor	0
Transport from Scene	factor	1,144

Note: N = 8,182

Imputation of Comprehensive State Data Set. The state data set was imputed using "hot deck" imputation in the **VIM** R statistical package. State data missing mechanism was assumed to be "missing at random." Hot deck imputation replaces values from a randomly selected "similar" record. Hot deck in **VIM** implements the popular Sequential, Random (within a domain) hot deck algorithm for imputation.

Data Analysis for National and Comprehensive State Models

Descriptive statistics including frequency distributions for grouped data or categorical variables and central tendency (mean, median, and mode) and dispersion (range and standard deviation) of continuous variables were tabulated. Some of the variables contain the field values: not applicable (-25), not recorded (-20), not reporting (-15), not known (-10), and not available (-5). These field values were recoded to missing data. Descriptive statistics were performed in R to verify the results obtained in STATA.

In the NEMSIS data, approximately 1% of the data contained observations for EMS Total Call Time containing greater than 426 minutes. These outliers were recoded as missing. EMS Total Call Time was binned into 15 and 30 minutes increments. For both models, age was binned by increments of 10 and turned into a factor. In the state data set, systolic blood pressure, pulse rate, pulse ox, and respiratory rate were recoded from continuous to categorical values based on the Revised Trauma Score and normal physiologic values. Data was changed from continuous to categorical values to reduce skewness, eliminate outliers, and make the results more interpretable.

Data was split to create testing and training sets of data (Kuhn, 2013). Seventy percent of the data were used for model training and the other 30% of the data were used for evaluating model performance. The seed was set to “123.” The “sample” command was used in R. An index number was used to divide the dataset into training and testing data sets.

The variable of interest was pre-hospital ETI success, a binary categorical variable coded 0 or 1. Pearson’s chi-square tests were used to determine if the categorical predictors were related to the binary outcome, pre-hospital ETI success. Cramer’s V post-tests were then run to examine the strength of association between the independent variables and the dependent variable (Field, Miles, and Field, 2012).

According to Donabedian (1988), quality of care is best described as a linear model consisting of structure, process, and outcome. Due to the binary nature of the outcome variable, pre-hospital ETI success, and the hierarchical structure of the theory, a hierarchical multivariate logistic regression was used to estimate the probability of success or failure of the independent variables. Previous studies used hierarchical logistic regression to model data using Donabedian's Quality of Care Model (Kajonius and Kazemi, 2015; Truman, 2012; Yaffe, Laffan, Harrison, Redline, Spira, Ensrud, Ancoli-Israel, & Stone, 2011). The first block of independent variables entered into the analysis included the structure variables. The second block of independent variables entered into analysis included the process variables.

Logistic regression is classified as a generalized linear model (GLM). GLM provides a flexible framework to describe how a dependent variable can be explained by a range of explanatory variables (predictors). The dependent variable in logistic regression is discrete, and the explanatory variables can be quantitative (covariates) or categorical (factors). The model is assumed to have linear effects on some transformation of the dependent variable, defined by a link function, and the error distribution has a binomial shape (Fox, 2008).

To find the best logistic regression model, **glmulti**, an R package for automated model selection, was used. To summarize, **glmulti** is essentially a wrapper for **GLM**: it generates all possible model formulas (from specified effects and given some constraints), fits them with **GLM**, and returns the best models based on Aikake Information Criteria (AIC). The best model has the lowest AIC.

Glmulti produces model formulas and passes them to the **GLM** fitting function. The building blocks of the model have to be specified. By default, the intercept is included in all models. AIC was selected to compare models. Method "h" was used to produce all non-redundant formulas. **glmulti** then fits them and computes the AIC. For a predictor to be included in the model, an evidence weight of 80% is the minimum. These procedures were taken into account when preparing the data for analysis.

Wald tests were performed using the **aod** package to determine if the overall effect of each of the predictors was statistically significant. To assess the overall fit of the model, the likelihood ratio test was conducted. Multicollinearity was checked using variance inflation factor (VIF) statistics performed in the **car** package. The ROC curve for the training data was created using the **LogisticDX** package. PseudoR2s were calculated using the **BaylorEdPsych** package. Naglekerke's pseudo-R-squared was used to estimate how well the model predicts pre-hospital ETI success.

Cross-validation was conducted to assess how the results of the statistical analysis would generalize to an independent data set. The training data set was used to create the model. The testing data set was used to test the model to see how accurately it predicts. Receiver operating characteristic (ROC) curves were assessed (Kuhn, 2013). The area under the curve (AUC) measures discrimination or the ability of the test to correctly classify successful and unsuccessful pre-hospital ETIs. The AUC can range from 0.5 (no predictive ability) to 1 (perfect discrimination). A model is perfect at classifying observations if there is 100% sensitivity (true positive rate complementary to the false negative rate) and 100% specificity (true negative rate complementary to the false positive rate). This is difficult to obtain in practice.

Hypotheses and Statistical Methods

Due to the large number of hypotheses, the hypotheses are presented in an abbreviated manner. The hypothesized relationship of independent variables to pre-hospital ETI success is presented in Table 4.

Table 4

Hypothesized Relationships of Independent Variables to Pre-Hospital ETI Success

Variables	Hypothesized Relationship
Structure Variables	
System Characteristics	
Type of Service Requested	911 Response (Scene)
Primary Role of Unit	Rescue
USCensusDivision	Northeast
Urbanicity	Large Metropolitan Area
EMS Total Call Time	Fewer Minutes
Provider Characteristics	
Personnel Level of Certification	EMT-Paramedic
CMS Service Level	Fixed-wing/Rotary-wing
Patient Characteristics	
Age	Older
Gender	Male
Race	White
Ethnicity	Non-Hispanic
Possible Injury	No
Chief Complaint Organ System	Pulmonary
Cardiac Arrest	Yes
Cardiac Arrest Etiology	Presumed Cardiac
First Monitored Cardiac Rhythm*	PEA
ROSC*	No
Systolic Blood Pressure*	Lower
Pulse Rate*	Lower
Pulse Oximetry*	Lower
Respiratory Rate*	Lower
GCS (initial)*	Lower
Level of Responsiveness*	Unresponsive
Process Variables	
Number of Attempts	Fewer Attempts
Response Mode to Scene	Lights and Sirens
Transport Mode from Scene	Lights and Sirens

Note: * Variables Only Included in the Comprehensive State Model

RQ1. What variables representing structural factors (system characteristics, provider characteristics, and patient characteristics) predict pre-hospital ETI success? Bivariate Chi-square analysis and Cramer's Vs followed by multivariate logistic regression, comprising Block 1 of the hierarchical logistic regression, to test the predictive value of variables adjusted for one another, were used to evaluate the hypotheses.

Null Hypotheses: None of the variables will significantly predict pre-hospital ETI success when variables are adjusted for each other.

Alternate Hypotheses: Variables will significantly predict pre-hospital ETI success when adjusted for one another.

RQ2. What variables representing process factors predict pre-hospital ETI success? Bivariate Chi-square analysis and Cramer's Vs will be used to evaluate the hypotheses followed by multivariate logistic regression to test the predictive value of variables adjusted for one another.

Null Hypotheses: None of the variables will significantly predict pre-hospital ETI success.

Alternate Hypotheses: Variables will significantly predict pre-hospital ETI success.

RQ3. Does the combination of structural measures and process measures add strength to the prediction of pre-hospital ETI success? Bivariate Chi-square analysis and Cramer's Vs followed by multivariate hierarchical logistic regression (the addition of block two variables) was used to test the predictive value of the variables adjusted for one another.

Null Hypotheses: None of the variables will significantly predict pre-hospital ETI success when variables are adjusted for each other.

Alternate Hypotheses: Variables will significantly predict pre-hospital ETI success when adjusted for one another.

CHAPTER IV

RESULTS

Donabedian's Quality of Care Model was used to frame the research questions regarding the predictive nature of patient care. Structural and process variables are related to pre-hospital ETI success. The research questions were:

RQ1: What variables representing structural measures predict pre-hospital ETI success?

RQ2: What variables representing process measures predict ETI success?

RQ3: Does the combination of structural measures and process measures add strength to the prediction of pre-hospital ETI?

This chapter presents the results of the statistical analysis of data; results from the National and Comprehensive models. For each model, a general summary of the data and descriptive statistics are first presented, then, the results of the analysis of data for each research question are presented. The chapter concludes with bivariate hypotheses.

All data were analyzed using RStudio in R version 3.2.0, "Full of Ingredients." Two sets of analyses were performed for both the national and state datasets. Tables 5 and 11 provide descriptive statistics for the variables of the national and state imputed training data variables. Descriptive statistics for the original (See Appendix B) and imputed (See Appendix C) NEMSIS data sets can be found in Appendices. Descriptive statistics for the original (See Appendix D) and imputed (See Appendix E) state data sets can also be found in the Appendices. Continuous independent variables were categorized in order to reduce skewness and eliminate outliers. Assumptions for the use of hierarchical logistic regression were met, and tests were selected as an acceptable method for evaluation of prediction of pre-hospital ETI success.

National Model

Descriptive Statistics.

Structure Variables. Emergency or 9-1-1 response (92%) was the predominant type of service requested. The primary role of the unit was mostly transport (92%). The majority of data was collected in the South census region (39%) and originated from urban areas (80%). The majority of pre-hospital calls (89%) were advanced life-saving (ALS) as determined by the Center for Medicare and Medicaid Services. The majority of EMS total times ranged from 61 to 90 minutes (36%). The majority of patients were male (60%). The racial majority was White (74%) and not of Hispanic or Latino ethnicity (94%). Most patients did not sustain an injury (84%). The most common chief complaint organ system was cardiovascular (50%) followed by global complaints (24%). Most patients (54%) suffered a cardiac arrest before EMS arrived on the scene. The predominant etiology of cardiac arrests was presumed to be cardiac (67%). Age of patients ranged from less than one year of age to over 100 years of age. A significant number of patients were 100 years or older (19%) followed by those 80 to 89 years of age (18%). Table 5 presents the descriptive statistics for the imputed national training data set used for modeling purposes.

Process Variables. The majority of ambulances responded to the scene (89%) and transported patients to the hospital (79%) using lights and sirens. Eighty-four percent of pre-hospital ETIs were completed in one attempt. See Table 5.

Outcome Variable. The national pre-hospital ETI rate was almost 79%. Tables 5 provides descriptive statistics for the imputed national training data set which was used to run the data analyses.

Table 5

National Model: Descriptive Analysis of Variables

Variable	Category	N	Percent
Type of Service Requested	911 response (scene)	51,327	92.29
	Intercept	642	1.15
	Interfacility transport	2,710	4.87
	Medical transport	777	1.40
	Mutual aid	131	0.24
	Standby	28	0.05
Primary Role of Unit	Non-transport	3,893	7.00
	Rescue	588	1.06
	Supervisor	114	0.20
	Transport	51,020	91.74
US Census Region	Northeast	15,329	27.56
	Midwest	11,556	20.78
	South	21,850	39.29
	West	6,785	12.20
	Island Areas	95	0.17
Urbanicity	Urban	44,316	79.68
	Suburban	4,320	7.77
	Rural	5,873	10.56
	Wilderness	1,106	1.99
CMS Service Level	BLS	1,322	2.38
	ALS	49,710	89.38
	Paramedic intercept	157	0.28
	Specialty care transport	639	1.15
	Fixed wing (airplane)	99	0.18
	Rotary wing (helicopter)	3,688	6.63
EMS Total Call Time (minutes)	0-15	184	0.33
	16-30	1,332	2.40
	31-45	4,999	8.99
	46-60	9,209	16.56
	61-90	19,944	35.86
	91-120	10,526	18.94
	121-150	4,493	8.08
	151-180	1,895	3.41
	181-210	945	1.70
	211-240	545	0.98
	241+	1,533	2.76

Table 5

Continued

Variable	Category	N	Percent
Gender	Male	33,702	60.00
	Female	21,913	39.40
Race	American Indian or Alaskan Native	476	0.86
	Asian	888	1.60
	Black or African American	10,634	19.12
	Native Hawaiian or Other Pacific Islander	416	0.75
	White	40,952	73.63
	Other race	2,249	4.04
Ethnicity	Hispanic or Latino	3,537	6.36
	Not Hispanic or Latino	52,078	93.64
Possible Injury	No	46,573	83.74
	Yes	9,042	16.26
Chief Complaint Organ System	Cardiovascular	28,015	50.37
	CNS/Neuro	6,331	11.38
	Global	13,475	24.23
	Other	686	3.75
	Pulmonary	5,708	10.26
Cardiac Arrest	No	19,216	34.55
	Yes, prior to EMS arrival	30,122	54.16
	Yes, after EMS arrival	6,277	11.29
Cardiac Arrest Etiology	Presumed cardiac	37,504	67.44
	Trauma	4,790	8.61
	Drowning	471	0.85
	Respiratory	7,668	13.79
	Electrocution	82	0.15
	Other	5,100	9.17
Age (in years)	0-9	574	1.03
	10-19	132	0.24
	20-29	539	0.97
	30-39	2,898	5.21
	40-49	3,114	5.60
	50-59	3,568	6.42
	60-69	6,249	11.24
	70-79	9,117	16.39
	80-89	9,843	17.70
	90-99	9,003	16.19
	100+	10,578	19.02

Table 5

Continued

Variable	Category	N	Percent
Response to Scene	Lights and Sirens	49,530	89.06
	No Lights and Sirens	6,085	10.94
Transport from Scene	Lights and Sirens	44,134	79.36
	No Lights and Sirens	11,481	20.64
Number of ETI Attempts	1	46,480	83.57
	2	7.596	13.66
	$\geq$3	1,539	2.77
Pre-hospital ETI Success	No	11,682	21.02
	Yes	43,923	78.98

Note: N = 55,615; CMS = Center for Medicare and Medicaid Services; BLS = Basic Life Support; ALS = Advanced Life Support

Data Analysis Approach for Research Questions

Bivariate analyses were performed as preparation for multivariate analyses. Multivariate results for the dependent variable, pre-hospital ETI success, follow the bivariate results. Chi-square tests provide omnibus results and were performed for purposes of dichotomous comparisons. Post-hoc tests conducted to factor out sample size and measure the strength of the relationship or effect size between two nominal variables included phi (performed on variables with two levels) and Cramer's *V* (performed on variables with more than two levels). To answer RQ1, multivariate analysis was done. Variables entered into the first block of the hierarchical logistic regression model included: a) type of service requested, b) U.S. census region, c) EMS total call time, d) CMS service level, e) race, f) age, and g) chief complaint organ system. This procedure allowed for the adjustment of each independent variable and provided odds ratios and levels of significance. Results for RQ2 include multivariate analysis of the process variables: a) number of attempts, b) response mode to scene, and c) transport mode from scene in the prediction of pre-hospital ETI. The bivariate results from RQ2 allowed us to determine which variables should be included in the second block of the hierarchical logistic regression model. Results for RQ3 contain Block 1 with the addition of Block 2 hierarchical logistic regression multivariate results.

RQ1. What variables representing structural measures predict pre-hospital ETI success?

Bivariate Analysis of Structure Variables. Table 6 displays results of the chi-square analysis and phi and Cramer's V post-tests for independent variables and the dependent variable, pre-hospital ETI success. Variables significantly associated with pre-hospital ETI included: a) time, f) CMS service level, g) gender, h) race, i) age, j) cardiac arrest, k) cardiac arrest etiology, l) chief complaint organ system, and m) injury. Ethnicity was not associated with pre-hospital ETI success, x^2 (1, N = 55,615) = 3.31, p = .069. Because large sample sizes can make the insignificant significant, phi and Cramer's *V* were performed post-hoc to measure the strength of the relationship between the independent and dependent variables. Post-hoc analysis revealed that U.S. census region, x^2 (4, N=55,615) = 938.60, p < .001, ϕ_c = .128, and chief compliant organ system, x^2 (4, N=55,615) = 799.70, p < . 001, ϕ_c = .120, were most closely associated with pre-hospital ETI success.

Table 6

National Model: Bivariate Analysis of Structure Variables and Pre-hospital ETI Success

Variable	Category	N	Success	Success Percent	x^2 test statistic	df	*p*-value	φ_c or Cramer's V
Type of Service Requested	911 response (scene)	51,327	40,132	78%	307.88	5	< .001	.074
	Intercept	642	508	79%				
	Interfacility transport	2,710	2,461	91%				
	Medical transport	777	701	90%				
	Mutual aid	131	99	76%				
	Standby	28	22	78%				
Primary Role of Unit	Non-transport	3,893	3,173	82%	20.08	3	.000	.021
	Rescue	588	455	77%				
	Supervisor	114	82	72%				
	Transport	51,020	40,213	79%				
Urbanicity	Urban	44,316	34,915	79%	19.31	3	.000	.018
	Suburban	4,320	3,376	78%				
	Rural	5,873	4,748	80%				
	Wilderness	1,106	884	80%				
US Census Region	Northeast	15,329	13,026	85%	938.60	4	< .001	.128
	Midwest	11,556	8,186	71%				
	South	21,850	16,918	77%				
	West	6,785	5,710	84%				
	Island Areas	95	83	87%				
EMS Total Call Time	0-15	184	133	72%	510..17	10	< .001	.072
	16-30	1,332	844	63%				
	31-45	4,999	3,939	79%				
	46-60	9,209	7,435	81%				
	61-90	19,944	15,732	79%				
	91-120	10,526	8,075	77%				
	121-150	4,493	3,506	78%				
	151-180	1,895	1,531	81%				
	181-210	945	819	87%				
	211-240	545	475	87%				
	241+	1,533	1,434	93.5%				
CMS Service Level	BLS	1,322	1,130	85%	388.02	5	< .001	.083
	ALS	49,710	38,733	78%				
	Paramedic intercept	157	94	60%				
	Specialty care transport	639	567	89%				
	Fixed wing (airplane)	99	94	95%				
	Rotary wing	3,688	3,300	89%				

Table 6

Continued

Variable	Category	N	Success	Success Percent	$x2$ test statistic	df	*p*-value	φc or Cramer's V
Gender	Male	33,702	26,381	78%	25.11	1	< .001	.021
	Female	21,913	17,542	80%				
Race	American Indian or Alaskan Native	476	410		706.51	5	< .001	.111
	Asian	888	765	86%				
	Black or African American	10,634	7,490	70%				
	Native Hawaiian or Other Pacific Islander	416	397	95%				
	White	40,952	33,119	80%				
	Other race	2,249	1,742	77%				
Ethnicity	Hispanic or Latino	3,537	2,876	81%	3.31	1	.069	
	Not Hispanic or Latino	52,078	41,047	79%				
Age	0-9	574	470	82%	287.8	10	< .001	.072
	10-19	132	103	78%				
	20-29	539	452	83%				
	30-39	2,898	2,327	80%				
	40-49	3,114	2,445	84%				
	50-59	3,568	2,737	77%				
	60-69	6,249	4,698	75%				
	70-79	9,117	6,927	76%				
	80-89	9,843	7,632	78%				
	90-99	9,003	7,329	81%				
	100+	10,578	8,803	83%				
Cardiac Arrest	No	19,216	15,536	81%	62.27	2	< .001	.033
	Yes, prior to EMS arrival	30,122	23,507	78%				
	Yes, after EMS arrival	6,277	4,880	78%				
Cardiac Etiology	Presumed cardiac	37,504	29,502	79%	18.26	5	.002	.018
	Trauma	4,790	3,823	80%				
	Drowning	471	363	77%				
	Respiratory	7,668	6,168	80%				
	Electrocutio n	82	70	85%				
	Other	5,100	3,997	78%				

Table 6

Continued

Variable	Category	N	Success	Success Percent	$x2$ test statistic	df	*p*-value	φc or Cramer's V
Chief Complaint Organ System	Cardiovascular	28,015	22,888	82%	799.70	4	< .001	.120
	CNS/Neuro	6,331	5,145	81%				
	Global	13,475	9,477	70%				
	Other	2,086	1,672	80%				
	Pulmonary	5,708	4,741	83%				
Possible Injury	No	46,573	36,861	79%	5.64	1	.018	.010
	Yes	9,042	7,062	78%				

Note. N = 55,516. df = degrees of freedom, CMS = Center for Medicare and Medicaid Services; BLS = Basic Life Support; ALS = Advanced Life Support; EMS = Emergency Medical Services; CNS = Central Nervous System, Neuro = Neurological

Multivariate Analysis of Block 1.

