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Modeling Decision Making In Trauma Centers From The Standpoint Of Complex Adaptive Systems

Castanon de Policarpo
North Carolina Agricultural and Technical State University

Modeling Decision Making in Trauma Centers from the Standpoint of Complex Adaptive Systems

Policarpo Castanon de Mattos

North Carolina A&T State University

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Policarpo Castanon de Mattos

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Approved by:

Dr. Eui H. Park Major Professor	Dr. Daniel M. Miller Committee Member
Dr. Daniel N. Mountjoy Committee Member	Dr. Younho Seong Committee Member
Dr. Tonya L. Smith-Jackson Department Chairperson	Dr. Sanjiv Sarin Dean, The Graduate School

Biographical Sketch

Policarpo Castanon de Mattos was born on December 23, 1947, in the city of Guarani, in the state of Minas Gerais, Brazil. He received the Bachelor of Business Administration degree from Pace University of New York in 1982 and a Master of Science degree in Industrial Engineering from North Carolina Agricultural and Technical State University in 2007. He is a candidate for the Ph.D. degree in Industrial and Systems Engineering from North Carolina Agricultural and Technical State University in Greensboro, NC.

Dedication

I dedicate this dissertation to my loving and supportive parents, Annette Castanon deMattos and Dolirio Martins deMattos; my children, Anastasia, David John, and Edward Carlos, and my grandchildren, Aaliyah, Raven John, and Winter Dianne.

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Table of Contents

List of Figures

List of Tables

List of Symbols or Nomenclature

ABC:	Airway, Breathing, Circulation
ABCDE:	Airway, Breathing, Circulation, Disability, Exposure/Environment
ACS-COT:	American College of Surgeons – Committee on Trauma
ACS:	American College of Surgeons
AMD:	Attending Medical Doctor or Attending Physician
ATLS:	Advanced Trauma Life Support for Doctors
BP:	Blood Pressure
CAS:	Complex Adaptive System
CDC:	Center for Disease Control
CM:	Confusion Matrix
CMs:	Confusion Matrices
CPR:	Cardio-Pulmonary Resuscitation
CT Scan:	Computerized Tomography Scan
DMPUS:	Decision Making Process under Stress
DTI:	Decision Time Interval
ED:	Emergency Department (formerly known as "Emergency Room")
EKG:	Electrocardiography
EM:	Emergency Medicine
EMAP:	Emergency Medicine Attending Physician
EMS:	Emergency Medical Services
EP:	Emergency Physician
HR:	Heart Rate (Pulse)
ICU:	Intensive Care Unit

IV:	Intravenous
IRB:	Institutional Review Board
L1TRU:	Level 1 Trauma Resuscitation Unit
MD:	Medical Doctor or Physician
mmHg:	Millimeters of Mercury
OR:	Operating Room
RDMP:	Rational Decision Making Process
RN:	Registered Nurses
RR:	Respiratory Rate
TC:	Trauma Center
WFU:	Wake Forest University
WHO:	World Health Organization

Abstract

This research examines complex clinical decision-making processes in trauma center units of hospitals in terms of the impact of complexity on the medical team involved in the trauma event. The science of complex adaptive systems together with human judgment theories provide important concepts and tools for responding to health care challenges in this century and beyond. Clinical decision-makers in trauma centers are placed in urgent and anxious situations that are increasingly complex, making decision-making and problem-solving processes multifaceted. Under stressful circumstances, physicians must derive their decision-making schemas ("internal models" or "mental models") without the benefits of judicious identification, evaluation, and/or application of relevant medical information, and always using fragmentary data. This research developed a model of decision-making processes in trauma events that uses a Bayesian Classifier model jointly with Convolution and Deconvolution operators to study real-time observed trauma data for decision-making processes under stress. The objective was to explore and explain physicians' decision-making processes during actual trauma events while under the stress of time constraints and lack of data. The research addresses important operations that describe the behavior of a dynamic system resulting from stress placed on the physician's rational decision-making processes by the conditions of the environment. Deconvolution, that is, determining the impulse response of the system, is used to understand how physicians clear out extraneous environmental noise in order to have a clearer picture of their mental models and reach a diagnosis or diagnostic course of action.