Multivariate Logistic Regression Model. Logistic regression was conducted to assess how well the structure variables predicted pre-hospital ETI success. Variables with a Cramer's V over 0.077 were included in the hierarchical logistic regression model. The structure variables included system, provider and patient characteristics. System variables used in the multivariate analysis included: a) type of service requested, b) U.S. census region, and c) EMS total call time. CMS service level was the provider characteristic included in the multivariable analysis. Patient characteristics for multivariate analysis included: a) race, b) age group, and c) chief complaint organ system. All of these structure variables comprised Block 1 of the hierarchical logistic regression model. Table 7 provides results for Block 1 of the multivariate hierarchical logistic regression model.

Table 7

National Model: Block 1 Multivariate Analysis of Structure Variables.

Variable	Category	B	S.E.	Wald	*p*-Value	Exp B	95% CI Lower	95% CI Upper
Intercept		1.358	.409	3.321	.001***	3.889	1.785	8.938
Type of Service Requested	911 Response	Referent						
	Intercept	0.112	.103	1.086	.278	1.118	0.971	1.373
	Interfacility transfer	0.686	.078	8.829	<.001***	1.990	1.708	2.317
	Medical Transport	0.784	.126	6.248	<.001***	2.191	1.724	2.822
	Mutual Aid	0.118	.232	0.509	.611	1.125	0.727	1.810
	Standby	0.409	.494	0.829	.406	1.506	0.622	4.490
US Census Region	Island Areas	Referent						
	Midwest	-0.275	.337	-0.814	.416	0.760	0.376	1.428
	Northeast	0.534	.337	1.584	.113	1.706	0.845	3.208
	South	0.083	.337	0.346	.806	1.086	0.538	2.040
	West	0.329	.338	0.976	.329	1.391	0.687	2.617
EMS Total Call Time (minutes)	0-15	Referent						
	16-30	-0.443	.175	-2.524	.012*	0.642	0.452	0.900
	31-45	0.188	.169	1.111	.266	1.207	0.860	1.671
	46-60	0.300	.168	1.790	.073	1.350	0.964	1.863
	61-90	0.159	.166	0.959	.337	1.173	0.839	1.615
	91-120	0.085	.167	0.511	.609	1.089	0.779	1.501
	121-150	0.109	.170	0.644	.519	1.115	0.794	1.545
	151-180	0.270	.176	1.537	.124	1.311	0.922	1.841
	181-210	0.653	.194	3.371	.001***	1.922	1.308	2.800
	211-240	0.653	.209	2.224	.026*	1.592	1.054	2.394
	241+	0.465	.197	6.250	<.001***	3.442	2.326	5.057
CMS Service Level	ALS	Referent						
	Airplane	0.256	.402	0.639	.523	1.292	0.631	3.119
	BLS	0.813	.085	9.613	<.001***	2.255	1.916	2.669
	Helicopter	0.786	.061	12.981	<.001***	2.195	1.952	2.475
	Paramedic Intercept	-0.529	.187	-2.840	.005**	0.589	0.410	0.853
	Specialty Care Transport	0.531	.137	3.873	.000***	1.701	1.308	2.242
Race	American Indian/Alaska Native	Referent						
	Asian	-0.143	.162	-0.884	.377	0.867	0.629	1.187
	Black	-0.737	.132	-5.575	<.001***	0.479	0.367	0.616
	Native Hawaiian/Pacific Islander	1.129	.281	4.010	<.001***	3.092	1.819	5.516
	White	-0.308	.131	-2.357	.018*	0.735	0.564	0.943
	Other	-0.478	.140	-3.418	.001***	0.620	0.268	0.811

Table 7

Continued

Variable	Category	B	S.E.	Wald	*p*-Value	Exp B	95% CI Lower	95% CI Upper
Age	1-19	Referent						
	20-29	0.130	.151	0.865	.387	1.139	0.848	1.534
	30-39	0.239	.111	2.151	.031*	1.270	1.019	1.576
	40-49	0.158	.109	1.443	.149	1.172	0.942	1.451
	50-59	0.024	.108	0.221	.825	1.024	0.826	1.263
	60-69	-0.011	.104	-0.106	.916	0.989	0.803	1.211
	70-79	-0.033	.103	-0.318	.751	0.968	0.788	1.182
	80-89	0.042	.103	0.409	.683	1.043	0.849	1.274
	90-99	0.333	.104	3.191	.001**	1.395	1.134	1.707
	100+	0.462	.104	4.441	<.001***	1.588	1.291	1.942
Chief Complaint Organ System	Cardiovascular	Referent						
	CNS/Neuro	-0.309	.038	-8.062	<.001***	0.734	0.681	0.792
	Global	-0.564	.025	-22.262	<.001***	0.568	0.541	0.597
	Other	-0.332	.060	-5.561	<.001***	0.717	0.639	0.807
	Pulmonary	-0.067	.040	-1.116	.096	0.935	0.865	1.103

Note: B = Coefficient, S.E. = Standard Error, CI = Confidence Interval, CNS = Central Nervous System, Neuro = Neurological, (*p at .01 ** p at .001 *** p at 0)

Results of Multivariate Logistic Regression Model. When considered together, structure variables significantly predicted pre-hospital ETI success x^2 = (42, N = 55,615) = 3297.791. The log likelihood statistic was -26,996.76 (df = 43). The AIC of the model was 54,080. The Durbin-Watson test statistic was 1.8 (acceptable range is 1.5-2.5) suggesting no serial correlation among residuals. The VIF statistics for predictor variables included: a) type of service requested [x^2 (5) = 1,326], b) US census region [x^2 (4) = 1.244], c) EMS total call time [x^2 (10) = 1.195], d) CMS service level [x^2 (5) = 1.402], e) race [x^2 (5) = 1.180], f) age [x^2 (9) = 1.106], and g) chief complaint organ system [x^2 (4) = 1.188]. VIF statistics were close to 1 and suggested no multicollinearity among predictors. The Wald test results included the following: a) type of service requested [x^2 (5) = 111.5, p = .000], b) US census region [x^2 (4) = 677.3, p = .000], c) EMS total call time [x^2 (10) = 271.3, p = .000], d) CMS service level [x^2 (5) = 271.7, p = .000], e) race [x^2 (5) = 326.2, p = .000], f) age [x^2 = 289.7, p = .000], and g) chief complaint organ system [x^2 (4) = 519.9, p = .000]. The results of the Wald tests were all significant, suggesting all predictors should be included in the model. Nagelkereke's pseudo R2 was .0895 suggesting approximately 9% of variance was explained by the structural variable model. Cross-validation was conducted to assess how the results of the statistical analysis generalize to an independent data set. The ROC curve for the training set can be found in Figure 5 and for the testing set in Figure 6. The curves appear similar suggesting the results will generalize to an independent data set.

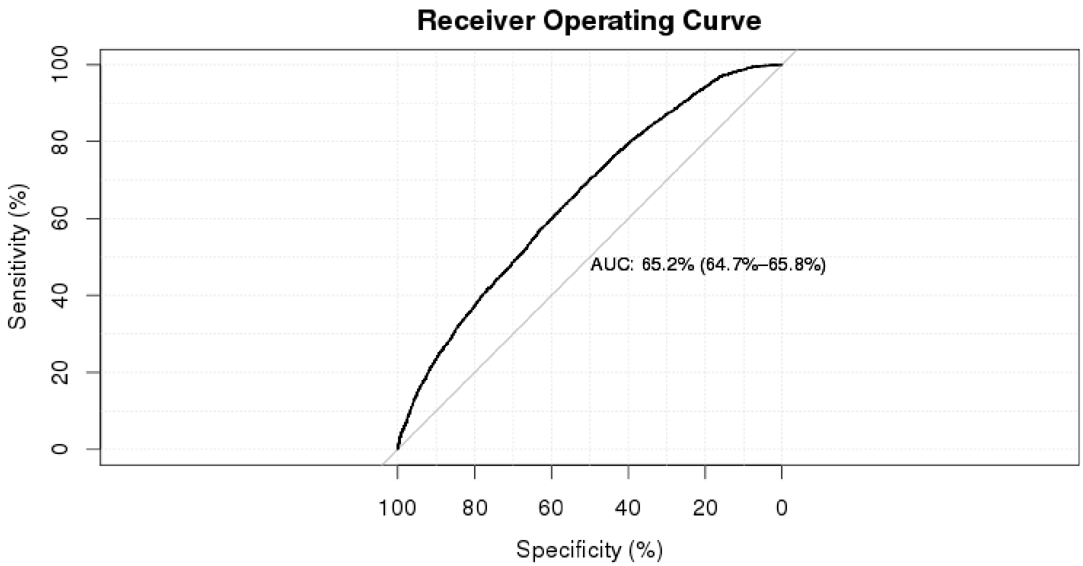


Figure 5. National Model ROC Curve for Block 1 Training Data Set.

The AUC in this figure is 65.2 and is poor at separating success from no success. For this model, the ROC curve deviates from the 45-degree diagonal to the upper left corner, so the model aids in prediction of success.

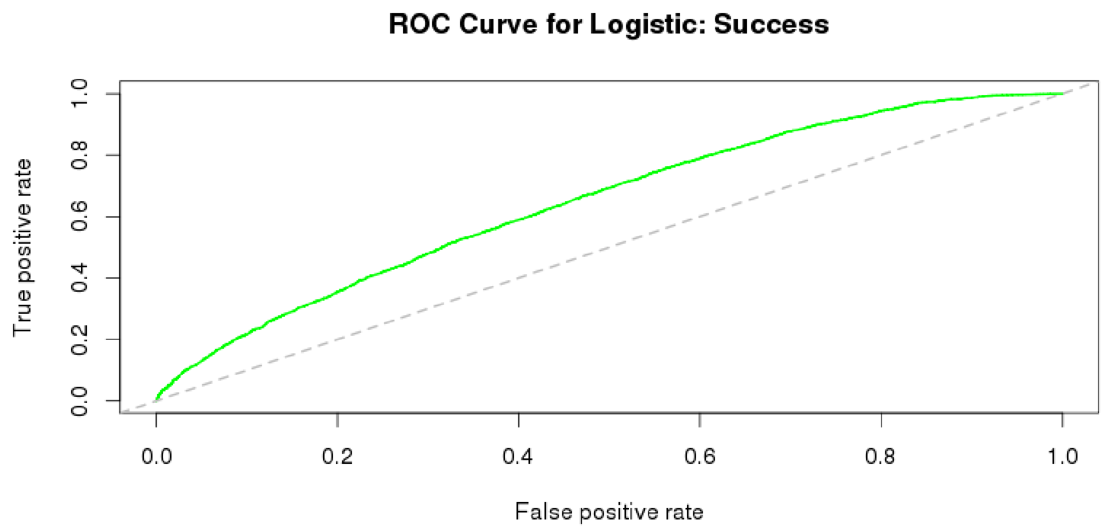


Figure 6. National Model *ROC* curve for Block 1 Testing Data Set.

In this ROC curve, if the false positive rate is 0.4, the true positive rate is 0.6. If you pick a line of determination for your false positive rate and move it to the left, such as from 0.4 to 0.2, the area under the curve increases giving you a greater number of true positives or greater sensitivity.

The logistic regression for pre-hospital ETI success suggests the odds of success are:

- higher for interfacility transfer (OR = 1.9) and medical transport (OR= 2.2) than 911 response when looking at type of service requested
- lower when EMS total call times average 16-30 minutes (OR = 0.6) compared to 0-15 minutes
- higher when EMS total call times range from 181-210 minutes (OR = 1.9), 211-241 minutes (OR = 1.6), and 241+ minutes compared to 0-15 minutes
- higher for BLS (OR = 2.3), helicopter (OR = 2.2), and specialty care transport (OR = 1.7) compared to ALS service level
- lower for paramedic intercept (OR = 0.6) than for ALS service level

- lower for Black or African American (OR = 0.5), White (0.7), and other (OR=0.6) races compared to American Indian and Alaska Native race
- higher for Native Hawaiian/Pacific Islander (OR = 3.1) race compared to American Indian and Alaska Native race
- higher for age groups 30-39 (OR = 1.3), 90-99 (OR = 1.4), and 100+ (OR = 1.6) than for those in the 1-19 year of age group
- lower for CNS/Neuro (OR = 0.7), Global (OR = 0.5), and Other (OR = .6) chief complaints compared to cardiovascular complaints.

RQ2. What variables representing process measures predict pre-hospital ETI success?

Bivariate Analysis of National Process Variables. Table 8 displays results of the chi-square and post-hoc analysis (i.e. phi and Cramer's *V*) for independent variables and the dependent variable, pre-hospital ETI success. Number of attempts, response mode to scene, and transport mode from scene were significant with pre-hospital ETI success at the < .001 significance level (See Table 8). The phi tests revealed that both response mode to scene, x^2 (1, N = 55,615) = 243.48, p = < .001, $\phi_c = .066$, and transport mode from scene, x^2 (1, N = 55,615) = 243.48, p = < .001, $\phi_c = .043$, had very low strengths of association with prehospital ETI success. Cramer's *V* revealed that the variable attempts (x^2 (1, N= 55,615) = 101.04, p < .001, $\phi_c = .092$ had the strongest association out of the three process variables (See Table 8).

Table 8

National Model Bivariate Analysis of Process Variables and ETI Success

Variable	Category	N	Success	Success Percent	*x*2 test statistic	df	*p*-value	φc or Cramer's V
Number of Attempts	1	46,480	37,468	81%	470.15	2	< .001	.092
	2	7.596	5,466	72%				
	>3	1,539	989	64%				
Response Mode to Scene	Lights and Sirens	49,530	38,655	78%	243.48	1	< .001	.066
	No Lights and Sirens	6,085	5,268	87%				
Transport Mode from Scene	Lights and Sirens	44,134	34,437	78%	101.04	1	< .001	.043
	No Lights and Sirens	11,481	9,486	83%				

df = Degrees of Freedom

Multivariate Analysis of National Process Variables

Multivariate Logistic Regression Model. Logistic regression was conducted to determine how well the process variables predicted pre-hospital ETI success. Variables that were significant with pre-hospital ETI success were included in the logistic regression model to answer RQ2. The process variables entered into the multivariate model included: a) attempts, b) response mode to scene, and c) transport model from scene. This procedure allowed for the adjustment of each of the independent variables and provided odds ratios and levels of significance. Table 9 provides results of the multivariate logistic regression analysis.

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Table 9

National Model: Multivariate Analysis of Process Variables

Variable	Category	B	S.E.	Wald	p-Value	Exp B	95% CI Lower	95% CI Upper
Intercept		1.346	.013	104.840	<.001***	3.844	3.749	3.942
Number of Attempts	1	Referent						
	2	-0.473	.028	-16.796	<.001***	0.622	0.590	0.658
	$\geq$3	-0.852	.055	-15.571	<.001***	0.426	0.383	0.475
Response Mode to Scene	Lights and Sirens	Referent						
	No Lights and Sirens	0.525	.042	12.642	<.001***	1.691	1.559	1.835
Transport Mode from Scene	Lights and Sirens	Referent						
	No Lights and Sirens	0.150	.029	5.177	<.001***	1.162	1.098	1.230

Note: B = Coefficient, S.E. = Standard Error, CI = Confidence Interval (*p at .01 ** p at .001 *** p at 0)

Results of Multivariate Regression Model. When considered together, process variables significantly predicted pre-hospital ETI success, x^2 (4, N = 55,615) = 747.421, p < .001. The AIC of the model was 56,454. The log likelihood of the model was -28,227.01. The Durbin-Watson test statistic was 1.670, suggesting no serial correlation among residuals. The VIF statistics for predictor variables included: a) number of attempts [x^2 (2) = 1.001], b) response mode to scene [x^2 (1) = 1.118], c) transport mode from scene [x^2 (1) = 1.117]. VIF statistics were close to one and suggested no multi-collinearity among predictors. The Wald test results included the following: a) number of attempts [x^2 (2) = 481.6, p=.000], b) response mode to scene [x^2 (1) = 159.8, p < .001], and c) transport mode from scene [x^2 (1) = 26.8, p < .001]. The results of the Wald tests were all significant, suggesting all predictors should be included in the model. Nagelkerke's pseudo R2 was .002, suggesting approximately 2% of variance was explained by the process model.

The logistic regression for pre-hospital ETI success suggests the odds of success are:

- lower when two attempts (OR = 0.62) or three attempts (OR 0.43) are attempted at ETI when compared to one attempt
- higher when no lights and sirens (OR = 1.161) are used during response to scene compared to when lights and sirens are used on response to scene
- higher when no lights and sirens (OR=1.69) are used during transport from scene compared to when lights and sirens are used during transport from scene

RQ3. Does the combination of structural measures and process measures add strength to the prediction of pre-hospital ETI success?

Multivariate Analysis of Block 1and Block 2. Hierarchical logistic regression was conducted to assess if the structure and process variables together better predict ETI success. System variables used in the first block of the multivariate analysis included: a) type of service requested, b) U.S. census region, c) EMS total call time, d) CMS service level, d) race, e) age group, and f) chief complaint organ system. The process variable included in the second block of the hierarchical logistic regression was the number of pre-hospital ETI attempts, x^2 (2, N=55,615) = 101.04, $p < .001$, $\phi_c = .092$. Table 10 provides results for the two blocks of structure and process variables together for predicting pre-hospital ETI success.

Table 10

National Model: Block 1 and Block 2 Multivariate Analysis.