CHAPTER 1

Introduction

This dissertation explores clinical decision-making processes under stress (DMPUS) at trauma centers from the perspective of complex adaptive system (CAS) theory, including its approach to managing complex, collaborative work. It is an attempt to provide an understanding of the work of trauma physicians while in the act of saving a human life during a distressing trauma situation. Trauma is defined as a major threat to the immediate and often long-term health of individuals. Complex adaptive systems are dynamically evolving situations involving multiple operations. Everyone—physicists, mathematicians, psychologists, engineers, business leaders, trauma physicians, other medical personnel, artists, and even politicians—deals with this kind of complexity (Suh, 2005). The theory of CAS as applied to clinical decision-making is a way to manage the complex, dynamic, unpredictable work of trauma centers. This exploration into complex clinical decision-making processes has revealed how health care workers in trauma centers self-adjust and survive despite uncertainty, change, and constant interaction with the environment. It includes both participant observation and interviews with medical doctors which combine to provide a complex, rich portrait of trauma centers.

This research focuses on the complexity of decision-making processes that exists in hospitals' trauma center systems, with their rapidly changing environments. The scenario at trauma centers is completely unpredictable from hour to hour, and decisions are constantly made in the face of complex situations with ill-defined, fuzzy, and uncertain goals. One issue of particular interest is the role of the physician in reducing the complexity of the milieu and anchoring a robust medical team. Trauma physicians need to 'keep afloat in a turbulent sea of unexpected demands, unfunded mandates, and diminishing recourses" (Kenagy, 2009). This implies that physicians as decision-makers should learn and adapt and have the ability to make responsive adjustments to changes in the environment by finding clear and unambiguous way to problem-solve—all within a real-world time. To facilitate the effort to study a suitable cross section of different patients, as well as a suitable cross section of varied treatment instances, this research was done in real-time at a Level 1 trauma resuscitation center. However, we have had the opportunity to analyze our data and make judgments based upon it at considerably more leisure than is usually afforded to doctors at trauma centers.

1.1 The Practice of Emergency Medicine: Dilemmas of an Emergency Department

In today's hospital Emergency Departments (ED), patients present via walk-in as well as via emergency transport services. Upon arrival, patients are triaged and assigned acuity levels, which are generally accomplished with the use of an Emergency Severity Index (ESI). ESIs are a series of triage algorithms that yield rapid, reproducible, and clinically relevant stratification of patients into five groups from Level 1 (most urgent) to Level 5 (least urgent). The ED stands alone as the only area of the hospital in which patients can be expected to present with chief complaints of such variance, which run the gamut from toothache to myocardial infarction; from ambiguous unspecified "pain" to severe burns or trauma; and even psychological issues, such as substance dependency and suicidal thoughts. EDs are outfitted with differing levels of treatment rooms to accommodate the differing acuity levels of the patients, an example of which can be seen in Figure 1.1. One hospital in North Carolina, in particular, boasts an ED divided into both major care and minor care areas, with 41 double-bed treatment rooms and with the major care area further equipped with six "Level 1" trauma resuscitation treatment rooms.

In such an environment, the attending physicians present will find themselves faced with incidences which call for rational decision-making but which may also come with an enormous number of stressors. Sometimes those stressors are directly related to the urgency of the situation; other times, they are not. At an ED in today's hospital, one can expect to be presented with patients who have neither insurance nor the ability to pay for routine medical procedures. For this reason, they utilize the ED (which by law must provide them with care) for their routine needs, such as acquisition of prescription medications, treatment of aches and pains, even kidney dialysis. In these situations, it is likely that the patient will present to the physician with a routine chief complaint, as well as a series of familiar symptoms and other medical parameters. It is almost a certainty that these patient cases will not contain an element of urgency due to time, thereby allowing the physician to employ a rational decision-making process (RDMP) without convolutions and reach an accurate diagnosis.

Figure 1.1. Level 1 trauma center bay (Walleigh, 2011).