Variable	Category	B	S.E.	Wald	*p*-Value	Exp B	95% CI Lower	95% CI Upper
Intercept		1.782	.397	4.486	<.001***	5.947	2.797	13.390
Type of Service Requested	911 Response	Referent						
	Intercept	0.032	.103	.305	.760	1.032	0.845	1.268
	Interfacility transfer	0.603	.076	7.983	<.001***	1.828	1.579	2.214
	Medical Transport	0.855	.125	6.819	<.001***	2.353	1.852	3.032
	Mutual Aid	-0.237	.209	1.134	.256	0.789	0.530	1.204
	Standby	-.134	.468	0.296	.775	0.875	0.371	2.404
US Census Region	Island Areas	Referent						
	Midwest	-0.447	.332	1.344	.179	0.639	0.319	1.189
	Northeast	0.382	.333	1.148	.250	1.465	0.731	2.726
	South	-0.113	.332	0.339	.735	0.894	0.446	1.660
	West	0.156	.333	0.469	.639	1.169	0.582	2.177
EMS Total Call Time (minutes)	0-15	Referent						
	16-30	1.317	.181	1.760	.078	0.728	0.507	1.031
	31-45	0.216	.174	1.236	.216	1.241	0.875	1.735
	46-60	0.300	.173	1.738	.082	1.350	0.955	1.882
	61-90	0.232	.172	1.349	.177	1.261	0.893	1.753
	91-120	0.128	.172	0.745	.456	1.137	0.805	1.583
	121-150	0.167	.174	0.956	.117	1.182	0.833	1.654
	151-180	0.283	.181	1.567	.339	1.328	0.925	1.883
	181-210	0.639	.197	3.242	.001**	1.895	1.281	2.779
	211-240	0.626	.216	2.895	.004**	1.870	1.221	2.854
	241+	1.131	.202	6.502	<.001***	3.723	2.494	5.517
CMS Service Level	ALS	Referent						
	Airplane	0.479	.470	1.021	.307	1.615	0.710	4.652
	BLS	0.724	.082	8.854	<.001***	2.064	1.762	2.429
	Helicopter	0.767	.060	12.76	<.001***	2.154	1.916	2.426
	Paramedic Intercept	-0.439	.184	2.377	.017*	0.644	0.451	0.930
	Specialty Care Transport	0.459	.135	3.410	<.001***	1.582	1.223	2.075

Table 10

Continued

Variable	Category	B	S.E.	Wald	*p*-Value	Exp B	95% CI Lower	95% CI Upper
Race	American Indian/Alaska Native	Referent						
	Asian	-0.101	.169	-0.598	.550	0.904	0.646	1.255
	Black	-0.757	.138	-5.489	<.001***	0.469	0.355	0.610
	Native Hawaiian/Pacific Islander	1.055	.281	3.760	<.001***	2.873	1.689	5.105
	White	-0.333	.137	-2.437	.015*	0.716	0.544	0.930
	Other	-.493	.146	-3/385	<.001***	0.610	0.456	0.808
Chief Complaint Organ System	Cardiovascular	Referent						
	CNS/Neuro	-0.319	.038	-8.413	<.001***	0.726	0.674	0.782
	Global	-0.584	.025	-23.00	<.001***	0.558	0.531	.586
	Other	-0.355	.059	-6.002	<.001***	0.701	0.625	0.788
	Pulmonary	-0.107	.040	-2.693	.007**	0.899	0.831	0.972
Number of Attempts	1	Referent						
	2	-0.453	.029	-15.66	<.001***	0.636	0.601	0.673
	$\geq$3	-0.915	.057	-15.99	<.001***	0.400	0.358	0.448

Note: B = Coefficient; SE = Standard Error, CI = Confidence Interval; EMS = Emergency Medical Services; CMS = Center for Medicaid and Medicare Services; ALS = Advanced Life Support; BLS = Basic Life Support;(*p at .01 ** p at .001 *** p at 0)

When structure (Block 1) and process (Block 2) predictor variables were considered together, they significantly predicted pre-hospital ETI success x^2 (35, N = 55,615) = 3385.714, p = .000). The log likelihood statistic was -26,907 (df = 36). Compared to Block 1 model's log likelihood statistic of -26,996 (df = 42) (structure variables only), Block 2's (structure and process variables together) log likelihood statistic is closer to zero, indicating a better model. When the variable number of attempts was added to the model, age was knocked out of the model. The AIC of the model (54,080) was equal to Block 1's AIC. The Durbin-Watson test statistic was 1.7, indicating no serial correlation among residuals. The VIF statistics included: a) type of service requested [x^2 (5) = 1.326], b) U.S. census region [x^2 (4) = 1.256, c) EMS total call time [x^2 (10)= 1.199], d) CMS service level [x^2 (5)= 1.390, e) race [X^2 (5) = 1.190], f) chief complaint organ system [x^2 (4) = 1.137], and g) attempts [x^2 (2) = 1.009]. The VIFs were all close to 1.0, suggesting no multi-collinearity among predictors. The results of Wald tests for each predictor variable were as follows: a) type of service requested [x^2 (5) = 105.8, p = .000], b) US census region [x^2 (4)=711.2, p = .000], c) EMS total call time (x^2 (10) = 235.9, p = .000], d) CMS service level [x^2 (5) = 247.8, p = .000], e) race [x^2 (5)= 321.0, p=.000], f) chief complaint organ system [x^2 (4)=551.0, p = .000], and g) attempts (x^2 (2)= 221.2, p = .000]. All were significant, suggesting all of the predictors should be included in the model. Nagelkerke's pseudo R2 was .089, suggesting approximately 9% of variance was explained by the model. Cross validation was conducted to assess how the results of the statistical analysis generalized to an independent data set. The ROC curve for the training set can be found in Figure 7 and for the testing set in Figure 8. The curves appear similar suggesting the results of the statistical analysis generalize to an independent data set.

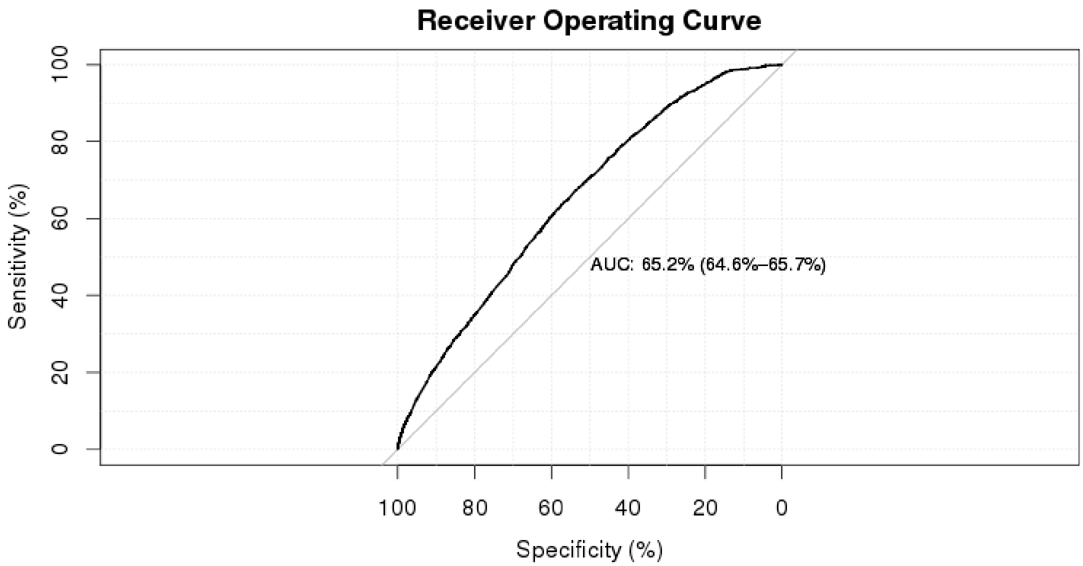

Figure 7. National Model ROC Curve for Block 1 and Block 2 Training Data Set.

The AUC in this figure is 65.2 and is poor at separating success from no success. The model provides some discrimination between success and no success.

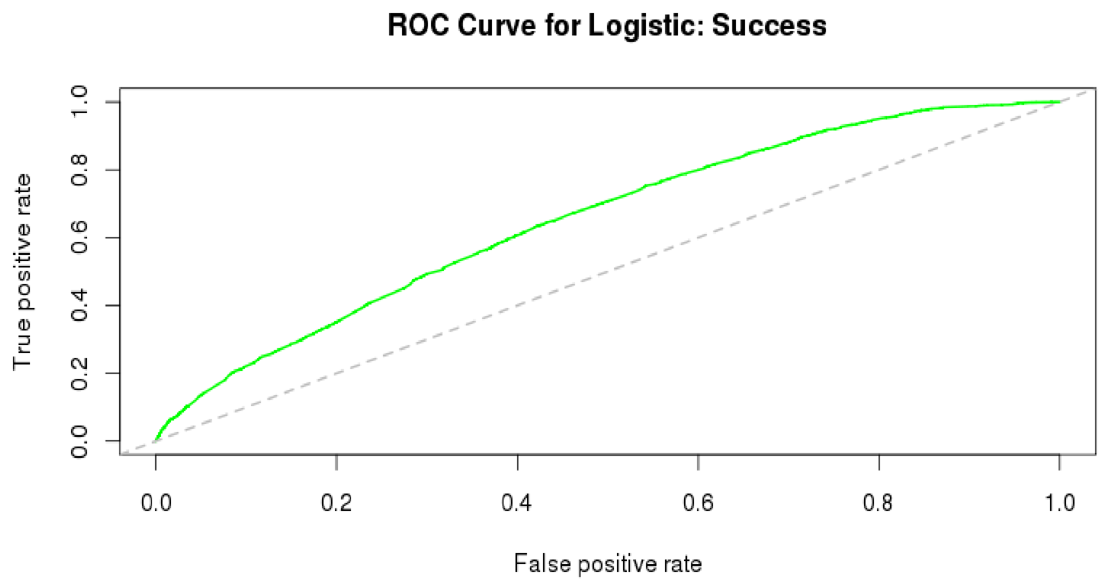

Figure 8. National Model ROC Curve for Block 1 and Block 2 Testing Data Set.

The ROC curve for the testing set of data appears similar to the ROC curve for the training data meaning the results of the model should generalize to an independent set of data. In this ROC curve, if the false positive rate is 0.6, the true positive rate is 0.8.

The logistic regression for pre-hospital ETI success suggests the odds of success are:

- higher for interfacility transfer (OR = 1.83) and medical transport (OR = 2.35) than 9-1-1 response when looking at type of service requested
- higher when EMS total call times range from 181-210 minutes (OR = 1.90), 211-240 minutes (OR = 1.87), and 241+ minutes (OR=3.72) when compared to EMS total call times of 0-15 minutes
- higher for basic life support (BLS) (OR = 2.06), helicopter (OR = 2.15), and specialty care transport (OR = 1.58) when compared to advanced life support (ALS) CMS service level

- lower for paramedic intercept (OR = 0.64) CMS service level compared to ALS CMS service level
- lower for Black or African American (OR = 0.47), White (OR = 0.71), and Other (OR = 0.61) races when compared to American Indian/Alaska Native race
- higher for Native Hawaiian/Pacific Islanders (OR = 2.87) when compared to American Indian/Alaskan Native race
- lower for CNS/Neuro (OR = 0.73), Global (OR = 0.56), Other (OR = .70), and pulmonary (OR = .90) chief complaint organ systems when compared to cardiovascular complaints
- lower for two attempts (OR = 0.64) and 3 attempts (OR = 0.40) at pre-hospital ETI when compared to one attempt.

Age was not a significant predictor when adding the process variables (Block 2) to the structure variables (Block 1) of the hierarchical logistic regression model.

Comprehensive State Model

Descriptive Statistics

Structure Variables. Structure variables include system, provider, and patient characteristics. System variables include a) type of service requested, b) primary role of the unit, and c) U.S. census region. Variables representing provider characteristics include a) provider certification level and b) CMS service level. Patient variables include a) gender, b) race, c) ethnicity, d) possible injury, e) chief complaint organ system, f) cardiac arrest, g) cardiac arrest etiology, h) age, i) patients' response level (AVPU, alert, verbal, painful, and unresponsive), j) return of spontaneous circulation, k) first monitored heart rhythm, l) Glasgow coma score, m) pulse oximetry, n) pulse rate, and o) systolic blood pressure.

Emergency or 9-1-1 scene response (96%) was the predominant type of service requested. The primary role of the unit was mostly transport (96%). The South census region was represented by Virginia and represented the greatest amount of data (44%). Advanced life support (86%) represented the majority of patient calls as defined by the Center for Medicare and Medicaid Service. Most providers were EMT-Paramedics (85%). Most patients were male (60%). White race (64%) predominated. Most patients were not of Hispanic or Latino origin (95%). Most patients did not sustain an injury (84%). The most common chief complaint organ system was cardiovascular (43%) followed by global complaints (41%). Most patients suffered a cardiac arrest prior to EMS arrival on scene (30%). The primary etiology of cardiac arrest was presumed cardiac (56%). Age of patients ranged from one year of age to over 100 years of age. A significant number of patients were 60-69 years of age (19%). Most patients receiving pre-hospital ETI were unresponsive (91%). Return of spontaneous circulation was not seen in most patients (58%). The majority of first monitored cardiac rhythms were asystole (48%). The majority of patients had a Glasgow Coma Score of three (89%). Patients predominately had a pulse oximetry reading (58%), pulse rate reading (59%), and systolic blood pressure reading (59%) of zero. (See Table 11).

Process Variables. For the Comprehensive State Model, the majority of ambulances responded to the scene (95%) and transported patients from the scene to the hospital (81%) using lights and sirens. Eighty-one percent of pre-hospital ETIs were completed in one attempt. (See Table 11).

Outcome Variable. Pre-hospital ETI success was the dependent variable and outcome of interest in this study. The success rate for Maine, Virginia, Illinois, and Utah combined was 60%.

Table 11

Comprehensive State Model: Descriptive Analysis of Variables.

Variable	Category	N	Percent
Type of Service Requested	9-1-1 response (scene)	5,521	96.40
	Intercept	25	0.44
	Interfacility transport	132	2.30
	Medical transport	21	0.37
	Mutual aid	28	0.49
Primary Role of the Unit	Non-transport	132	2.30
	Rescue	83	1.45
	Supervisor	37	0.65
	Transport	5,475	95.60
U.S. Census Region	Northeast	196	3.42
	Midwest	2,348	41.00
	South	2,520	44.00
	West	663	11.58
CMS Service Level	BLS	69	1.20
	ALS	4,919	85.89
	Paramedic intercept	24	0.42
	Specialty care transport	147	2.57
	Fixed wing (airplane)	26	0.45
	Rotary wing (helicopter)	542	9.46
Provider Certification Level	EMT-Basic	57	1.00
	EMT-Advanced/Enhanced	62	1.08
	EMT-Intermediate	646	11.28
	EMT-Paramedic	4,890	85.39
	RN/MD/Other	72	1.26
Gender	Male	3,454	60.31
	Female	2,273	39.69
Race	Asian	42	0.73
	Black or African American	1,609	28.09
	White	3,671	64.10
	Other race	405	7.07
Ethnicity	Hispanic or Latino	300	5.24
	Not Hispanic or Latino	5,427	94.76
Possible Injury	No	4,830	84.34
	Yes	897	15.66
Chief Complaint Organ System	Cardiovascular	2,427	42.55
	CNS/Neuro	420	7.33
	Global	2,359	41.19
	Other	124	6.76
	Pulmonary	387	2.17
Cardiac Arrest	No	1,724	30.10
	Yes, prior to EMS arrival	3,624	63.28
	Yes, after EMS arrival	370	6.62
Cardiac Arrest Etiology	Presumed cardiac	3,190	55.70
	Trauma	185	3.23
	Respiratory	539	9.41
	Not Applicable	1,438	25.11

Table11

Continued

Variable	Category	N	Percent
Age (in years)	0-9	163	2.85
	10-19	137	2.39
	20-29	316	5.52
	30-39	351	6.13
	40-49	511	8.92
	50-59	979	17.09
	60-69	1,111	19.40
	70-79	1,007	17.58
	80-89	869	15.17
	90-99	274	4.78
	100+	9	0.16
Response Level	Alert	317	5.54
	Painful	105	1.83
	Unresponsive	5,222	91.18
	Verbal	83	1.45
Return of Spontaneous Circulation	No	3,358	58.63
	Not Applicable	904	15.78
	Yes, Prior to EMS Arrival and at the ED	1,111	19.40
	Yes, Prior to EMS Arrival	354	6.18
First Monitored Heart Rhythm	Asystole	2,742	47.88
	Bradycardia	140	2.44
	Normal Sinus Rhythm	121	2.11
	Other	140	2.44
	Paced Rhythm	20	0.35
	Pulseless Electrical Activity (PEA)	1,194	20.85
	Unknown AED Non-shockable Rhythm	193	3.37
	Unknown AED Shockable Rhythm	72	1.26
	Ventricular Fibrillation	1,049	18.32
	Ventricular Tachycardia	56	0.98
Glasgow Coma Score	3	5,069	88.51
	4-5	160	2.79
	6-8	180	3.14
	9-12	117	2.04
	13-15	201	3.51
Pulse Oximetry	0	3,346	58.43
	1-49	171	2.99
	50-69	343	5.99
	70-79	298	5.20
	80-89	430	7.51
	90-100	1,139	19.89
Pulse Rate	0	3,391	59.21
	1-59	449	7.84
	60-99	794	13.86
	100-149	927	16.19
	150-199	141	2.46
	200+	25	0.44

Table 11

Continued

Variable	Category	N	Percent
Systolic Blood Pressure	0	3,374	58.91
	<50	49	0.86
	50-75	283	4.94
	76-119	807	14.09
	120-139	470	8.21
	140-189	569	9.94
	190-219	120	2.10
	220+	55	0.96
Response to Scene	Lights and Sirens	5,462	95.37
	No Lights and Sirens	265	4.63
Transport from Scene	Lights and Sirens	4,669	81.53
	No Lights and Sirens	1,058	18.47
Number of ETI Attempts	1	4,639	81.00
	2	960	16.76
	$\geq$3	128	2.24
Pre-hospital ETI Success	No	2,256	39.39
	Yes	3,471	60.61

Note: N = 5,727; BLS = Basic Life Support; ALS = Advanced Life Support

RQ1. What variables representing structural measures predict pre-hospital ETI success?

Bivariate Results of Structure Variables. Table 12 displays results of the chi-square and post-hoc phi and Cramer's *V* analysis for the independent variables and dependent variable, pre-hospital ETI success. Variables significantly associated with pre-hospital ETI success included: a) type of service requested, b) primary role of the unit, c) U.S. census region, d) CMS service level, e) provider certification level, f) patient race, g) ethnicity, h) chief complaint organ system, i) cardiac arrest, j) cardiac arrest etiology, k) return of spontaneous circulation, l) pulse oximetry, and m) Glasgow Coma Score. Variables not significantly associated with pre-hospital ETI success included: a) gender, b) age, c) injury, d) first monitored cardiac rhythm, e) systolic blood pressure, f) pulse rate, g) respiratory rate, and h) patient response level were not significantly associated with pre-hospital ETI success. Results are found in Table 12.

Table 12

Comprehensive State Model: Bivariate Analysis of Structure Variables and Pre-Hospital ETI Success

Variable	Category	N	Success	Success Percent	x^2 test statistic	df	*p*-value	φ_c or Cramer's V
Type of Service Requested	911 response (scene)	5,521	3,306	60%	39.412	4	< .001	.083
	Intercept	25	15	60%				
	Interfacility transport	132	111	84%				
	Medical transport	21	17	81%				
	Mutual aid	28	22	79%				
Unit Role	Non-transport	132	86	65%	7.949	3	.047	.037
	Rescue	83	61	73%				
	Supervisor	37	25	68%				
	Transport	5,475	3,299	60%				
US Census Region	Northeast	196	141	72%	549.22	3	< .001	.309
	Midwest	2,348	998	43%				
	South	2,520	1,865	74%				
	West	663	467	70%				
CMS Service Level	BLS	69	44	64%	13.382	5	.020	.043
	ALS	4,919	2,958	60%				
	Paramedic intercept	24	10	42%				
	Specialty care transport	147	101	69%				
	Fixed wing (airplane)	26	21	80%				
	Rotary wing	542	337	62%				
Provider Certification Level	Paramedic	4,890	2,859	58%	76.392	5	< .001	.115
	Basic	57	41	72%				
	Advanced/ Enhanced	62	41	66%				
	Intermediate	646	464	72%				
	RN/MD/Other	72	66	92%				

Table 12

Continued

Variable	Category	N	Success	Success Percent	x^2 test statistic	df	*p*-value	φ_c or Cramer's V
Response Level	Alert	317	193	61%	0.39	3	.941	.008
	Painful	105	64	61%				
	Unresponsive	5,222	3,161	61%				
	Verbal	83	53	64%				
ROSC	No	3,358	1,979	59%	13.293	3	.004	.048
	Not Available	904	547	61%				
	Prior to EMS arrival and at ED	1,111	718	65%				
	Prior to EMS Arrival	354	227	645				
Pulse Oximetry	0	3,346	1,899	57%	65.92	5	< .001	.107
	1-49	171	105	61%				
	50-69	343	207	60%				
	70-79	298	206	69%				
	80-89	430	265	62%				
	90-100	1,139	789	69%				
Glasgow Coma Score	3	5,069	3,024	60%	18.311	4	.001	.057
	4-5	160	109	68%				
	6-8	180	127	71%				
	9-12	117	74	63%				
	13-15	201	137	68%				
First Monitored Heart Rhythm	Asystole	2,742	1,669	61%	9.24	9	.415	.040
	Bradycardia	140	88	63%				
	Norma Sinus Rhythm	121	74	61%				
	Other	140	89	64%				
	Paced	20	11	55%				
	PEA	1,194	734	61%				
	Unknown AED non-Shockable	193	118	61%				
	Unknown AED Shockable	72	41	57%				
	Ventricular Fibrillation	1,049	606	58%				
	Ventricular Tachycardia	56	41	73%				

Table 12

Continued

Variable	Category	N	Success	Success Percent	x^2 test statistic	df	*p*-value	φ_c or Cramer's V
Pulse Rate	0	3,391	2,037	60%	4.706	5	.452	.029
	1-59	449	271	60%				
	60-99	794	499	63%				
	100-149	927	558	60%				
	150-199	141	87	62%				
	200+	25	19	76%				
Respiratory Rate	0	3,523	2,104	60%	13.115	7	.069	.047
	< 5	242	140	58%				
	5-11	617	383	62%				
	12-19	753	479	64%				
	20-29	332	191	58%				
	30-39	133	88	66%				
	40-49	56	34	61%				
	50+	71	52	73%				
Systolic Blood Pressure	0	3,374	2,029	60%	10.371	7	.168	.042
	< 50	49	36	73%				
	50-75	283	187	66%				
	76-119	807	485	60%				
	120-139	470	271	58%				
	140-189	569	355	62%				
	190-219	120	72	60%				
	220+	55	36	65%				

Note: df = Degrees of Freedom, CMS = Center for Medicare and Medicaid Services; BLS = Basic Life Support; ALS = Advanced Life Support; CNS = Central Nervous System; Neuro = Neurological; EMS = Emergency Medical Services; ED = Emergency Department; PEA = Pulseless Electrical Activity

Multivariate Analysis of Block 1

Multivariate Logistic Regression Model. Logistic regression was conducted to assess how well the structure variables predicted pre-hospital ETI success for the state data. Variables with a Cramer's V greater than .100 were included in the first block of the logistic regression model. System variables include system, provider, and patient characteristics. Only one system variable, U.S. census region, was included in the model. One provider variable, provider certification level, was included in the model. Patient variables included in the model were race, chief complaint organ system, pulse oximetry, and cardiac arrest. Table 13 provides results of the Comprehensive Model Block 1 multiple logistic regression analysis.