Other patients may present regularly for amorphous conditions. These "frequent flyers" might be homeless, drug-seekers, hypochondriacs, or merely those desiring attention. In these situations, physicians are presented with a series of familiar symptoms (albeit less specific, e.g., “abdominal pain”), which in turn translate into batteries of tests which fit with the chief complaint. A patient presenting routinely with unspecific abdominal pain might receive, as a matter of course, a urine test, blood screen, and abdominal CT scan—computerized tomography scan. The physician then interprets the results of these tests and provides diagnosis based on his knowledge of the original symptom parameters and the new information provided by the test results and again, the element of time does not play a significant role. This is because decision analysis techniques have been developed to assist physicians in making rational decisions that reflect the best available evidence for each patient’s individual needs.

However, in a given shift at an ED, physicians will also be faced with a variety of bona fide emergent situations, which introduce various stressors into the clinical decision-making process. These stressors (noises) are the “convolutions” which alter the physician’s interpretation of the scenario, as well as his/her response to it. The most pertinent of these stressors is the element of time constraint, which is one of the characteristic of emergency medicine. A patient who presents with acute myocardial infarction may need immediate transport to a cardiac catheterization lab. In this particular scenario, there is a controllable variable of time as well as an uncontrollable variable of time. The elapsed time from onset of symptoms to the moment when the patient presents at the ED trauma center is an uncontrollable variable of time. The medical staff has had no control over how long the individual has waited before seeking medical attention. However, once the patient presents with these symptoms, the element of time then becomes a variable completely under the control of the medical staff. Upon presenting to an ED, the patient will be *registered, triaged, evaluated, examined, and treated.* Each of these stages takes a measure of time, and the decision-making process of the members of the medical staff determine how great or small that measure of time is. Because of the critical nature of emergent medical situations, the decision-making process will be different from routine or rational decision making, due to the introduction of the convolution of *time constraint* as well as the introduction of another convolution: *resource management.*

Emergency Departments operate with finite staff, finite materials, and finite resources of all types. In most scenarios, the levels of staffing and material are non-factors, as they prove more than sufficient to meet the level of need. Even when supply exceeds the demand, the level of supply does not play a role in decision-making. In emergency medicine, it is not uncommon to have several emergent situations arise and require attention within moments of one another. A vehicle crash with multiple occupants, an assault with multiple victims, or even a spill of some type of hazardous material might bring multiple patients in need of emergency care to the doors of an ED without warning—or more often, a combination of singular events can do the same. In one scenario during this study, there was a victim of severe burns in one room, an assault victim and recipient of multiple stab wounds in another, a severe head trauma resulting from a 30 foot fall in a third, and acute respiratory distress in a fourth. Each of these patients presented at nearly the same time, and while these treatments were being attended to, a fifth patient presented with symptoms of a myocardial infarction. In each of these cases, the element of time constraint plays a strong role, exacerbated by the fact that now the physician is required to divide his time, attention, and decision-making acumen between multiple cases (each case having its own case-specific convolutions). Furthermore, the physician must divide the time of others, as qualified staff is a finite resource. Qualified respiratory specialists, EKG technicians, registered nurses (RN), nursing assistants, radiology technicians and others all play a role as valuable resources and must be managed accordingly. Beyond human resources, the material resources must be divided and dispensed. Units of blood for transfusion must be acquired and dispensed, IV pumps, EKG monitors, portable x-ray machines—all of these items must be requested, acquired, transported to rooms, and operated by qualified staff. The convolution of time comes into play at all levels, from the moment a patient comes through the doors, and then the convolution of resource management rears its head as well. Seamlessly, those convolutions come together and are must be resolved as the physician makes treatment decisions. The risk/benefit ratio must be weighed at every moment: Is the risk of taking the time to perform this task outweighed by the benefit of the task to the patient?

1.2 Background

The Newtonian worldview has been the dominant approach to science for more than three centuries in almost all areas of physics, social sciences, engineering design, and in the biological sciences. It is based in an attempt to see things at their most fundamental level and has been referred to as "the machine metaphor" in which any entity could be studied and fully understood by reducing it to its smallest parts, or in which one event is understood as the consequence of another (Hoffman, 2000). Once each of its separate parts (or each discrete event) was understood, the entity's current state outlined, and the rules that made it functional were understood, its future behavior (or the outcome of the events) could be predicted without much difficulty. This, in essence, defines a deterministic system. This reductionistic conceptual framework worked well during the Industrial Revolution, promoting both the capacity for mass production and a dependency upon predictable environments. Its science is simple and strongly reflects a view of causality that assumes the ability to understand systems in the simple terms of the processes from which these systems have been created or structured.

This Newtonian conceptual framework is not sufficient for many other things. It does not allow understanding of the complexity of dynamic systems in which there are a myriad of small parts (agents), all interacting with each other. A trauma center is a dynamic, highly complex adaptive system which is itself dealing with other dynamic systems in the form of living organisms wherein the source of the problem is not self-evident and decisions at all times involve a complex set of choices. As such, a trauma center does not well fit the machine metaphor of science.

The word “trauma” is of Greek origin, signifying wound. The American College of Surgeons (ACS) uses the word “trauma” interchangeably with “injury” to mean damage to human tissue and/or organs resulting from the transfer of some form of energy from the environment to a human host. Injury occurs when the impact of this energy is beyond the body’s resilience in absorbing it (Jacobs, & Hoyt, 2000). In this research, it is important to differentiate between a trauma system and a trauma center. Therefore, the next two subsequent subsections describe these differences.

1.2.1 Trauma system. A trauma system, shown in Figure 1.2, is a coordinated set of procedures and programs that address the continuum of care from prevention to acute care, through rehabilitation and the integration of the sick or injured individual back into society. Trauma systems, in this sense, may vary from country to country. In the United States, trauma systems change from state to state to accommodate the needs of the communities and the regions they serve. Despite their diversity, all trauma systems are designed and intended to reduce the rate of deaths and permanent disability in trauma patients (Maier, 2003). As Figure 1.2 indicates, a trauma system involves the integration of many services, including but not limited to Emergency Medical Services (EMS), rehabilitation facilities, and many types of trauma prevention organizations. In essence, a trauma system analyzes the causes and medical consequences of serious trauma, while promoting the continuum of care that provides timely and appropriate delivery of medical care for the rehabilitation and reintegration into society of patients with acute traumatic injuries and illnesses.

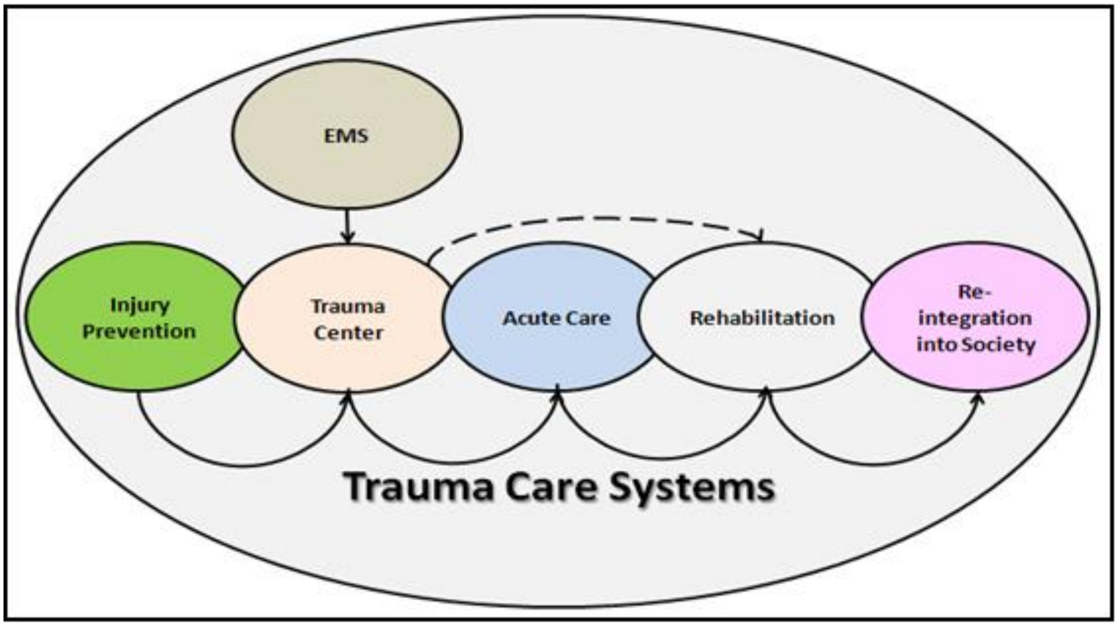

Figure 1.2. Depth of trauma care systems.