Table 13

Block 1: Comprehensive State Model Multivariate Analysis of Structure Variables

							95% CI	
Variable	Category	B	S.E.	Wald	*p*-Value	Exp B	Lower	Upper
Intercept		0.415	.099	4.636	<.001***	1.515	1.271	1.806
US Census Region	Midwest	Referent						3.802
	Northeast	0.994	.170	5.833	<.001***	2.703	1.846	3.802
	South	1.154	.074	15.525	<.001***	3.174	2.745	3.674
	West	.939	.099	9.443	<.001***	2.556	2.107	3.111
Provider Certification Level	EMT-Paramedic	Referent						
	EMT-Basic	-0.026	.309	-0.084	.933	0.974	0.541	1.835
	EMT-Advanced/Enhanced	-0.372	.282	-1.320	.187	0.689	0.402	1.218
	EMT-Intermediate	-0.142	.105	-1.358	.174	0.867	0.706	1.067
	RN/MD/Other	1.219	.436	2.793	.005**	3.383	1.556	8.790
Race	White	Referent						
	Black	-.648	.067	-9.653	<.001***	0.523	0.458	0.597
	Asian	-0.172	.330	-0.521	.602	0.842	0.437	1.609
	Other Race	-0.339	.114	-2.973	.003**	0.713	0.570	0.891
Chief Complaint Organ System	Cardiovascular	Referent						
	CNS/Neuro	-0.064	.125	-0.508	.612	0.938	0.735	1.202
	Global	-0.878	.065	-13.47	<.001***	0.415	0.366	0.472
	Other	0.047	.216	0.218	.827	1.048	0.692	1.618
	Pulmonary	0.190	.134	1.416	.157	1.208	0.933	1.577
Cardiac Arrest	No	Referent						
	Yes, After EMS Arrival	-0.318	.132	-2.409	.016*	0.727	0.561	0.941
	Yes, Prior to EMS Arrival	.025	.071	.353	.724	1.025	0.893	1.177

Note: B = Coefficient, SE = Standard Error; CI = Confidence Interval; EMT = Emergency Medical Technician; RN = Registered Nurse; MD = Medical Doctor; CNS = Central Nervous System; Neuro = Neurological; Significance Codes: 0 '***' .001 '**' .01 '*'

Results of Multivariate Logistic Regression Model. When the predictor variables of Block 1 were considered together, they significantly predicted pre-hospital ETI success, x^2 (16, N=5,727) = 951.646, p = < .001. The log likelihood statistic was -3,363.963 (df = 17). The AIC of the model was 6761.1. The Durbin-Watson statistic was 1.6, suggesting no serial correlation among residuals. VIF statistics for the model were: a) US Census region = [x^2 (3) = 1.402], b) provider certification level [x^2 (4) = 1.276, c) race [x^2 (3) = 1.047], d) chief complaint organ system [x^2 (4) = 1.142], and e) cardiac arrest [x^2 (1) = 1.225]. VIF statistics suggest no multicollinearity for the model. Results for Wald tests for each variable were significant, suggesting all of the predictor variables should be included in the model and include: a) U.S. census region [x^2 (3) = 272.4, p = .000], b) provider certification level [x^2 (4) = 11.7, p = .020], c) race [x^2 (3) = 94.5, p = .000], d) chief complaint organ system [x^2 (4) = 225.1, p = .000], and e) cardiac arrest [x^2 (2) = 7.9, p = .019]. Nagelkerke's pseudoR2 was .207, suggesting approximately 21% of the variance was explained by the model. The ROC curve for the training data can be found in Figure 9 and for the testing data in Figure 10. The ROC curves appear similar suggesting the results of the statistical analysis can be generalized to an independent data set.

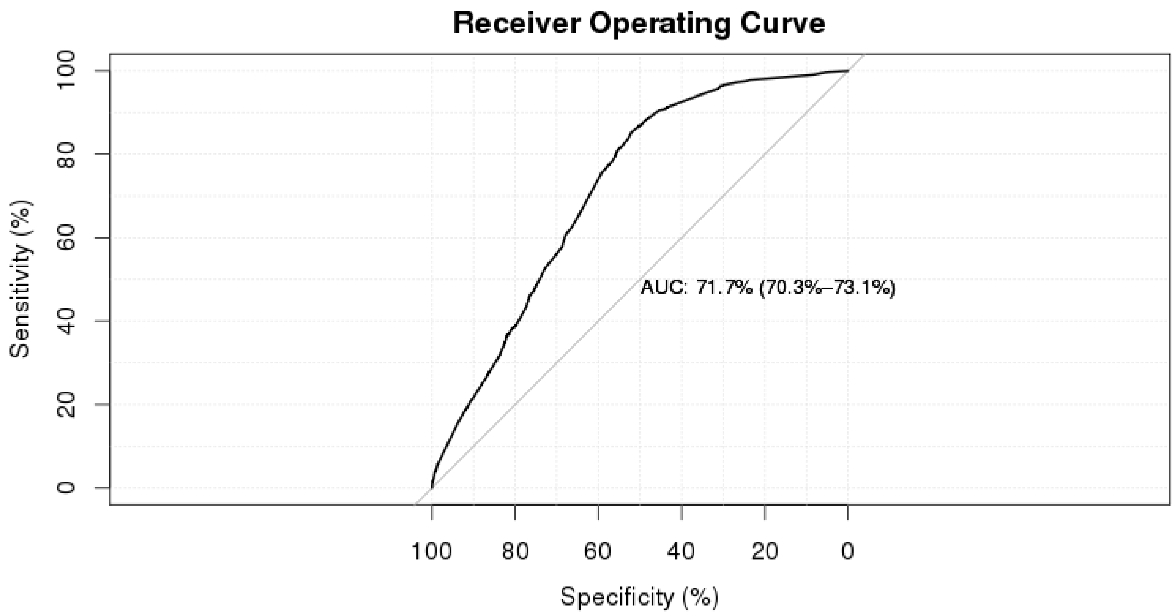

Figure 9. Comprehensive State Model ROC Curve for Block 1 Training Data Set.

The AUC in this figure is 71.7% and is fair at separating success from no success. For this model, the ROC curve deviates from the 45-degree diagonal to the upper left corner, so the model aids in prediction of success.

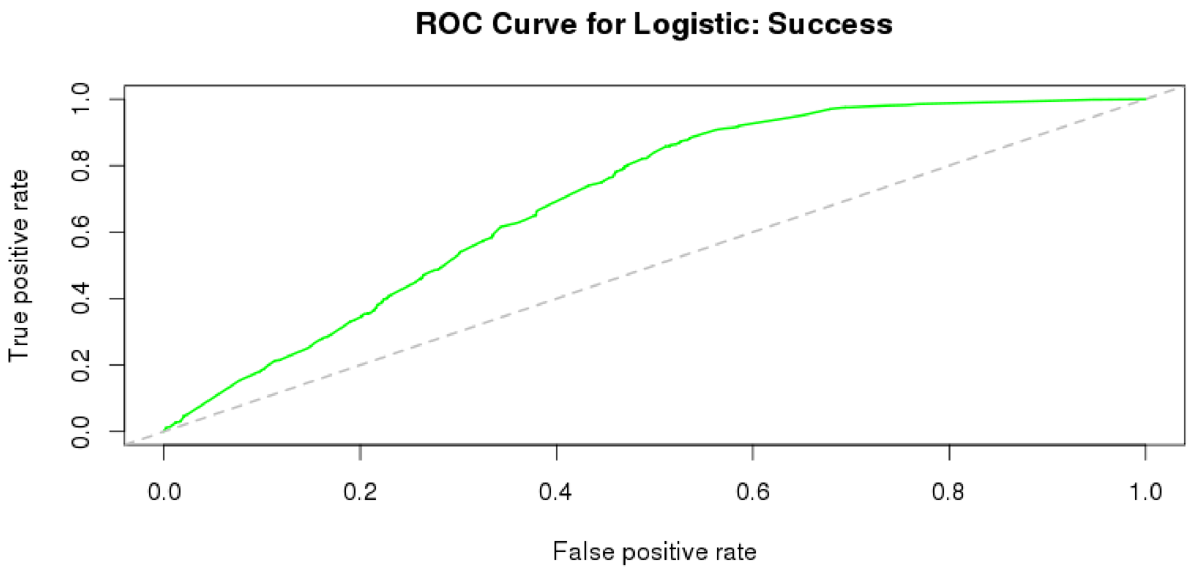

Figure 10. Comprehensive State Model ROC curve for Block 1 Testing Data Set.

The ROC curve for the testing set of data appears similar to the ROC curve for the training data meaning the results of the model should generalize to an independent set of data. In this ROC curve, if the false positive rate is 0.6, the true positive rate is 0.95. If you pick a line of determination for your false positive rate and move and it to the left, such as from 0.8 to 0.2, the area under the curve increases giving you a greater number of true positives or greater sensitivity.

The Block 1 logistic regression for the state data for pre-hospital ETI success suggests the odds of success are:

- higher in the Northeast (OR = 2.70), South (OR = 3.17), and West (OR = 2.56) than in the Midwest when observing U.S. census region
- higher when registered nurses (RN), medical doctors (MD), and others (OR = 3.38) performed pre-hospital ETI when compared to EMT-Paramedics when looking at provider certification level
- lower for Black or African American race (OR=0.52) and other race (0.71) when compared to White race
- lower for global complaints (OR=0.41) compared to cardiovascular complaints when looking at chief complaint organ system
- lower for patients who had cardiac arrest after EMS arrival when compared to patients who did not have a cardiac arrest.

Pulse oximetry was not a significant predictor of pre-hospital ETI success among Block 1 variables included in the model. U.S. census region, provider certification level, race, chief complaint organ system, and cardiac arrest were all significant predictors as seen in Table 13.

RQ2. What variables representing process measures predict pre-hospital ETI success?

Bivariate Analysis of Process Variables. Table 14 displays results of the state bivariate analysis and phi and Cramer's V of process variables to pre-hospital ETI success. All three process variables: attempts, response mode to scene, and transport mode from scene, were significant with pre-hospital ETI success at the $p < .001$ significance level. Cramer's V for attempts x^2 (2, N = 8,182) = 195.240, $p < .001$, $\phi_c = .185$, was the greatest, suggesting a stronger strength of association compared to the other variables.

Table 14

Comprehensive State Model: Bivariate Analysis of Process Variables and Pre-Hospital ETI Success.

Variable	Category	N	Success	Success Percent	x^2 test statistic	df	*p*-value	φ_c or Cramer's V
Number of Attempts	1	4,639	3,012	65%	195.240	2	< .001	.185
	2	960	396	41%				
	3	128	62	48%				
Response	Lights and Sirens	5,462	3,251	60%	57.474	1	< .001	.101
	No Lights and Sirens	265	220	83%				
Transport	Lights and Sirens	4,669	2,717	58%	61.209	1	< .001	.103
	No Lights and Sirens	1,058	754	71%				

Note: df = Degrees of Freedom

Multivariate Analysis of Process Variables

Multivariate Logistic Regression Model. Logistic regression was conducted to determine how well the process variables predicted pre-hospital ETI success. Variables that were significant with pre-hospital ETI success were included in the logistic regression model to answer RQ2. The process variables entered into the multivariate model included: a) attempts, b) response mode to scene, and c) transport model from scene. This procedure allowed for the adjustment of each of the independent variables and provided odds ratios and levels of significance. Table 15 provides results of the multivariate logistic regression analysis.

Table 15

Comprehensive State Model: Multivariate Analysis of Process Variables

Variable	Category	B	S.E.	Wald	p-Value	Exp B	95% CI Lower	95% CI Upper
Intercept		0.488	.034	14.577	<.001***	1.630	1.526	1.741
Number of Attempts	1	Referent						
	2	-.952	.073	-13.033	<.001***	0.386	0.334	0.445
	$\geq$3	-0.633	.181	-3.503	.000***	0.531	0.372	0.756
Response Mode to Scene	Lights and Sirens	Referent						
	No Lights and Sirens	1.022	0.169	6.044	<.001***	2.778	2.014	3.913
Transport Mode from Scene	Lights and Sirens	Referent						
	No Lights and Sirens	0.496	0.076	6.513	<.001***	1.642	1.416	1.909

Note: B = coefficient, S.E. = standard error, CI = confidence interval (*p at .01 ** p at .001 *** p at 0)

Results of Multivariate Regression Model. When considered together, process variables significantly predicted pre-hospital ETI success, x^2 (4, N = 5,727) = 293.084, p < .001. The AIC of the model was 7,396.5. The Durbin-Watson test statistic was 1.410, suggesting there may have been serial correlation among residuals. This may have come from the fact that response mode to scene and transport model from scene are correlated, x^2(1, N = 55,615) = 7657.5, p = <.001, ϕ_c =.371. The VIF statistics for predictor variables included: a) number of attempts [x^2 (2) = 1.001], b) response mode to scene [x^2 (1) = 1.011], c) transport mode from scene [x^2 (1) = 1.011]. VIF statistics were close to one and suggested no multi-collinearity among predictors.

The Wald test results included the following: a) number of attempts [x^2 (2) = 176.4, p=.000], b) response mode to scene [x^2 (1) = 36.5, p < .001], and c) transport mode from scene [x^2 (1) = 42.4, p < .001]. The results of the Wald tests were all significant, suggesting all predictors should be included in the model. Nagelkerke's pseudo R2 was .068, suggesting approximately 6% of variance was explained by the process model.

The logistic regression for pre-hospital ETI success suggests the odds of success are:

- lower when two attempts (OR = 0.39) or three attempts (OR 0.53) are attempted at ETI when compared to one attempt
- higher when no lights and sirens (OR = 2.78) are used during response to scene compared to when lights and sirens are used on response to scene
- higher when no lights and sirens (OR=1.64) are used during transport from scene compared to when lights and sirens are used during transport from scene

RQ3. Does the combination of structural measures and process measures add strength to the prediction of pre-hospital ETI success?

Multivariate Analysis of Block 1 and Block 2. Hierarchical logistic regression was conducted to assess if the structure and process variables together better predict ETI success than the structure variables alone. System variables used in the first block of the multivariate analysis included: a) U.S. census region, b) provider c) certification level, d) race, e) chief complaint organ system, and f) cardiac arrest. The process variable included in the second block of the hierarchical logistic regression was the number of pre-hospital ETI attempts and response mode to scene. Transport mode to scene was not included as a predictor in the second block because it was collinear with response mode to scene. Table 16 provides results for the two blocks of structure and process variables together for predicting pre-hospital ETI success.

When Block 1 and Block 2 predictor variables were considered together, they significantly predicted pre-hospital ETI success (x^2 = 1176.217, df = 19, N = 5,727, p = < .001). The log likelihood statistic was -3,251.678 (df = 20). The AIC of the model was 6,543. The Durbin-Watson statistic was 1.657, suggesting no serial correlation among residuals. VIF statistics for the model were: a) U.S. Census region [x^2 (3) = 1.449], b) provider certification level [x^2 (4) = 1.289], c) race = [x^2 (3)= 1.054], d) chief complaint organ system [*x*2 (4) = 1.154], e) cardiac arrest [x^2 (2) = 1.243], f) attempts [x^2 (2) = 1.039], and g) response mode to scene [x^2 (1) = 1.033. VIF statistics suggest no multi-collinearity for the model. Results for Wald tests for each variable were significant suggesting all of the predictor variables should be included in the model and include: a) U.S. census region (x^2 = 289.3 (3), p = .000), b) provider certification level (x^2 = 11.9 (4), p = .018), c) race (x^2 = 88.6 (3), p = .000), d) chief complaint organ system (x^2 = 200.3 (4), p = .000), e) cardiac arrest (x^2 = 214.1 (3), p = .000), f) attempts (x^2 = 191.5 (2), p = .000, and g) response mode to scene (x^2 = *0* .7 (1), p = <.001. Nagelkerke's pseudoR2 was .251, suggesting approximately 25% of the variance was explained by the model. The ROC curve for the training data can be found in Figure 11 and for the testing data in Figure 12. The ROC curves appear similar suggesting the results of the statistical analysis can be generalized to an independent data set.

Table 16

Comprehensive State Model: Block 1 and Block 2 Multivariate Analysis

Variable	Category	B	S.E.	Wald	*p* Value	Exp B	95 % CI Lower	95 % CI Upper
Intercept		0.520	.093	5.596	<.001***	1.683	1.403	2.021
US Census Region	Midwest	Referent						
	Northeast	0.976	.173	5.643	<.001***	2.654	1.902	3.751
	South	1.259	.077	16.36	<.001***	3.523	3.032	4.100
	West	0.881	.101	8.717	<.001***	2.415	1.983	2.949
Provider Certification Level	EMT-Paramedic	Referent						
	EMT-Basic	-0.111	.315	-0.353	.724	0.895	0.491	1.704
	EMT-Advanced/Enhanced	-0.415	.289	-1.434	.151	0.661	0.379	1.184
	EMT-Intermediate	-0.155	.108	-1.441	.150	0.856	0.694	1.059
	RN/MD/Other	1.228	.449	2.732	.006**	3.413	1.527	9.147
Race	White	Referent						
	Black	-0.644	.069	-9.377	<.001***	0.525	0.459	0.600
	Asian	-0.135	.337	-0.401	.689	0.874	0.448	1.693
	Other Race	-0.299	.117	-2.554	.010*	0.741	0.590	0.933
Chief Complaint Organ System	Cardiovascular	Referent						
	CNS/Neuro	-0.116	.129	-0.909	.363	0.890	0.693	1.470
	Global	-0.851	.067	-12.79	<.001***	0.427	0.374	0.486
	Other	0.623	.220	0.286	.775	1.065	0.698	1.656
	Pulmonary	0.180	.137	1.313	.189	1.197	0.918	1.570
Cardiac Arrest	No	Referent						
	Yes, After EMS Arrival	-0.297	.135	-2.196	.028*	0.743	0.570	0.968
	Yes, Prior to EMS Arrival	0.068	.073	0.934	.350	1.070	0.928	1.234
Attempts	1	Referent						
	2	-1.078	.081	-13.37	<.001***	0.340	0.291	0.398
	$\geq$3	-0.939	.201	-4.675	<.001***	0.391	0.263	0.580
Response to Scene	Lights and Sirens	Referent						
	No Lights and Sirens	0.809	.178	4.549	<.001***	2.243	1.599	3.211

Note: B = Coefficient; CI = Confidence Interval; SE = Standard Error; CNS = Central Nervous System; Neuro = Neurological; EMT = Emergency Medical Technician; RN = Registered Nurse; MD = Medical Doctor; EMS = Emergency Medical Services; (*p at .01 ** p at .001 *** p at 0)

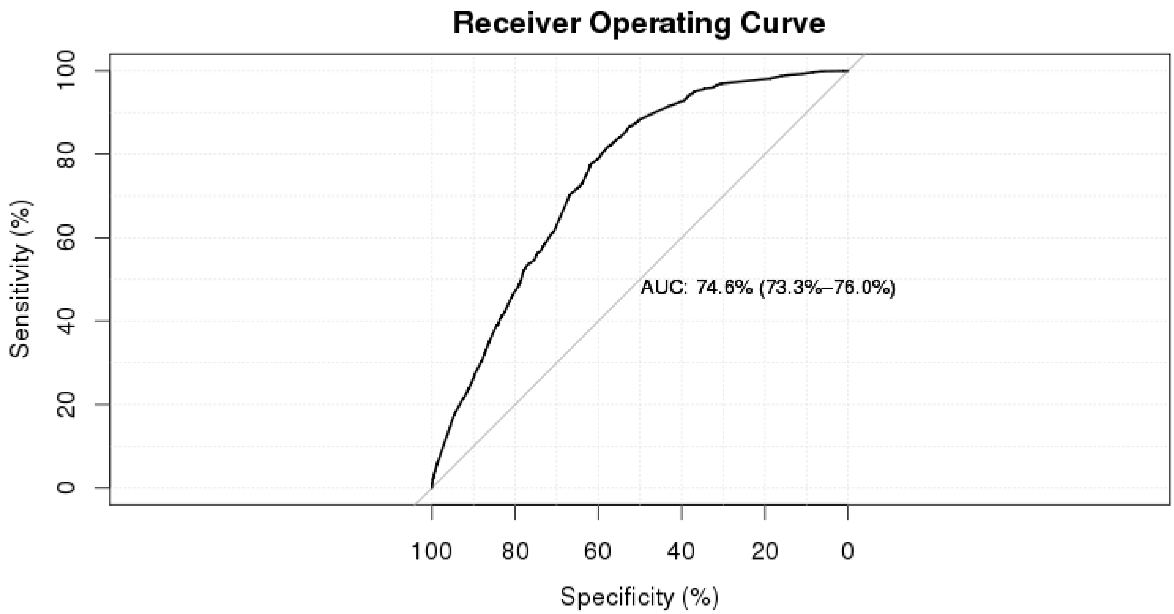

Figure 11. Comprehensive State Model: ROC Curve for Block 1 and Block 2 Training Data Set.

The AUC in this figure is 74.6 and is fair at separating success from no success. The model provides fair discrimination between success and no success.

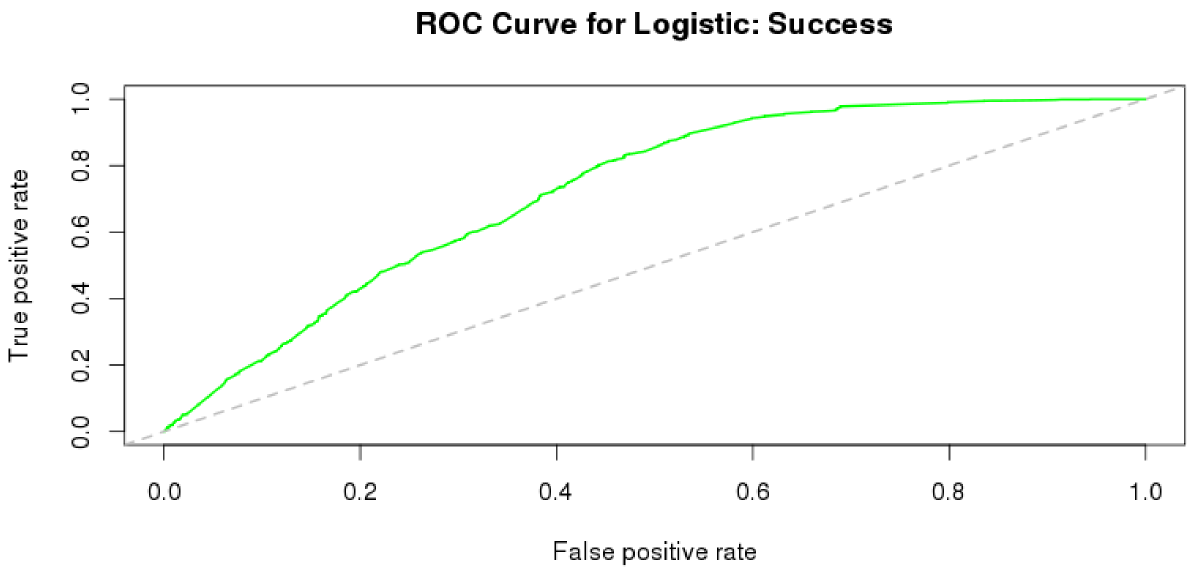

Figure 12. Comprehensive State Model ROC Curve Block 1 and Block 2 Testing Data Set.

The ROC curve for the testing set of data appears similar to the ROC curve for the training data meaning the results of the model should generalize to an independent set of data. In this ROC curve, if the false positive rate is 0.4, the true positive rate is 0.75. If you pick a line of determination for your false positive rate and move it to the left, such as from 0.8 to 0.2, the area under the curve increases giving you a greater number of true positives or greater sensitivity.

The final Comprehensive hierarchical logistic regression model including the first and second blocks for pre-hospital ETI success suggests the odds of success are:

- higher for the Northeast (OR = 2.65), South (OR = 3.52), and West (OR = 2.42) census regions when compared to the Midwest census region
- higher for registered nurses, medical doctor and others (OR = 3.41) when compared to EMT-Paramedic provider certification level
- lower for global (OR = 0.43) complaints than cardiovascular complaints when examining chief complaint organ system
- lower for patients who had a cardiac arrest prior to EMS arrival (OR = 0.74) when compared to patients who did not have a heart attack
- lower for two (OR = 0.34) and three attempts (OR=0.39) when compared to one attempt
- higher for response mode to scene when no lights and sirens (OR = 2.24) were used compared to when lights and sirens were used.

National Bivariate Hypotheses

Structure Hypotheses

System characteristics

Bivariate H_o*:* Type of service requested and pre-hospital ETI success are independent.

Bivariate H_a*:* Type of service requested is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Type of service requested and pre-hospital ETI success are related, $\chi^2(5) = 307.88, p < .001, \phi_c = .074$. Interfacility transfers had the highest percentage of successes, when it was hypothesized that 911 responses would have the greatest number of successes. The results were not in the hypothesized direction.

Bivariate H_o: Primary role of the unit and pre-hospital ETI success are independent.

Bivariate H_a: Primary role of the unit is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Primary role of the unit and pre-hospital ETI success are related, $\chi^2(3) = 20.08, p = .000, \phi_c = .021$. Non-transport vehicles had the greatest number of successes when it was hypothesized that rescue units would have the greatest likelihood of success. The results were not in the hypothesized direction.

Bivariate H_o: U.S. census region and pre-hospital ETI success are independent.

Bivariate H_a : U.S. census region is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. U.S. census region and pre-hospital ETI success are related, $\chi^2(4) = 938.60, p = <.001, \phi_c = .128$. Island areas had the highest number of pre-hospital ETI successes when it was hypothesized that the Northeast would have the greatest number of successes. The results were not in the hypothesized direction.

Bivariate H_o: Urbanicity and pre-hospital ETI success are independent.

Bivariate H_a : Urbanicity is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Urbanicity and pre-hospital ETI success are related, $\chi^2(3) = 19.31, p = .001, \phi_c,= .018$. It was hypothesized that urban areas would have the greatest percentage of successes. The results revealed that urban, suburban, rural, and wilderness areas almost had equal percentages of success. The results were not in the hypothesized direction.

Bivariate H_o: EMS total call time and pre-hospital ETI success are independent.

Bivariate H_a *:* EMS total call time is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. EMS total call time and pre-hospital ETI success are related, $\chi^2(10) = 510.17, p < .001\ \phi_c = .072$. It was hypothesized that EMS total call times completed in a shorter duration would have the greatest number of successes. The results revealed that longer EMS total call times had the highest percentage of successes. The results were not in the hypothesized direction.

Provider Characteristics

Bivariate H_o*:* CMS service level and pre-hospital ETI success are independent.

Bivariate H_a *:* CMS service level is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. CMS service level and pre-hospital ETI success are related, $\chi^2(5) = 388.02, p < .001, \phi_c = .083$. Fixed-wing airplanes for CMS were hypothesized to have the greatest number of successes. This hypothesis was supported by the bivariate results.

Patient Characteristics

Bivariate H_o*:* Gender and pre-hospital ETI success are independent.

Bivariate H_a *:* Gender is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Gender and pre-hospital ETI success are related, $\chi^2(1) = 25.11, p < .001, .\ \phi_c = .021$. It was hypothesized that males would have the greatest percentage of successes. Females had a two percent higher rate of success than males.

Bivariate H_o*:* Race and pre-hospital ETI success are independent.

Bivariate H_a: Race is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Race and pre-hospital ETI success are related, $\chi^2(5) = 706.51, p < .001, \phi_c = .111$. It was hypothesized that Whites would have the greatest percentage of successes. The results exposed Native Hawaiian or other Pacific Islander had the greatest percent of success. The results were not in the hypothesized direction.

Bivariate H_o: Ethnicity and pre-hospital ETI success are independent.

Bivariate H_a: Ethnicity is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was accepted. Ethnicity and pre-hospital ETI success are independent, $\chi^2(1) = 3.31, p = .069$.

Bivariate H_o: Possible injury and pre-hospital ETI success are independent.

Bivariate H_a: Possible injury is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Possible injury and pre-hospital ETI success are related, $\chi^2(1) = 5.64, p = .018, \phi_c = .010$. Patients who had sustained an injury and patients who did not have an injury almost had an equal percentage of successes. The results were not in the hypothesized direction.

Bivariate H_o: Chief complaint organ system and pre-hospital ETI success are independent.

Bivariate H_a: Chief complaint organ system is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Chief complaint organ system and pre-hospital ETI success are related, $\chi^2(4) = 799.70, p < .001, \varphi_c = .120$. It was hypothesized that pulmonary chief complaints would have the highest percentage of successes. The results supported the hypothesis.

Bivariate H_o: Cardiac arrest and pre-hospital ETI success are independent.

Bivariate H_a : Cardiac arrest is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Cardiac arrest and pre-hospital ETI success are related, $\chi^2(2) = 62.27, < .001, \phi_c = .033$. It was hypothesized that patients in cardiac arrest would have the highest percentage of successes. Patients who were not having a cardiac arrest were found to have the highest percentage of successes. The results were not in the hypothesized direction.

Bivariate H_o: Cardiac arrest etiology and pre-hospital ETI success are independent.

Bivariate H_a: Cardiac arrest etiology is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Cardiac arrest etiology and pre-hospital ETI success are related, $\chi^2(5) = 18.26, p = .002$. It was hypothesized that presumed cardiac etiology would have the highest percentage of successes. Electrocution had the greatest percentage of successes. The results were not in the hypothesized direction.

Bivariate H_o: Age and pre-hospital ETI success are independent.

Bivariate H_a : Age is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Age and pre-hospital ETI success are related, $\chi^2(10) = 287.8, p < .001, \phi_c = .072$. It was hypothesized that older age groups would have a greater number of successes. Results were mixed for age group.

Process Hypotheses

Bivariate H_o: Response mode to scene and pre-hospital ETI success are independent.

Bivariate H_a: Response mode to scene is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Response mode to scene and pre-hospital ETI success are related, $\chi^2(1) = 243.48, p < .001, \phi_c = .066$. Contrary to the hypotheses, the number of successes of pre-hospital ETI was greater when no light and sirens were used for response to the emergency scene.

Bivariate H_o: Transport mode from scene and pre-hospital ETI success are independent.

Bivariate H_a: Transport mode from scene is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Transport mode from scene and pre-hospital ETI success are related, $\chi^2(1) = 101.04, p < .001, \phi_c = .043$. Contrary to the hypotheses, the number of successes of pre-hospital ETI was greater when no light and sirens were used for transport from the emergency scene.

Bivariate H_o: Number of procedure attempts and pre-hospital ETI success are independent.

Bivariate H_a: Number of procedure attempts is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Number of procedure attempts and pre-hospital ETI success are related, $\chi^2(3) = 470.15, p < .001, . \varphi c = .092$. The hypothesis that a greater percentage of successes would be in fewer pre-hospital ETI attempts was supported by the result.

Comprehensive State Model Bivariate Hypotheses

Structure Hypotheses

System characteristics

Bivariate H_o: Type of service requested and pre-hospital ETI success are independent.

Bivariate H_a: Type of service requested is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Type of service requested and pre-hospital ETI success are related, $\chi^2(5) = 39.412$, $p < .001$, $\phi_c = .083$. Interfacility transfers had the highest percentage of successes, when it was hypothesized that 9-1-1 responses would have the greatest number of successes. The results were not in the hypothesized direction.

Bivariate H_o: Primary role of the unit and pre-hospital ETI success are independent.

Bivariate H_a: Primary role of the unit is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Primary role of the unit and pre-hospital ETI success are related, $\chi^2(3) = 7.95$, $p = .047$, $\phi_c = .037$. It was hypothesized that rescue units would have the greatest percentage of successes. The result supported the hypothesis.

Bivariate H_o: U.S. census region and pre-hospital ETI success are independent.

Bivariate H_a : U.S. census region is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. U.S. census region and pre-hospital ETI success are related, $\chi^2(3) = 549.22$, $p = <.001$, $\phi_c = .309$. It was hypothesized that the Northeast census region would have the greatest percentage of successes. The result supported the hypothesis.

Provider Characteristics

Bivariate H_o: CMS service level and pre-hospital ETI success are independent.

Bivariate H_a: CMS service level is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. CMS service level and pre-hospital ETI success are related, $\chi^2(5) = 13.382$, $p = ,020$, $\phi_c = .043$. The result supported the hypothesis that fixed-wing airplanes would have the greatest percentage of successes.

Bivariate H_o: Provider certification level and pre-hospital ETI success are independent.

Bivariate H_a: Provider certification level is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Provider certification level and pre-hospital ETI success are related, $\chi^2(5) = 76.392$, $p < .001$, $\phi_c = .115$..RN/MD/Other provider certification level had the greatest percentage of successes. The hypothesis that EMT-Paramedics would have the greatest percentage of successes was not supported by the result.

Patient Characteristics

Bivariate H_o: Gender and pre-hospital ETI success are independent.

Bivariate H_a: Gender is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was accepted. Gender and pre-hospital ETI success are independent, $\chi^2(1) = 0.67$, $p = .411$.

Bivariate H_o: Race and pre-hospital ETI success are independent.

Bivariate H_a: Race is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Race and pre-hospital ETI success are related, $\chi^2(3) = 227.13, p < .001, . \phi_c = .120.$ It was hypothesized that Whites would have the greatest percentage of successes. The hypothesis was supported by the result.

Bivariate H_o*:* Ethnicity and pre-hospital ETI success are independent.

Bivariate H_a *:* Ethnicity is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Ethnicity and pre-hospital ETI success are related, $\chi^2(1) = 15.393, p < .001, \phi_c = .053.$ The hypothesis that non-Hispanics would have a greater percentage of successes was supported by the result.

Bivariate H_o*:* Possible injury and pre-hospital ETI success are independent.

Bivariate H_a *:* Possible injury is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was accepted. Possible injury and pre-hospital ETI success are independent, $\chi^2(1) = 1.764, p = .184, . \phi_c = .018.$

Bivariate H_o*:* Chief complaint organ system and pre-hospital ETI success are independent.

Bivariate H_a *:* Chief complaint organ system is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Chief complaint organ system and pre-hospital ETI success are related, $\chi^2(4) = 414.9, p < .001, \varphi_c = .269.$ The hypothesis that pulmonary complaints would have the greatest percentage of successes was supported by the result.

Bivariate H_o*:* Cardiac arrest and pre-hospital ETI success are independent.

Bivariate H_a *:* Cardiac arrest is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Cardiac arrest and pre-hospital ETI success are related, χ^2 *(2) = 109.38, < .001,* ϕ_c *= 138.* The hypothesis that patients in cardiac arrest would have a greater percentage of successes was not supported. Patients not in cardiac arrest had the greatest percentage of successes.

Bivariate H_o*:* Cardiac arrest etiology and pre-hospital ETI success are independent.

Bivariate H_a *:* Cardiac arrest etiology is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Cardiac arrest etiology and pre-hospital ETI success are related, $\chi^2(4) = 36.106, p < .001, \phi_c = .079$. The hypothesis that presumed cardiac etiology had the greatest number of successes was supported by the result.

Bivariate H_o*:* Age and pre-hospital ETI success are independent.

Bivariate H_a *:* Age is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was not rejected. Age and pre-hospital ETI success are independent, χ^2 $(10) = 16.905, p = .077$.

Bivariate H_o*:* Response level and pre-hospital ETI success are independent.

Bivariate H_a*:* Response level is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was not rejected. Response level and pre-hospital ETI success are independent, $\chi^2(3) = 0.39, p = .941$.

Bivariate H_o*:* Return of spontaneous circulation (ROSC) and pre-hospital ETI success are independent.

Bivariate H_a*:* ROSC is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. ROSC and pre-hospital ETI success are related, $\chi^2(3) = 13.293, p = .004, \phi_c = .048$. The hypothesis that the greatest number of successes would be in individuals without ROSC was not supported by the hypothesis. The greatest numbers of successes were in individuals with ROSC prior to EMS arrival and at the ED.

Bivariate H_o*:* Pulse oximetry and pre-hospital ETI success are independent.

Bivariate H_a*:* Pulse oximetry is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Pulse oximetry and pre-hospital ETI success are related, $\chi^2(5) = 65.92, p < .001, \phi_c = .107$. The hypothesis that patients with lower pulse oximetry would have a greater percentage of successes was not supported by the results. Patients with a pulse ox of 90% to 100% had the greatest number of successes.

Bivariate H_o*:* Glasgow Coma Score (GCS) and pre-hospital ETI success are independent.

Bivariate H_a*:* GCS is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. GCS and pre-hospital ETI success are related, $\chi^2(4) = 183.11, p = .001, \phi_c = .057$. The hypothesis that patients with a low GCS would have the greatest number of successes was not supported by the results. The results were mixed. Patients with a GCS of four to five and 13 to 15 had the greatest number of successes.

Bivariate H_o*:* First monitored heart rhythm and pre-hospital ETI success are independent.

Bivariate H_a*:* First monitored heart rhythm is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was not rejected. First monitored heart rhythm and pre-hospital ETI success are independent, χ^2*(9) = 9.24, p = .415.*

Bivariate H_o*:* Pulse rate and pre-hospital ETI success are independent.

Bivariate H_a*:* Pulse rate is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was not rejected. Pulse rate and pre-hospital ETI success are independent, χ^2*(5) = 4.706, p = .452.*

Bivariate H_o*:* Respiratory rate and pre-hospital ETI success are independent.

Bivariate H_a*:* Respiratory rate is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was not rejected. Respiratory rate and pre-hospital ETI success are independent, χ^2*(7) = 13.115, p = .069.*

Bivariate H_o*:* Systolic blood pressure and pre-hospital ETI success are independent.

Bivariate H_a*:* Systolic blood pressure is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was not rejected. Systolic blood pressure and pre-hospital ETI success are independent, χ^2*(7) = 10.371, p = 168.*

Process Hypotheses

Bivariate H_o*:* Response mode to scene and pre-hospital ETI success are independent.

Bivariate H_a*:* Response mode to scene is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Response mode to scene and pre-hospital ETI success are related, χ^2*(1) = 57.474, p < .001,* ϕ_c *= .101.* The hypothesis that the greatest number of successes would occur when an ambulance uses lights and sirens when responding to the scene was not supported by the result. Ambulances that responded with no lights and sirens had the greatest percentage of successes.

Bivariate H_o*:* Transport mode from scene and pre-hospital ETI success are independent.

Bivariate H_a*:* Transport mode from scene is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Transport mode from scene and pre-hospital ETI success are related, χ^2*(1) = 61.209, p < .001,* ϕ_c *= .103.* The hypothesis that ambulances transport patients from the scene to the emergency room with lights and sirens would have the greatest percentage of successes was not supported by the result. The results suggest the greatest number of successes occur in ambulances that do not use lights and sirens.

Bivariate H_o*:* Number of procedure attempts and pre-hospital ETI success are independent.

Bivariate H_a*:* Number of procedure attempts is related to pre-hospital ETI success.

Test: Pearson's chi-square test of independence

The null hypothesis was rejected. Number of procedure attempts and pre-hospital ETI success are related, χ^2*(2) = 195.240, p < .001, .* φc *= .185.* The hypothesis that fewer attempts leads to greater success was supported by the result.