Because of the benefits a trauma system brings to a region, local governments create task forces whose job are to license healthcare facilities with trauma systems, to evaluate and recommend criteria concerning the development of trauma systems, and to operate trauma centers within its region. The systems thus created must be grounded in legislation, with policies and procedures to ensure that they continue to meet regional needs. Thus, there must be a means to ensure adequate funds and personnel to support operations, as well as continuing quality improvement. These trauma systems are built with flexibility to provide the best possible care even in the most remote circumstances.

1.2.2 Trauma center. A trauma center is located in a hospital that is designated as such by a state or local authority or is verified by the American College of Surgeons. Trauma centers are spread throughout the United States, distinguishing them by a strong commitment to provide 24-hours-a-day, 7-days-a-week availability of dedicated medical resources for the care of the injured. Medical personnel, from trauma surgeons and nurses to technologists and clerical staff—all with specialized knowledge in trauma care—must be immediately available at the trauma center for achieving the purpose of caring for sick and injured patients.

Trauma centers are designated according to the level of care each is capable of providing. Levels of care are construed to mean the type of trauma services provided by the healthcare organization, as shown by the degree of commitment in personnel and facilities made to the delivery of care to the sick and injured. In the United States, the number of levels of care depends upon the region, local governments, and healthcare systems. Some trauma systems have four types of trauma centers, varying in their specific capabilities. Trauma centers throughout the country are identified by acuity "level" designations that have the following requirements (refer to *Appendix A* for detailed criteria for Levels 1 and 2 trauma code):

- Level 1 trauma centers provide multidisciplinary treatment and specialized resources for trauma patients and require trauma research, a surgical residency program and an annual volume of 600 major trauma patients per year.
- Level 2 trauma centers provide similarly experienced medical services and resources but do not require the research and residency components. Volume requirements are 350 major trauma patients per year.
- Level 3 trauma centers are smaller community hospitals that have services to care for patients with moderate injuries and the ability to stabilize the severe trauma patient in preparation for transport to a higher-level trauma center. Level 3 trauma centers also do not require neurosurgical resources.
- Level 4 trauma centers are able to provide initial care and stabilization of traumatic injury while arranging transfer to a higher level of trauma care.

Table 1.1

Trauma Center Resources Needed to Reflect Maximum Commitment

Trauma Center Medical Specialists	
Trauma Surgery	Emergency Medicine
Anesthesiology	Neurosurgery
Orthopedic Surgery	Ophthalmology
Plastic Surgery	Micro Surgery
Hand Surgery	Cardiac Surgery
Thoracic Surgery	Critical Care Medicine
Oral Surgery	Radiology
Pediatric Surgery	OB/GYN Surgery

Levels 1 and 2 trauma centers can also be categorized as either “Adult Trauma Centers” or “Pediatric Trauma Centers.” In many healthcare systems, the adult and pediatric TCs are physically separated by location in a totally different building or in a different ward in the same building complex.

To be considered a “Level 1” trauma center, a facility must have up to 16 physicians in specialties ranging from neurosurgery to OB/GYN who are available in-house or on-call at all times. These specialties are defined in Table 1.1 and all the medical specialties in the United States *are outlined in Appendix B.*

1.2.3 Trauma care. Trauma centers, which are part of local and regional trauma systems, must prioritize their treatment of the patients who come to them. They are usually triaged into five “levels of care,” reflecting the large variety of medical problems potentially resulting from illness or injury. These levels are labeled “Level 1” for the most serious injuries and illnesses, to “Level 5” for the less severely involved patients. Patients are evaluated by *acuity* by either the charge nurse or the attending physician or by either of these care providers in conjunction with EMS providers who are in the field with the patient. Patients who present with Level 1 and Level 2 conditions are also evaluated by *resource needs.* Patients who are triaged at Levels 3, 4, and 5 are considered to have less pressing needs both in terms of acuity and in terms of resources. For these less acute cases, experienced RNs and nurses who have attended comprehensive triage educational program assess each patient to determine triage level based on the number of resources needed.

1.3 Trauma Centers as Complex Adaptive Systems

This research is based on the premise that many social systems are too complex to accurately predict their futures and that, nevertheless, such systems exhibit patterns that can help humankind cope with an increasingly complex and unpredictable future (Gell-Mann, 1996, 1999; Janssen, 1998; Levin, 1998; Yolles, 2006; Miller and Page, 2007). These systems may be understood by Complex Adaptive System (CAS) theory. Complexity science has proved to be the birthing ground of computational techniques which allow for exploration of models far beyond that of Adam Smith's "invisible hand" economic model. Adam Smith in 1776 described the benefits to society of this “invisible hand” leading groups of people (agents) who are working and behaving in their own self interests; yet, unknowingly and unintentionally creating well-formed structures that today’s scientists label as complex adaptive systems (Smith, 1776). These techniques include and provide for the emergent and self-organized behaviors of Complex Adaptive Systems.

The science of CAS provides important concepts and tools for responding to the challenges of health care during this century and beyond. Today's trauma physicians face fuzzier boundaries due to substantial changes in the social, economic, and cultural environmental contexts within which they work. In addition, a changing range of lifestyle choices provide people with the ability to make decisions that can affect their risk for developing disease or having serious accidents. Clinical decision-makers are placed in situations that are increasingly complex, in which they must cope effectively with the inter-relationships, inter-actions, and inter-connectivity of these elements (Chan, 2001, Gell-Mann, 1996). Figure 1.3 provides a visual conceptual framework for a trauma event's diagnostic course of action that takes into account its complexity, represented by the intertwining helical strands some of the types of decisions the medical team faces.

The complexity of trauma center care is most directly demonstrated by the large numbers of individuals of all ages who are daily brought in to trauma centers with complex pathophysiological conditions and difficult problems that need immediate solutions. Despite constantly dealing with variables that seem to be too many to count, too uncertain to express, and, at times, too difficult even to understand, physicians still make life-and-death decisions that generate predictable outcomes by adjusting continuously in real time toward a diagnosis and treatment. When confronted with a massive amount of information and cues originating from the trauma event, retrospective experience and real-time speed are the major physician-linked variables in making sound medical diagnosis and treatment decisions. Another key variable in such dynamic and uncertain situations is communication skills. All communications are centrally concerned with the accurate processing of information. In the TC setting, communication is complicated by its need to be interdisciplinary, drawing on the knowledge and skills of health care specialists from a variety of fields. All these agents are interacting so as to make sense of the situation that confronts them, and their interactions must be coordinated and consistent with one another. This communication task may become even more convoluted at times because of the patients' physiological conditions, which may include multiple interacting injuries that complicate each other. In this setting, the amount of total information conveyed about the patient and the situation during team interactions may be drastically reduced. Depending on who is directing the interaction, however, higher information content may be achieved. Thus, information acquisition dynamics also play a central role in attempts to manage complexity.