CHAPTER V

DISCUSSION

The purpose of this research was to construct valid and reliable models that predict pre-hospital endotracheal intubation (ETI) success using Donabedian's Quality of Care Model as a framework. We titled the first model the "National Model". This National Model is based on the 2013 NEMSIS data. The second model incorporated NEMSIS variables and the embedded vital signs gleaned from state data. From this information we created the "Comprehensive State Model", which is a four state regional representation of U.S. EMS data for 2013. Both models were successful in identifying statistically significant factors that are associated with successful pre-hospital ETI. This chapter will cover the major study findings in relation to the current state of the science, including how our results relate to or differ from current findings as reflected in the literature.

Model-Guided Analysis

Donabedian's Quality of Care Model and significant data variables derived from the National and Comprehensive models can be found in Figure 13. In the analysis of the national data, we revealed, among the different types of services that could be requested, there were significantly better odds of pre-hospital ETI success when planned medical and inter-facility transports were requested when compared to the reduced success level of emergency (9-1-1) responses. Medical transports and interfacility transfers had 135% and 83%, respectively, greater odds of success than 9-1-1 responses.

Our results might be explained in a number of ways: medical transports and interfacility transfers utilize providers with more advanced care certification levels and/or licenses as providers, and they also have prior knowledge of the patients' medical condition. Additionally, this type of planned service transport tends to be less chaotic an environment. They do not use

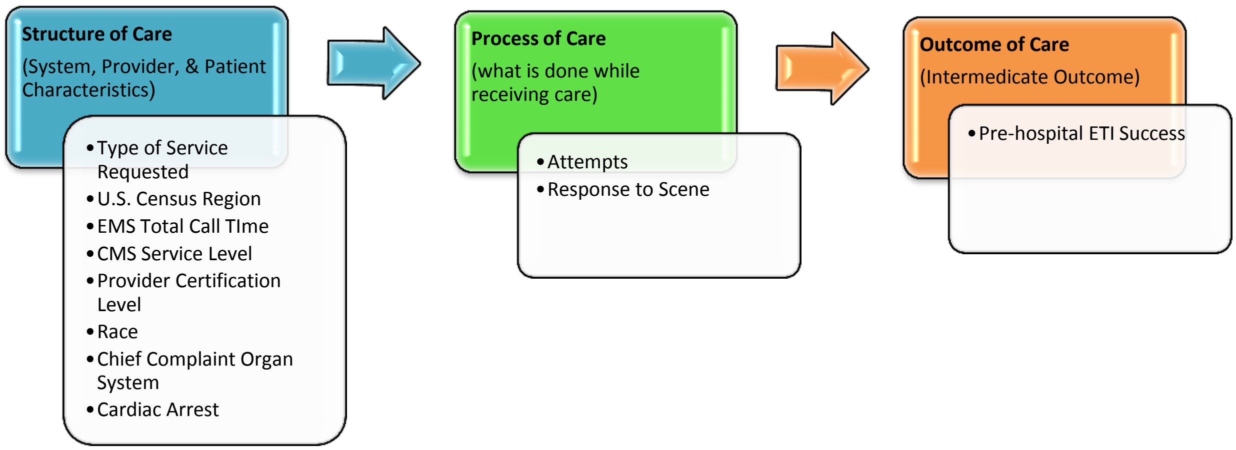

Figure 13. Donabedian's Quality of Care Model and Significant Variables Derived from the National and Comprehensive Models. The white boxes contain the components of Donabedian's model. The grey boxes contain significant variables found by National and Comprehensive model analysis.

lights and sirens, which can create stress and heightened anxiety in the patient as well as in the provider. When lights and sirens are indicated and used, the ambulance driver may be required to swerve to avoid traffic to allow continued progress to the hospital emergency department making for a rather rough ride in which to try to intubate. Additionally, as sound is the last of our senses to leave a person as they lose consciousness (Sisson, 1990), the wale of the siren may create an adrenaline rush secondary to the patient's fear. Sometimes even weak and hypoxic patients can become combative as they struggle for air, making the EMS provider's job even more difficult (Wang, Kupas, Paris, et al., 2003). Fighting for air and fear-induced tachycardia can further complicate the patient's already declining health status. So, when searching the literature for further information related to these transport effects, it was noted that there is a significant gap in the literature with regard to type of service requested and how it aids the prediction of pre-hospital ETI success. Consequently, we strongly recommend that further study be conducted in this interesting area as it is needed to examine this relationship.

We found U.S. census region to be a significant predictor of pre-hospital ETI success in both the National and Comprehensive State Models. Our results are in accord with Bulger (2007) who found significant regional differences in pre-hospital ETI success when examining differences in national trauma care. This regional variation in pre-hospital ETI success rates may be due to varying protocols for out-of-hospital treatment, variance in emergency medical provider educational curricula and standards for entering practice, as well as the variety of different provider certification levels across census regions (Bulger, 2007). We show the differences in provider certification levels in the four states in Table 17. Future research needs to take into account the variability in current practice and skill of EMS providers involved in the study.

We found EMS total call time to be a significant predictor of pre-hospital ETI success in the National Model. Surprisingly, longer call times were found to have greater odds of success compared to shorter call times. Longer call times could be explained by geographic distance or less injury severity of patients. No other researchers have examined EMS total call time and the variables predictive nature as it relates to the success of pre-hospital ETI, therefore nothing corroborates this finding. This finding may have come from a skewed sampling distribution. This covariate intuitively should not directly affect pre-hospital ETI success. This factor is present primarily because of the systematic nature of statistical modeling. EMS total call time

Table 17

Example of State Provider Certification Levels and Skill

State	Certification Levels	Skill examples
Maine	Basic Emergency Medical Treatment	
	Emergency Medical Responder (EMR)	Patient immobilization for transport, patient loading, and patient care directly supervised by providers licensed above the EMR level.
	Emergency Medical Technician (EMT)	Basic care including non-medicated IV maintenance. Set up IV fluid equipment and attachment of cardiac monitor leads to patient. Assist patient with own medication.
	Advanced Emergency Medical Treatment	
	Advanced Emergency Medical Technician (AEMT)	Blind insertion airway devices, IV/IO therapy, blood sampling, cardiac monitoring/counter shock, drug administration per protocol.
	EMT-Critical Care (EMT-CC)	ETI, magill forceps for foreign body airway obstruction, drug and medication administration as approved by protocol.
	Paramedic	ETI, magill forceps, drug and medication administration by protocol, chest decompression, transtracheal insufflation, cricothyroidotomy, other techniques published by the Board.
Virginia	Basic Emergency Medical Treatment	
	Emergency Medical Responder (EMR)	Nasopharyngeal airway, pressure points for hemorrhage control, nasal cannula oxygen, non-rebreather face mask, AED, BVM, auto injector, blood pressures, eye irrigation.
	Emergency Medical Technician (EMT)	Insertion of nasogastric and orogastric tubes, supraglottic airway devices remove activated charcoal from formulary, oxygen humidifiers, partial rebreather masks, face masks, Venturi masks, pulse oximetry, blood glucose, automated transport ventilators, patient restraint, assist patient own medication, nebulizer treatment, aspirin by mouth, auto injector, foley catheter
	Advanced Emergency Medical Treatment	
	Advanced Emergency Medical Technician (AEMT)	IV access and infusion, IO access
	Intermediate (EMT-I)	ETI over 12 years of age, administer protocol medications, BiPAP/CPAP, manage chest tube, cricothyroidotomy, monitor end-tidal carbon dioxide, waveform capnography, PEEP, multi-lead EKG, synchronized cardioversion, carotid massage, central line monitoring, IO insertion, IV medication

Table 17

Continued

State	Certification Levels	Skill examples
Virginia (continued)	Paramedic	thrombolytic meds, blood chemistry analysis, ETI with adult neuromuscular blockage, pediatric paralytics, pediatric sedation, nasotracheal intubation, cricothyroidotomy, blood administration,,
Utah	Basic Emergency Medical Treatment	
	Emergency Medical Responder	Basic lifesaving and first aid
	EMT-Basic	Basic care and transportation, activated charcoal, oral glucose, metered dose inhalers, BVM, nasopharyngeal airway, oral pharyngeal airway, oxygen by nasal cannula and masks, CPR, semiautomatic defibrillation
	Advanced Emergency Medical Treatment	
	Advanced EMT (AEMT)	same as EMT-Intermediate
	EMT-Intermediate	medications vary by agency, physical exam, end-tidal carbon dioxide, extubation, pulse oximetry, defibrillation, draw blood samples, blood glucose, administer medications orally, IV, subcutaneously, intravenously, and endotracheal,
	EMT Intermediate Advanced	end-tidal carbon dioxide, foreign body airway removal, ETI and dual lumen airways, nasogastric and orogastric tubes, IV administration, cannulation of external jugular, interpret cardiac dysrhythmias, needle chest decompression, newborn resuscitation, rectal medication
	Paramedic	Cricothyroidotomy, subclavian vein access
Illinois	Basic Emergency Medical Treatment	
	First Responder	BVM, AED, Oxygen administration, trauma assessment, medical assessment
	EMT-Basic	Shock management, joint immobilization, long bone immobilization, spinal immobilization, trauma assessment
	Advanced Medical Treatment	
	Advanced EMT	IV therapy, bolus medications, pediatric IO infusion
	EMT-Intermediate	supraglottic airway devices

Table 17

Continued

State	Certification Levels	Skill examples
Illinois (continued)	Paramedic	dynamic and static cardiology, pediatric ventilatory management ETI, adult ETI
	Pre-hospital Registered Nurse	
	Emergency Communications Registered Nurse	

BVM = bag valve mask, Information retrieved from: Maine Department of Public Safety (2013), Illinois Department of Public Health (2016), Utah Bureau of EMS. (2010), Virginia Department of EMS (2011).

should not be misinterpreted to constitute a direct causal relationship. Further research is needed on this topic. We recommend high quality pre-hospital care in the minimum amount of time necessary to get the patient safely to definitive in-hospital care. Sampalis, Denis, Lavoie, Frechette, Boukas, Nikolis, & Mulder (1999) showed that for every minute of additional pre-hospital time, the risk of dying increased by 5% when examining regionalization of a trauma system in Quebec. We place the emphasis on quality medical care. Research has also shown that the time saved by transporting with lights and sirens does not provide "extra" time at the hospital for life-saving treatments (Marques-Bapista, Ohman-Stricklamd, Baldino, Praston, & Merlin, 2010). Eighty percent of cases where collisions occurred happened when the ambulance was operating with lights and sirens (Sanddal, Sanddal, Ward, & Stanley, 2010).

Our national model found that the odds of pre-hospital ETI success were greater when patients received the highest levels of transport care and resources per the Center for Medicare and Medicaid Services (CMS). These service transport platforms include fixed-wing air medical services, rotary wing helicopter services, paramedic intercept, specialty care transport, advanced life support, and basic life support. We found the odds of success to be significantly greater for rotary wing helicopter (OR = 2.2), paramedic intercept (OR = 0.64), and specialty care transport

(OR = 1.6) when compared to the staffing and resources of units that maximally provided advanced life support. We found the odds of success were also greater for fixed-wing air medical service (OR = 1.6) when compared to advanced life support, but we found the result to be insignificant.

These results could be explained by the fact that helicopter, air medical services, and specialty care transport often include the provision of medically necessary supplies and services beyond the scope of an EMT-Paramedic. The patient may require ongoing care by professionals in an appropriate specialty such as emergency or critical care nursing, emergency medicine, respiratory or cardiac care, or paramedics with additional training such as a critical care paramedic. Paramedic intercepts occur when a patient being transported on a basic life support ambulance requires advanced life support services (Centers for Medicare and Medicaid Services, 2011). Critical care paramedics and specialty care service providers often have more experience and provide pre-hospital ETIs at greater frequencies than advanced life support paramedics. Air medical outcomes have been found to be better than ground transport in both intubated and non-intubated patients (Davis, Peay, Sise, Kennedy, Simon, Tominaga, Steele, Coimbra, 2010). Wang, et al., 2005 found ETI frequency to be associated with higher patient volume. Pre-hospital ETIs are performed more frequently by both air medical and urban providers. Current evidence suggests a positive association between paramedic experience and ETI procedural frequency and pre-hospital ETI success (Garza, et al., 2003; Pointer, 1988; Wang, Kupas, Hostler, Cooney, Yealy, & Lave, 2005; Wang, Seitz, Hostler, and Yealy, 2005).

We found provider certification level to be a significant predictor of pre-hospital ETI success in the Comprehensive State Model. Registered Nurses (RNs), medical doctors (MDs), and other professional licensed care providers were found to have a 3.4 greater odds of success than EMT-Paramedics. Other studies have corroborated this finding (Hubble, et al., 2010; Lossius, Roislien, and Lockey, 2012; Timmerman, Russo, and Hollmann, 2008). Diggs, et al., 2014 also found provider certification level to be a significant multivariate predictor of pre-hospital ETI success.

Better training of EMS personnel may improve the success rate of pre-hospital ETI. Prekker, et al, (2014) demonstrated a 99% pre-hospital ETI success rate in a Washington EMS system that devoted resources to paramedic acquisition and maintenance of airway management skills. This success rate is comparable to success rates of emergency physicians and trainees in the emergency department. A relationship between the number of ETI experiences and ETI success is currently supported by research (Bernhard, Mor, Weigand, Martin, and Walther, 2012). Paramedics are required to perform a minimum of five ETIs for national certification in the U.S. In Europe, most ambulances are manned by physicians. German EMS systems require 25 to 50 intubations for physicians participating in their EMS system. A survey of U.S. based paramedic training programs reported the median number of ETIs per student was seven and suggested 20-25 ETIs were required to achieve an overall success rate of 90% (Wang, Seitz, Hostler, and Yealy, 2005). ETI success rates show no correlation with the total number of hours of annual training, but a relationship exists between pre-hospital ETI success rate and ETI training frequency (Warner, Carlbom, Cooke, Bulger, Copass, & Sharar, 2010). Thus, U.S. EMS providers need more continuous training in ETI skill maintenance to improve pre-hospital success rates.

We found race to be a significant predictor of pre-hospital ETI in both the National Model and Comprehensive State Model. Anthropomorphic differences between races, as well as within races, could explain this phenomenon. No other researchers have examined race as a predictor of pre-hospital ETI success. Further exploration of the contribution of this variable is needed. For example, are there states wherein persons from one race are overrepresented, and/or experience health and health care disparities that result in higher prevalence of cardiovascular disease as compared to other states or regions?

When examining cardiac arrest, the Comprehensive State Model revealed that the odds of success were 26% less when a patient had a cardiac arrest after EMS arrival and 7% greater when a patient had a cardiac arrest prior to EMS arrival when compared to not having a cardiac arrest. Table 18 below compiles the various cardiac arrest states and the research reported efficacy of the ETI process initiated at different phases. The research results reflect mixed messages. Process and data quality must be questioned. There may be a need to institute clinical protocols that require assessment of cardiac status both pre- and post-EMS arrival and the relationship to pre-hospital ETI success. The most appropriate advanced airway management intervention in pre-hospital cardiac arrest is unproven. Publications have suggested that pre-hospital ETI may not be the best technique for airway management in cardiac arrest (Lyon, Ferris, Young, McKeown, Oglesby, Robertson, & Field, 2010). Cardiac arrest patients require adequate oxygenation, which can be achieved by basic airway management, such as with the use of a bag valve mask. Pre-hospital ETI is associated with significant complications and may reduce survival. Repeated attempts at laryngoscopy and the inability to perform a successful ETI compromises oxygenation and ventilation, extends on time on scene, and increases the risk of aspiration. Intubating patients after a traumatic cardiac arrest may be challenging due to airway trauma. We recommend using the most appropriate airway technique, which may be bag-valve-mask, to provide the patient with maximal oxygenation and minimal interruption in chest compressions during CPR when treating pre-hospital cardiac arrest patients. We concur with

Lyon, et al. (2010) that the use of pre-hospital ETI as a routine intervention in cardiac arrest should be reconsidered.

Table 18

Pre-Hospital ETI Success and Cardiac Arrest Status

Reference	National EMS Database	State EMS Data	No Cardiac Arrest	When Arrest Occurs Before EMS Arrives: Relative Success to no cardiac arrest	When Arrest Occurred after EMS Arrived : Relative Success to no cardiac arrest	ETI Attempted With Patient in Cardiac Arrest
This study		X			26% < success	
		X		7% > success		
Wang et al., 2001		X				> rates of success
Hubble, et al., (2010)		X				> rates of success
Hansen et al., 2015	X					< rates of success

We found the variable, chief complaint organ system, to be a significant predictor of ETI success in both the National and Comprehensive State Models. We found that there was less likely odds of success for central nervous system/neurological (CNS/Neuro) complaints, global complaints, other (endocrine/metabolic, obstetric [OB/Gyn], skin, musculoskeletal, psych, and renal), and pulmonary when compared to cardiovascular complaints. Cardiac arrest could facilitate pre-hospital ETI success because the patient may be unconscious, more malleable, and without restriction, so they are can be more easily positioned and intubated.

Our multivariate analysis of both Models highlighted the significance of pre-hospital ETI attempts for predicting pre-hospital endotracheal intubation success.. This is not to support the notion that ETI attempts should be repeated until ETI is achieved. The goal of emergency airway management is to complete pre-hospital ETI in a correct, safe, and quick manner. Repeated ETI attempts increase patient morbidity and mortality (Wang and Yealy, 2006). Most U.S. paramedic protocols limit the number of ETI attempts on a patient to a maximum of three. This study showed a decline in the odds of success with each successive attempt. The National Model showed a 36% decrease in the odds of success with two attempts and a 60% decrease in the odds of success with three or more attempts when compared to one attempt. The Comprehensive Model suggests a 66% decrease in the odds of success with two attempts and a 61% decrease in the odds of success for three attempts when compared to one attempt. Routine use of ETI is necessary to maintain proficiency. Enhanced training, exposure, and equipment will act to improve pre-hospital ETI success rates and decrease the number of attempts to perform a successful ETI.

` Response mode to scene was also found to be a significant predictor of pre-hospital ETI success in the Comprehensive State Model. The odds of success were 2.2 times higher when no lights and sirens were used compared to when lights and sirens were used. Time may be saved when using lights and sirens (Ho and Casey, 1998), but the risk of accident and the hazard to EMS providers is greater (Kahn, 2001). Brown, Whitney, Hunt, Addario, & Hogue (2009) showed that lights and sirens reduced response times an average of one minute and 46 seconds. This amount of time saved is likely to be clinically relevant in only a very few cases. One marker of quality EMS care is measured by meeting an eight minute response-time guideline. Recent evidence has shown that a paramedic response time within eight minutes was not associated with improved survival to hospital discharge after controlling for several confounders, including severity of illness (Pons, Haukoos, Bludworth, Cribley, Pons, & Markovchick, 2005).

Limitations

This retrospective exploratory study has several limitations. The accuracy of self-reported data can be questioned and is subject to substantial bias. It is possible that misclassification of the outcome variable, pre-hospital ETI success, and the predictor variable, ETI attempts occurred as these were self-reported variables. ETI success was determined by EMS personnel in the field and not verified by emergency care personnel or other health care providers on hospital arrival because these elements were not present in the data sets. The misclassification of number of attempts may be attributed to the paramedic's negative perception of multiple ETI attempts. More than likely, non-differential misclassification occurred, causing results to be biased towards the null. If differential misclassification had occurred, the estimated measures of effect were large enough, and it was unlikely that bias completely accounted for these findings (Jurek, Greenland, Maldonado, & Church, 2005).

Data quality was poor in both the NEMSIS and State data sets. The proportion of missing data in both the NEMSIS and State data sets was high for many variables, especially physiologic variables in the state data. Only 6,261 observations of 79,450 in the NEMSIS data and 47 of 8,182 in the state data were left after excluding all observations with at least one missing cell. Both data sets had great differences between the non-missing and original data, so multiple imputation was necessary. NEMSIS TAC has suggested that NEMSIS data are not missing at random; this has implications for the imputation methods used to provide plausible values for missing data. Multiple imputation is more advantageous for valid statistical inference and the prevention of type I errors, especially in large data sets. We assumed the data to be missing at random which may have produced biased results. Schafer and Graham (2002) concluded that multiple imputation is often unbiased with missing not at random data even though the data is assumed as missing at random.

The purpose of this research was to identify a set of factors that would be predictive of ETI in the pre-hospital environment linking EMS data. We were looking to identify the following variables in the data at hand, for example: length of time in EMS service, to include any corresponding military service such as a corpsman or medic. Upon investigation important variables were unavailable. Public release is not permitted. Consequently, our data set relied upon two major sources, NEMSIS and State data. The NEMSIS data set, as well as some of the state datasets that we received, did not consistently include several system, provider, and patient characteristics. System characteristics not included in the NEMSIS Version 2.2 Public Release Research Data Set were organization type, total service size area of the organization, total service area population, patient contact volume per year, or medical director's specialty. Additionally, the NEMSIS data set does not afford provider's demographic characteristics, as well as length of service and number of patient contacts per year. Patient variables not included in the NEMSIS data were patient height, weight, presence of clenched jaw/trismus, and presence of intact gag reflex. Many process variables could not be included due to the data possessing no time stamp on the procedure such as placement of electrocardiograph monitoring prior to ETI procedure and intravenous access prior to ETI attempts. We attempted to decrease the NEMSIS data-related limitations by collecting State data and constructing the Comprehensive State Models.

NEMSIS data is subject to the limitations of any convenience sample, namely subject to bias such as selection and information (Mantal and Haenszel, 1959). NEMSIS national data are submitted voluntarily from EMS agencies and states that are committed to monitoring and improving the care of patients transported by EMS. The data may not be representative of all states or EMS agencies in the nation and thus do not allow inferences about national incidence or prevalence. States also have different criteria for including patients in statewide EMS databases. Some states may include all 9-1-1 calls, while others may limit case additions to patient contacts or transports (NEMSIS TAC Steering Committee, 2010).

Implications

Clinical Implications. Provider type and amount of experience with pre-hospital ETI often varies. We found that CMS service level and provider certification level were significant predictors of pre-hospital ETI success. Hence, it is essential that EMS providers have a standard number of experiences with pre-hospital ETI for purposes of achieving minimal competence before entering practice. Simulation may be the best educational mode for helping providers to achieve clinical competency in this area. Simulated scenarios can provide structured opportunities for learning the knowledge and skill-set necessary to produce consistent success with pre-hospital EIT. Simulated cardiac events, traumatic injuries, and mass casualty scenarios allow EMS students and providers to experience different environments and the challenges they may encounter. Notably, computerized mannequins allow for realistic simulation of human physiology. Hall, et al., 2008 showed that paramedic students who were trained on simulators were as effective as students trained in the operating room. Therefore, simulations would allow students and providers to experience environmental issues that impact the senses such as moving ambulances, poor and brightly lit conditions, and interference by other motor vehicles as well as the variety of places where pre-hospital ETI must be performed.

EMS providers must be required to document a consistent and standardized record of the process and patient characteristics concerning pre-hospital health care encounters including ETI. This was reinforced by the poor quality of the data that we received from both the NEMSIS and the states. In some cases, as much as 85% of data was missing, including essential information such as patient vital signs. Clinical protocols for documentation must be mandated and standardized. The adoption of a national framework for data collection and documentation, such as the Utstein-style template for the uniform reporting of data from pre-hospital airway management, may be quite useful.

Policy Implications. The Triple Aim for improving health care systems has been proposed by the Institute of Healthcare Improvement (IHI) in 2008. This aim is threefold: a) to improve the patient experience of care (including quality and satisfaction), b) to improve the health of populations, and 3) to reduce the capita cost of health care (Whittington, et al., 2015). Achieving the goals of the aim are most relevant as it relates to pre-hospital emergency care. Because airway management and its association with patient health outcomes is the most important procedure performed by pre-hospital care providers, the need to create standardization of data collection is eminent. Any progress toward achievement will be impossible without mandated policies, rules, and regulations regarding standardization of EMS data collection, pre-hospital emergency care language and terminology, as well as preparation and education of EMS providers (Berwick, Nolan, & Whittington, 2008). Federally and state generated policies that mandate standardized data collection on pre-hospital intubation would allow studies to be compared across systems and type of patient and may allow the formation of recommended guidelines and evidence-based practice. Lack of standardization is a reflection on the quality of care and cripples the interoperability of EMS systems. A position statement on recommended guidelines for the uniform reporting of data from pre-hospital airway management was suggested by the National Association of EMS Physicians in 2006, and an Utstein-style template for uniform reporting of data from pre-hospital airway management was suggested from the European Pre-hospital Advanced Airway Management Expert Group in 2009. Neither format has been used by researchers at this time. The Utstein criteria for uniform reporting has allowed recent advances in cardiac pulmonary resuscitation and cardiac arrest survival (Soreide, 2013) and should be implemented for airway management.

Another hindrance to evaluating pre-hospital ETI success is the lack of uniform operational definitions, terminology, and reporting formats. The development of standard definitions and terminology would facilitate comparisons of data from multiple sources. Reporting formats should be made easy to use, so providers in the field fill out the forms. Checklists could be used instead of narratives that provide little value to researchers looking at data on the national scale.

There is a substantial variance in standards for EMS provider education. Certification levels, education requirements, and scope of practice vary from state to state and region to region. Of 30 states and territories that responded to a 2005 survey, 39 different licensure levels were identified between EMT and Paramedic levels (NHTSA, 2006). See Table 17 as an example of varying certification levels and skills performed by EMS providers. Therefore, policymakers must develop and mandate standardized paramedic certification levels and standards of training. The National Highway Traffic and Safety Administration and Heath Resources and Services Administration have a model scope of practice. The National Scope of Practice Model defines four levels of EMS licensure: 1) Emergency Medical Responder (EMR), 2) Emergency Medical Technician (EMT), 3) Advanced EMT (AEMT), and 4) Paramedic. This has great potential to serve as a framework for states' development of scope of practice legislation, rules, and regulations. EMS quality of care depends on a nationwide adoption of this framework. Such an adoption would create the platform for establishing more widely accepted terminology and competencies for EMS providers nationwide; making reciprocity easier between states, enhancing professional mobility, and creating a greater understanding of EMS.

Research Implications. Most of the published EMS research retrospectively focused on a single intervention or health problem rather than prospectively assessing more comprehensive system-level issues. Our study unearthed system level challenges such as variability in pre-hospital ETI success between U.S. census regions ranging from 43% to 85%. This variability requires an in-depth assessment of operational and structural factors including what is the optimum system configuration, what type of provider preparation and level of expertise is associated with the greatest success, and which patient characteristics portend the least success. Detangling the basis for this is quite challenging due to fragmentation of the U.S. EMS system. State and local areas have various EMS system structures. EMS systems may be fire-based, operated by municipal or county governments, private companies including both profit and non-profit ambulance provider-based, or hospital-based. In fact, there are more than six thousand 911 call centers which may be run by police, fire, county, city governments, or other entities (Committee on the Future of Emergency Care in the United States Health System, 2007). Therefore, foundational work that takes a mixed-methods qualitative approach including interviewing and/or direct observation of EMS system administrators, providers, and patients in addition to quantitative surveys may be necessary to discover which phenomena are associated with pre-hospital ETI success or lack of success.

Presently, there is great variability related to what is documented about pre-hospital ETI and airway management. Hence, there is limited ability to compile evidence about the state of airway management in the U.S. health care system. As previously discussed, an Utstein-based template for the uniform reporting of pre-hospital airway management has been proposed (Sollid, Lockey, Lossius, and the Pre-hospital Advanced Airway Management Expert Group, 2009). However, the template has not been adopted for EMS practice. Therefore, we assert that some level of consensus regarding which variables must be reported in research studies of airway management and pre-hospital ETI success are essential to making accurate comparisons of results across studies thereby increasing the generalizability of results and advancing the science.

Future Directions

We conducted a preliminary examination of the relationship between structural variables as well as process variables and pre-hospital ETI success. Our National and Comprehensive State models revealed variability among census regions and pre-hospital ETI success. Therefore, the nuances associated with this variability necessitate further exploration. Is EMS provider education standardized in those regions resulting in greater success? What are the average EMS total call times? What structural factors are in place including across region standardized protocols for pre-hospital ETI? Do structural factors such as standardized regulatory oversight exist in the States in those regions? In addition, we propose that future studies investigate outcomes associated with pre-hospital ETI. For example, is successful pre-hospital ETI ultimately associated with better intermediate and long-term patient outcomes? We assert that these questions must drive future research.

The lack of standardization among education, accreditation, provider type and experience level, and equipment cripples the interoperability of EMS systems. To enhance EMS, more systems research needs to be conducted. Future research needs to examine EMS systems which have the best outcomes for pre-hospital ETI and use the best practices evidence derived from these systems as examples on how to redefine training, staffing, and emergency response.

Future research models need to split data into patient-specific groups (e.g. cardiac arrest, non-arrest, and pediatrics) to see if different variables aid in the prediction of ETI success among a variety of populations. Future research needs to examine more multivariate relationships so we can make decisions on what variables are important in examining pre-hospital ETI success and outcomes. The National and Comprehensive State Models explained nine percent and 25 percent, respectively, of the variance for pre-hospital ETI success. More system, patient, and provider factors should be measured and examined. Health care service providers and researchers need to communicate with EMS providers so that every patient contact needs to be fully explained and documented to allow examination of high quality data. NEMSIS is still in its infancy, and as electronic patient records become more interoperable among systems and agencies more models need to be created and expanded. Policies need to be developed to allow researchers greater access to EMS data.

Conclusion

Our study revealed a low success rate of pre-hospital ETI at the national (79%) and regional (61%) level, similar to many system-level studies. In addition, the study highlighted the significance of several factors. Type of service requested, EMS total call times, U.S. census region, CMS service level, provider certification level, race, chief complaint organ system, and cardiac arrest were all found to be significant structure predictors of ETI success. The addition of process variables including the number of pre-hospital ETI attempts and response mode to the scene explained a substantial amount of variance of pre-hospital endotracheal intubation success.

Our results highlighted the importance of using theory when determining which relationships should be explored among variables.

In the future, we plan to conduct research that focuses on clarifying relationships between each factor and pre-hospital endotracheal intubation success. We will also design and implement studies that further examine the processes surrounding pre-hospital in greater detail. Systems that have the best patient outcomes need to be examined further. Researchers must use Utstein templates to frame data collection to allow comparisons between different populations and EMS systems. These approaches will help clarify the use of advanced airway management and help to develop more evidence-based guidelines for EMS providers. This will add to the body of knowledge while informing policy development and further development of best practices for the U.S. Emergency Medical System.

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APPENDIX A

Utstein Template for the Uniform Reporting of Pre-Hospital Airway Management Data

Data variable name	Type of data	Data variable categories or values	Definition of data variable
Core system variables			
Highest level of EMS provider on scene	Ordinal	1 = EMS non-Paramedic 2 = EMS Paramedic 3 = Nurse 4 = Physician 5 = Unknown	Highest level of EMS personnel on scene, excluding any non-EMS personnel (bystanders, family, etc.)
Airway devices available on scene	Nominal	1 = Bag Mask Ventilation 2 = SAD 3 = ETT 4 = Surgical airway 5 = None 6 = Unknown	Airway devices available on scene and provider on-scene who knows how to use it (select all that apply)
Drugs for airway management available on scene	Nominal	1 = Sedatives 2 = NMBA 3 = Analgesics/opioids 4 = Local/topical anesthetic 5 = None	Drugs used for airway management, available on scene and someone competent to administer them (select all that apply)
Main type of transportation	Nominal	1 = Ground ambulance 2 = Helicopter ambulance 3 = Fixed-wing ambulance 4 = Private or public vehicle 5 = Walk-in 6 = Police 7 = Other 8 = Not transported 9 = Unknown	Main type of transportation vehicle (if multiple selected, vehicle used for the majority of the transportation phase)
Response time	Continuous	Minutes	Time from when the Emergency Medical Communication Centre operator initiates transmission of the dispatch message to the first resource/unit time of arrival on the scene of the first unit, as reported by the first unit

Continued

Data variable name	Type of data	Data variable categories or values	Definition of data variable
Core patient variables			
Co-morbidity	Ordinal	1 = No (ASA-PS = 1) 2 = Yes (ASA-PS = 2-6) 3 = Unknown	ASA-PS definition 1 = A normal healthy patient 2 = A patient with mild systemic disease 3 = A patient with severe systemic disease 4 = A patient with severe systemic disease that is a constant threat to life 5 = A moribund patient who is not expected to survive without the operation 6 = A declared brain-dead patient whose organs are being removed for donor purposes
Age	Continuous	YY or MM	Years rounded down. Ages under 1 year are reported in decimals (e.g., 6 month = 0.5 year)
Gender	Nominal	1 = Female 2 = Male 3 = Unknown	Patient gender
Patient category	Nominal	1 = Blunt trauma (incl. burns and strangulation) 2 = Penetrating trauma 3 = Non trauma (incl. drowning and asphyxia) 4 = Unknown	Dominating reason for emergency treatment

Continued

Data variable name	Type of data	Data variable categories or values	Definition of data variable
Indication for airway intervention	Nominal	1 = Decreased level of consciousness 2 = Hypoxemia 3 = Ineffective ventilation 4 = Existing airway obstruction 5 = Impending airway obstruction 6 = Combative or uncooperative 7 = Relief of pain or distress 8 = Cardiopulmonary arrest 9 = Other, specify	Dominating indication for airway intervention
Respiratory rate, initial	Continuous	Number/ Not recorded	First value recorded by the EMS provider on scene
Systolic blood pressure, initial	Continuous	Number/ Not recorded	First value recorded by the EMS provider on scene
Heart rate, initial	Continuous	Number/ Not recorded	First value recorded by the EMS provider on scene
GCS, initial (m/v/e)	Ordinal	Motor 1-6 Verbal 1-5 Eyes 1-4 Not recorded	First value recorded by the EMS provider on scene
SpO2, initial state: with or without supplemental O2	Continuous and nominal	Number/Not record 1 = Without supplemental O2 2 = With supplemental O2 3 = Unknown if supplemental O2	First value recorded by the EMS provider on scene

Continued

Data variable name	Type of data	Data variable categories or values	Definition of data variable
Core post-intervention variables			
Post-intervention ventilation	Nominal	1 = Spontaneous 2 = Controlled 3 = Mixed 4 = Unknown	How is patient ventilated following airway management? If both spontaneous and controlled, choose mixed.
Post-intervention systolic blood pressure (SBP)	Continuous	Number/Not recorded	First value recorded by the EMS provider after finalized airway management.
Post-intervention SpO2	Continuous	Number/Not recorded	First value recorded by the EMS provider after finalized airway management
Post-intervention EtCO2	Continuous	Number/Not recorded	First value recorded by the EMS provider after finalized airway management.
Post intervention heart rate	Continuous	Number/Not recorded	First value recorded by the EMS provider after finalized airway management.
Post-intervention SBP on arrival	Continuous	Number/Not recorded	First value recorded by the EMS provider after patient arrives at hospital.
Post-intervention EtCO2 on arrival	Continuous	Number/Not recorded	First value recorded by the EMS provider after patient arrives at hospital.
Survival status	Nominal	1 = Dead on-scene or on arrival 2 = Alive on hospital arrival 3 = Unknown	Patient survival status: EMS treatment and on arrival at hospital.
Attempts at airway intervention	Nominal	1 = One attempt 2 = Multiple attempts by one provider 3 = Multiple attempts by two or more providers 4 = Unknown	Number of attempts at securing the airway with a supraglottic airway device (SAD) or tracheal intubation (TI).

Continued

Data variable name	Type of data	Data variable categories or values	Definition of data variable
Complications	Nominal	1 = ETT misplaced in esophagus 2 = ETT misplaced in right mainstem bronchus 3 = Teeth trauma 4 = Vomiting and/or aspiration 5 = Hypoxia 6 = Bradycardia 7 = Hypotension 8 = Other, define 9 = None recorded	Problems and mechanical complications recognized on scene and caused by airway management. Physiologic complications (5, 6, and 7) are regarded as such if they were not present before airway intervention and were recorded during or immediately after airway management. The following definitions are used: hypoxia: SpO2 < 90% bradycardia: pulse rate <60 bpm hypotension: SBP < 90
Drugs used to facilitate airway procedure	Nominal	1 = Sedatives 2 = NMBA 3 = Analgesics/opioids 4 = Local/topic anesthetic 5 = None	Drugs used to facilitate the airway intervention. Select all that apply
Intubation success	Nominal	1 = Success on first attempt 2 = Success after more than one attempt and one rescuer 3 = Success after more than one attempt and multiple rescuers 3 = Not successful	Successful intubation defined as tube verified in the trachea. An intubation attempt is defined as attempted laryngoscopy with the intent to intubate
Device used in successful airway management	Nominal	1 = Bag Mask Ventilation 2 = SAD 3 = Oral TI 4 = Nasal TI 5 = Surgical airway 6 = None 7 = Unknown	Device used to manage successful airway or device in place when patient is delivered at hospital/ED.

Note: Taken from: Sollid, Lockey, Lossius, and the Prehospital Advanced Airway Management Expert Group, 2009; ED = Emergency Department, ETT = endotracheal tube, GCS = Glasgow Coma Score, NMBA = Neuromuscular blocking agent, SAD = Supraglottic airway device

APPENDIX B

Descriptive Statistics for National Non-imputed NEMSIS Data

Variable	Total	Missing	Category	N	Percent
Type of Service Requested	79,450	0	911 response (scene)	73,274	92.23
			Intercept	953	1.20
			Interfacility transport	3,896	4.90
			Medical transport	1,100	1.38
			Mutual aid	188	0.24
			Standby	39	0.06
cPrimary Role of the Unit	79,450	0	Non-transport	5,486	6.90
			Rescue	833	1.05
			Supervisor	163	0.21
			Transport	72,968	91.84
US Census Region	79,450	0	Northeast	21,847	27.50
			Midwest	16,438	20.69
			South	31,429	39.33
			West	9,783	12.31
			Island Areas	133	0.17
US Census Division	79,450	0	New England	2,419	3.04
			Middle Atlantic	19,428	24.45
			East North Central	11,538	14.52
			West North Central	4,900	6.17
			South Atlantic	20,976	26.40
			East South Central	3,550	4.47
			West South Central	6,723	8.46
			Mountain	3,565	4.49
			Pacific	6,218	7.83
Urbanicity	77,403	2,047 (2.58%)	Urban	61,843	79.90
			Suburban	6,117	7.90
			Rural	7,884	10.19
			Wilderness	1,559	2.01
CMS Service Level	47,387	32,063 (40.36%)	BLS	889	1.88
			ALS	41,900	88.42
			Paramedic intercept	83	0.18
			Specialty care transport	573	1.21
			Fixed wing (airplane)	128	0.27
			Rotary wing (helicopter)	3,814	8.05

Continued

Variable	Total	Missing	Category	N	Percent
Gender	78,758	692 (0.87%)	Male	47,725	60.6
			Female	31,033	38.4
Race	64,696	15,054 (18.95%)	American Indian or Alaskan Native	561	0.87
			Asian	767	1.19
			Black or African American	12,920	20.06
			Native Hawaiian or Other Pacific Islander	199	0.31
			White	47,777	74.10
			Other race	2,172	3.37
Ethnicity	52,724	22,226 (27.97%)	Hispanic or Latino	2,747	4.8
			Not Hispanic or Latino	54,477	95.2
Possible Injury	67,407	12,043 (15.16%)	No	56,419	83.7
			Yes	10,988	16.3
Chief Complaint Organ System	50,029	29,421 (37.03%)	Cardiovascular	25,406	50.78
			CNS/Neuro	5,606	11.21
			Endocrine/Metabolic	226	0.45
			Global	12,226	24.44
			Musculoskeletal	1,007	2.01
			OB/Gyn	13	0.03
			Pulmonary	4,954	9.90
			Renal	38	0.08
			Skin	216	0.43
Cardiac Arrest	66,356	13,094 (16.48%)	No	21,000	31.65
			Yes, prior to EMS arrival	37,783	56.94
			Yes, after EMS arrival	7,573	11.41
Cardiac Arrest Etiology	31,362	43,588 (54.86%)	Presumed cardiac	25,802	71.95
			Trauma	2,045	5.70
			Drowning	306	0.85
			Respiratory	4,247	11.84
			Electrocution	41	0.11
			Other	3,421	9.54

Continued

Variable	Total	Missing	Category	N	Percent
Response Mode to Scene	79,450	0	Initial Lights and Sirens, Downgraded to No lights and Sirens	471	0.59
			Initial No Lights and Sirens, Upgraded to Lights and Sirens	536	0.67
			Lights and Sirens	70,229	93.70
			No Lights and Sirens	8,214	10.34
Transport Mode from the Scene	68,934	10,516 (13.24%)	Initial Lights and Sirens, Downgraded to No lights and Sirens	1,048	1.32
			Initial No Lights and Sirens, Upgraded to Lights and Sirens	700	0.88
			Lights and Sirens	54,134	68.14
			No Lights and Sirens	13,052	16.43
Number of Attempts	73,932	5,518 (6.95%)	1	61,804	83.60
			2	10,076	13.63
			3	1,770	2.39
			>3	282	0.38
Pre-hospital ETI Success	66,870	12,580 (15.83%)	No	14,166	21.18
			Yes	52,704	78.82

APPENDIX C

Descriptive Statistics for Imputed NEMSIS Data Set

Variable	Total	Category	N	Percent
Type of Service Requested	79,450	911 response (scene)	73,274	92.23
		Intercept	953	1.20
		Interfacility transport	3,896	4.90
		Medical transport	1,100	1.38
		Mutual aid	188	0.24
		Standby	39	0.05
Primary Role of the Unit	79,450	Non-transport	5,486	6.90
		Rescue	833	1.05
		Supervisor	163	0.21
		Transport	72,968	91.84
US Census Region	79,450	Northeast	21,847	27.50
		Midwest	16,438	20.69
		South	31,249	39.33
		West	9,783	12.31
		Island Areas	133	0.17
Urbanicity	79,450	Urban	63,154	79.49
		Suburban	6,246	7.86
		Rural	8,464	10.65
		Wilderness	1,586	2.00
CMS Service Level	79,450	BLS	1,858	2.34
		ALS	71,008	89.37
		Paramedic intercept	230	0.29
		Specialty care transport	928	1.17
		Fixed wing (airplane)	152	0.19
		Rotary wing (helicopter)	5,274	6.64
EMS Total Call Time	79,450	0-15	274	0.34
		16-30	1,884	2.37
		31-45	7,140	8.99
		46-60	13,231	16.65
		61-90	28,423	35.77
		91-120	14,978	18.85
		121-150	6,444	8.11
		151-180	2,736	3.44
		181-210	1,345	1.69
		211-240	779	0.98
		241+	2,216	2.79

Continued

Variable	Total	Category	N	Percent
Gender	79,450	Male	48,181	60.64
		Female	31,269	39.36
Race	79,450	American Indian or Alaskan Native	693	0.87
		Asian	1,310	1.65
		Black or African American	15,196	19.13
		Native Hawaiian or Other Pacific Islander	597	0.75
		White	58,460	73.58
		Other race	3,194	4,02
Ethnicity	79,450	Hispanic or Latino	4,957	6.24
		Not Hispanic or Latino	74,493	93.76
Possible Injury	79,450	No	66,518	83.72
		Yes	12,932	16.28
Chief Complaint Organ System	79,450	Cardiovascular	40,137	50.52
		CNS/Neuro	8,974	11.30
		Global	19,272	24.26
		Pulmonary	8,100	10.20
		Other	2,967	3.73
Cardiac Arrest	79,450	No	27,447	34.55
		Yes, prior to EMS arrival	42,998	54.12
		Yes, after EMS arrival	9,005	11.33
Cardiac Arrest Etiology	79,450	Presumed cardiac	53,735	67.63
		Trauma	6,841	8.61
		Drowning	662	0.83
		Respiratory	10,879	13.69
		Electrocution	113	0.14
		Other	7,220	9.09
Response Mode to Scene	79,450	Lights and Sirens	70,765	89.07
		No Lights and Sirens	8,685	10.93
Transport Mode from Scene	79,450	Lights and Sirens	62,963	79.25
		No Lights and Sirens	16,487	20.75
Attempts	79,450	1	66,312	83.46
		2	10,876	13.69
		3	1,950	2.45
		>3	312	0.39

Continued

Variable	Total	Category	N	Percent
Age	79,450	1-9	844	1.06
		10-19	183	0.23
		20-29	767	0.97
		30-39	4,134	5.20
		40-49	4,476	5.63
		50-59	5,067	6.38
		60-69	8,960	11.28
		70-79	13,097	16.48
		80-89	14,060	17.70
		90-99	12,743	16.04
		100+	15,119	19.03
Success	79,450	No	16,743	21.07
		Yes	62,707	78.93

APPENDIX D

Descriptive Statistics for Non-Imputed State Data Set

Variable	Total	Missing	Category	N	Percent
Type of Service Requested	8,181	0	911 response (scene)	7,875	96.26
			Intercept	30	0.37
			Interfacility transport	204	2.49
			Medical transport	36	0.44
			Mutual aid	36	0.44
Primary Role of the Unit	7,813	368	Non-transport	183	2.34
			Rescue	121	1.55
			Supervisor	49	0.63
			Transport	7,460	95.48
US Census Region	8,181	0	Northeast	285	3.48
			Midwest	3,342	40.85
			South	3,595	43.94
			West	959	11.72
CMS Service Level	2,752	5,429	BLS	34	1.24
			ALS	2,389	86.81
			Paramedic intercept	8	0.29
			Specialty care transport	70	2.54
			Fixed wing (airplane)	10	0.36
			Rotary wing (helicopter)	241	8.76
Provider Certification Level	7,204	977	EMT-Basic	71	0.99
			EMT-Advanced/Enhanced	77	1.07
			EMT-Intermediate	816	11.33
			EMT-Paramedic	6,156	84.45
			RM/MD/Other	84	1.17
Gender	8,144	37	Male	4,935	60.60
			Female	3,209	39.4
Race	6,931	1,250	Asian	47	0.68
			Black or African American	1,985	28.64
			White	4,411	63.64
			Other race	488	7.04

Continued

Variable	Total	Missing	Category	N	Percent
Ethnicity	6,402	1,779	Hispanic or Latino	346	5.40
			Not Hispanic or Latino	6,056	94.60
Possible Injury	7,607	574	No	6,404	84.19
			Yes	1,203	15.81
Chief Complaint Organ System	5,652	2,529	Cardiovascular	2,426	43.56
			CNS/Neuro	393	6.95
			Global	2,287	40.46
			Other	128	2.26
			Pulmonary	382	6.76
Cardiac Arrest	7,872	309	No	2,386	30.31
			Yes, prior to EMS arrival	530	6.73
			Yes, after EMS arrival	4,956	62.96
Cardiac Arrest Etiology	5,668	2,513	Presumed cardiac	3,141	55.42
			Trauma	190	3.35
			Respiratory	547	9.65
			Not Applicable	1,439	25.39
			Other	351	6.19
Age (in years)	8,105	76	0-9	221	2.73
			10-19	186	2.32
			20-29	451	5.56
			30-39	504	6.22
			40-49	728	8.98
			50-59	1,352	16.68
			60-69	1,560	19.25
			70-79	1,444	17.82
			80-89	1,247	15.39
			90-99	389	4.80
			100+	21	0.26
Response Level	2,847	5,340	Alert	168	5.91
			Painful	44	1.55
			Unresponsive	2,585	90.99
			Verbal	44	1.55
Return of Spontaneous Circulation	7,898	283	No	3,124	58.41
			Not Applicable	859	16.06
			Yes, Prior to EMS Arrival and at the ED	1,022	19.11
			Yes, Prior to EMS Arrival	6.41	6.41

Continued

Variable	Total	Missing	Category	N	Percent
First Monitored Heart Rhythm	4,709	3,472	Asystole	2,272	48.25
			Bradycardia	121	2.57
			Normal Sinus Rhythm	95	2.02
			Other	114	2.42
			Paced Rhythm	17	0.36
			Pulseless Electrical Activity (PEA)	996	21.15
			Unknown AED Non-shockable Rhythm	165	3.50
			Unknown AED Shockable Rhythm	61	1.30
			Ventricular Fibrillation	824	17.50
			Ventricular Tachycardia	44	0.93
Glasgow Coma Score	5,135	3,046	3	4,553	88.67
			4-5	133	2.59
			6-8	173	3.37
			9-12	93	1.81
			13-15	183	3.56
Pulse Ox	4,098	4,083	0	2,390	58.32
			1-49	344	8.39
			50-69	236	5.76
			70-79	210	5.12
			80-89	306	7.47
			90-100	610	14.89
Pulse Rate	5,112	3,069	0	3,029	59.25
			1-59	384	7.51
			60-99	712	13.93
			100-149	834	16.31
			150-199	126	2.46
			200+	27	0.53
Systolic Blood Pressure	3,344	4,837	0	1,984	59.33
			<50	35	1.05
			50-75	140	4.19
			76-119	491	14.68
			120-139	261	7.81
			140-189	330	9.87
			190-219	71	2.12
			220+	32	0.96

Continued

Variable	Total	Missing	Category	N	Percent
Respiratory Rate	4,910	3,271	Zero	3,017	61.45
			<5	212	4.32
			5-11	517	10.53
			12-19	633	12.89
			20-29	306	6.23
			30-39	121	2.46
			40-39	47	0.96
			50+	57	1.16
Response to Scene	8,181	0	Lights and Sirens	7,789	392
			No Lights and Sirens	95.21	4.79
Transport from Scene	7,037	1,144	Lights and Sirens	5,718	81.26
			No Lights and Sirens	1,319	18.74
Number of ETI Attempts	8,142	39	1	6,636	81.50
			2	1,328	16.31
			≥3	178	2.19
Pre-hospital ETI Success	7,963	218	No	3,178	60.09
			Yes	4,785	39.91

APPENDIX E

Descriptive Statistics for Imputed State Data Set

Variable	Category	N	Percent
Type of Service Requested	911 response (scene)	7,875	96.26
	Intercept	30	0.37
	Interfacility transport	204	2.49
	Medical transport	36	0.44
	Mutual aid	36	0.44
Primary Role of the Unit	Non-transport	193	2.36
	Rescue	126	1.54
	Supervisor	50	0.61
	Transport	7,812	95.49
US Census Region	Northeast	285	3.48
	Midwest	3,342	40.85
	South	3,595	43.94
	West	959	11.72
CMS Service Level	BLS	99	1.21
	ALS	7,014	85.74
	Paramedic intercept	35	0.43
	Specialty care transport	213	2.60
	Fixed wing (airplane)	39	0.48
	Rotary wing (helicopter)	781	9.55
Provider Certification Level	EMT-Basic	85	1.04
	EMT-Advanced/Enhanced	85	1.04
	EMT-Intermediate	938	11.47
	EMT-Paramedic	6,975	85.26
	RM/MD/Other	98	1.20
Gender	Male	4,957	60.59
	Female	3,224	39.41
Race	Asian	54	0.66
	Black or African American	2,334	28.53
	White	5,202	63.59
	Other race	591	7.22

Continued

Variable	Category	N	Percent
Ethnicity	Hispanic or Latino	433	5.29
	Not Hispanic or Latino	7,748	94.71
Possible Injury	No	6,889	84.21
	Yes	1,292	15.79
Chief Complaint Organ System	Cardiovascular	3,551	43.41
	CNS/Neuro	597	7.30
	Global	3,300	40.34
	Other	184	2.25
	Pulmonary	549	6.71
Cardiac Arrest	No	2,472	30.22
	Yes, prior to EMS arrival	5,168	63.17
	Yes, after EMS arrival	541	6.61
Cardiac Arrest Etiology	Presumed cardiac	4,545	55.56
	Trauma	270	2.30
	Respiratory	796	9.73
	Not Applicable	2,057	25.14
	Other	513	6.27
Age (in years)	0-9	222	2.71
	10-19	189	2.31
	20-29	455	5.56
	30-39	508	6.21
	40-49	735	8.98
	50-59	1,367	16.71
	60-69	1,577	19.28
	70-79	1,454	17.77
	80-89	1,262	15.43
	90-99	391	4.78
	100+	21	0.26
Response Level	Alert	466	5.70
	Painful	143	1.75
	Unresponsive	7,454	91.11
	Verbal	118	1.44
Return of Spontaneous Circulation	No	4,779	58.42
	Not Applicable	1,286	15.72
	Yes, Prior to EMS Arrival and at the ED	1,610	19.68
	Yes, Prior to EMS Arrival	506	6.10

Continued

Variable	Category	N	Percent
First Monitored Heart Rhythm	Asystole	3,956	48.36
	Bradycardia	208	2.54
	Normal Sinus Rhythm	169	2.07
	Other	203	2.48
	Paced Rhythm	30	0.37
	Pulseless Electrical Activity (PEA)	1,718	21.00
	Unknown AED Non-shockable Rhythm	270	3.30
	Unknown AED Shockable Rhythm	105	1.28
	Ventricular Fibrillation	1,443	17.64
	Ventricular Tachycardia	79	0.97
Glasgow Coma Score	3	7,249	88.61
	4-5	214	2.62
	6-8	286	3.50
	9-12	153	1.87
	13-15	279	3.41
Pulse Ox	0	4772	58.33
	1-49	251	3.07
	50-69	478	5.84
	70-79	434	5.30
	80-89	603	7.37
	90-100	1,643	20.08
Pulse Rate	0	4,819	58.90
	1-59	638	7.80
	60-99	1,143	13.97
	100-149	1,347	16.46
	150-199	193	2.36
	200+	41	0.50
Systolic Blood Pressure	0	4,825	58.98
	<50	65	0.79
	50-75	377	4.61
	76-119	1,170	14.30
	120-139	677	8.28
	140-189	825	10.08
	190-219	165	2.02
	220+	77	0.94

Continued

Variable	Category	N	Percent
Respiratory Rate	Zero	5,005	61.18
	<5	364	4.45
	5-11	870	10.63
	12-19	1,085	13.26
	20-29	498	6.09
	30-39	189	2.31
	40-39	78	0.95
	50+	92	1.12
Response to Scene	Lights and Sirens	7,789	95.21
	No Lights and Sirens	392	4.79
Transport from Scene	Lights and Sirens	6,638	81.14
	No Lights and Sirens	1,643	18.86
Number of ETI Attempts	1	6,666	81.48
	2	1,336	16.33
	≥3	179	2.19
Pre-hospital ETI Success	No	3,253	39.76
	Yes	4,928	60.24

APPENDIX F

R Code to Create Models and Run Statistical Tests

##To make training/testing 70/30 split data sets same code both National and Comprehensive directly after imputation of data in VIM GUI

```
>library(DescrTools)
>set.seed(123)
>data=data
>indexes=sample(1:nrow(data), size=0.3*nrow(data))
>test=data[indexes,>]
>dim(test)
>train=data[-indexes,]
>dim(train)
```

Ran descriptive statistics in Rcmdr (GUI) or used summary(train$variable) for descriptives

##To perform chi-square analyses/phi/Cramer's V

```
>tab<- table(train$rsuccess, train$X)  ###where X=structure or process variable)
>chisq.test(tab)
>CramerV(tab)
```

##To perform logistic regression block 1 in glmulti for Comprehensive Model and get results of tests

```
>block1.glmulti<- glmulti(rsuccess~ruscensus region+rcertlevel+rrace+rccorgsys+rpulseox,
data=train, level=1, method="h", crit="aic", confsetsize=150, family=binomial(logit))
>summary(block1.glmulti)
>block1.glm<- glm(rsuccess~1+ruscensus+rcertlevel+rrace+rccorgsys+rcardiac, data=train,
family=binomial(logit))
>summary(block1)    ##to get summary of block1.glm
>exp(cbind(OR=coef(block1.glm), confint(block1.glm)      ##to get odds ratios & 95% CI
>with(block1.glm, null.deviance-deviance)
>with(block1.glm, df.null-df.residual)
>with(block1.glm, pchisq(null.deviance-deviance, df.null-df.residual, lower.tail=FALSE))
>logLik(block1.glm)
>library(car)
>vif(block1.glm)
>durbinWatsonTest(block1.glm)      ###durbin Watson test
>library(aod)
>wald.test(b=coef(block1.glm), Sigma=vcov(block1.glm), Terms=2:4)   ###wald.tests
> wald.test(b=coef(block1.glm), Sigma=vcov(block1.glm), Terms=5:8)
> wald.test(b=coef(block1.glm), Sigma=vcov(block1.glm), Terms=9:11)
> wald.test(b=coef(block1.glm), Sigma=vcov(block1.glm), Terms=12:15)
> wald.test(b=coef(block1.glm), Sigma=vcov(block1.glm), Terms=16:17)
>library(ROCR)
>fitpred=prediction(fitpreds, test$rsuccess)        ###ROC Curve for testing data
>fitperf=performance(fitpred, "tpr", "fpr")
>plot(fit.perf, col="green", lwd=2, main="ROC Curve for Logistic: Success")
>abline(a=0, b=1, lwd=2, lty=2, col="gray")
>library(LogisticDx)    ### to get ROC Curve for training data
```

```
>gof(block1.glm, g=7, plotROC=TRUE)
>library(fmsb)
>NagelkerkeR2(block1.glm)    ###Nagelkerke's R2
```

>**To perform hierarchical logistic regression for block 1 and block 2 Comprehensive Model And get test results**

```
>block2.glmulti<- glmulti(rsuccess~
ruscensus+rcertlevel+rrace+ccorgsys+rpulseox+rcardiac+rresponseto+rattempts, data=train,
level=1, method="h", crit="aic", confsetsize=150, family=binomial(logit))
>summary(block2.glm
> block2.glm<-glm(rsuccess~1+ruscensus+rcertlevel+rrace+ccorgsys+rcardiac+rresponseto+
rattempts, data=train, family=binomial(logit))
summary(block2.glm)
> exp(cbind(OR=coef(block2.glm), confint(block2.glm)        ##to get odds ratios & 95% CI
>with(block2.glm, null.deviance-deviance)
>with(block2.glm, df.null-df.residual)
>with(block2.glm, pchisq(null.deviance-deviance, df.null-df.residual, lower.tail=FALSE))
>logLik(block2.glm)
>library(car)
>vif(block2.glm)
>durbinWatsonTest(block2.glm)       ###durbin Watson test
>library(aod)
>wald.test(b=coef(block2.glm), Sigma=vcov(block2.glm), Terms=2:4)   ###wald.tests
>wald.test(b=coef(block2.glm), Sigma=vcov(block2.glm), Terms=5:8)
>wald.test(b=coef(block2.glm), Sigma=vcov(block2.glm), Terms=9:11)
>wald.test(b=coef(block2.glm), Sigma=vcov(block2.glm), Terms=12:15)
>wald.test(b=coef(block2.glm), Sigma=vcov(block2.glm), Terms=16:17)
>wald.test(b=coef(block2.glm), Sigma=vcov(block2.glm), Terms=18)
>wald.test(b=coef(block2.glm), Sigma=vcov(block2.glm), Terms=19:20)
>library(ROCR)
>fitpred=prediction(fitpreds, test$rsuccess)          ###ROC Curve for testing data
>fitperf=performance(fitpred, "tpr", "fpr")
>plot(fit.perf, col="green", lwd=2, main="ROC Curve for Logistic: Success")
>abline(a=0, b=1, lwd=2, lty=2, col="gray")
>library(LogisticDx)     ### to get ROC Curve for training data
>gof(block1.glm, g=7, plotROC=TRUE)
>library(fmsb)
>NagelkerkeR2(block1.glm)    ###Nagelkerke's R2
```

Code/formula put into glmulti for National Model BLOCK1 and Block 1and 2rest of code same as above but diff. #s for wald tests)

```
>block1.glmulti<- glmuti(rsuccess~rtypeservice
requested+uscensusregion+remstct+rcmsservicelevel+rrace+rrage+ccorgsys, data=train,
level=1, method="h", crit="aic, confsetsize=150, family=binomial(logit))    ####BLOCK1

>block2.glmulti<- glmuti(rsuccess~rtypeservice
requested+uscensusregion+remstct+rcmsservicelevel+rrace+rrage+ccorgsys+rattempts,
data=train, level=1, method="h", crit="aic, confsetsize=150, family=binomial(logit))
######BLOCK1 AND BLOCK2
```

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