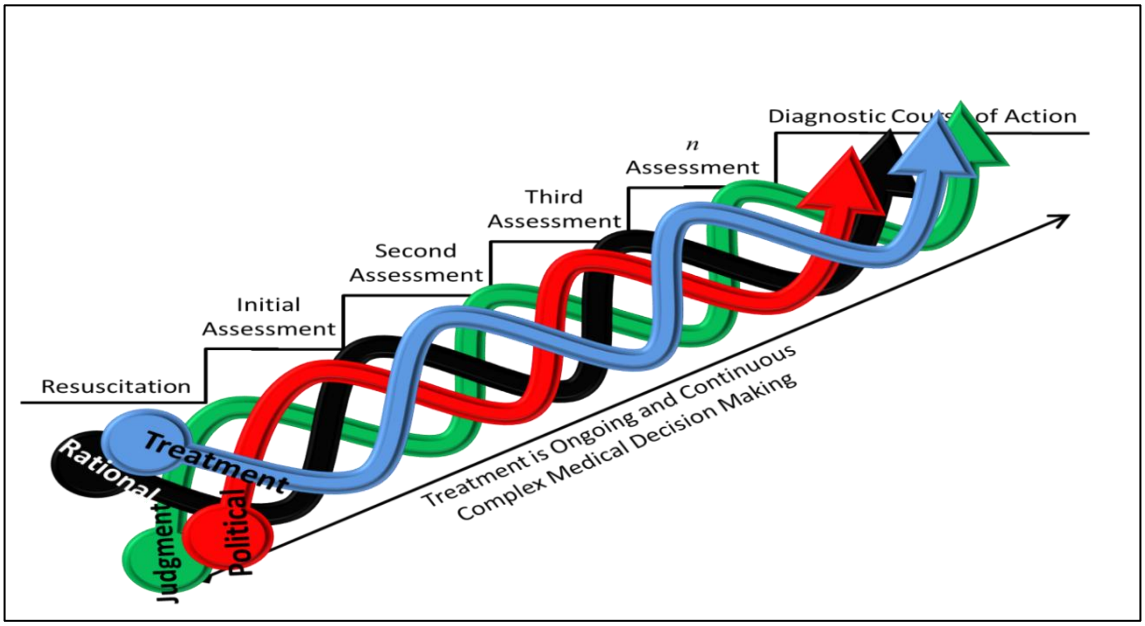

Figure 1.3. Conceptual framework for diagnostic course of action.

Trauma centers exhibit the important characteristics of complex adaptive systems (CAS), which are composed of several relatively independent agents (Paley, & Eva 2010), which in this case are the many different medical disciplines. Some of the most important features of CAS are: (1) sensitivity to small perturbations, (2) difficulty in performing as predicted, (3) difficulty in developing any type of experience, (4) inability to expect what worked last time to work this time, and (5) a tendency to undergo rapid adaptations, changing behaviors to improve the chances of success and creating novelty in the process. Probably the most salient of these features for trauma centers is the inability to predict outcomes. Dr. Thomas Scalea, a trauma physician, discusses the research findings of Dr. Claudia Goettler. Dr. Scalea raises the following questions: “Why are we so bad in predicting outcome? Is it inherently that difficult? Are the scoring systems and predictive models just that bad, or are we simply incapable of being objective? Are families unrealistic?” Replying to these questions, Dr. Goettler said: “In regards to our inability to correctly predict outcome, we are still hampered by too little data, the inherent differences in physiology between individuals, which likely will require genetic profiles to assess in the future, and our own individual biases regarding reasonable error and quality of life to be successful in prediction” (Goettler, 2010, pp. 1279-1288).

Decision-making studies, which vary according to the dynamic complexity of the system, often focus on the applications of agent-based modeling to investigate how decision-makers understand non-linear relationships within complex systems. In the framework of agent-based modeling, decision-makers (agents) scan their environments and develop schema (interpretive and action rules) to help them distinguish what is essential before engaging in decisive action. The unfolding of trauma centers’ events requires an ability to create mental models that are “holistic”—that sufficiently account for high complexity and uncertainty (Coffey, 2010). Understanding a trauma center’s turbulent and rapidly changing context requires appreciating each of its components and being able to visualize how each part is integrated into the whole framework. Because trauma centers are highly variable medical domains, it is necessary to have an excellent diagnosis and treatment protocol in place and a superior leader in charge who will prioritize with a genuine and sustained interest in organizational performance and who is capable of integrating, over time, all events faced by the medical team. One attending trauma physician described his working location as a “strategically positioned command center, as in a naval war ship,” from which every decision-making event is orchestrated both with electronic technology and with his medical team. The fundamental characteristics of CAS, therefore, provide trauma team members (i.e., physicians, nurses, and staff) with multiple and creative paths for learning and collaboration.

For these physicians, the trauma center medical team’s strategies and practices, together with the tools from CAS theories, help them form the mental models that affect the success or failure of the team as measured by the outcome of the life or death of the sick or injured patient. However, the current state of a trauma patient (living system) is no predictor of what that patient will be in any given time in the future, because small disturbances in complex systems can produce exponentially different outcomes—in other words, the “Butterfly Effect” (Lorenz, 1972) is exactly the reason as to why it is difficult to define failure. The intricate interrelationships of elements within a trauma center give rise to multiple chains of dependencies. Changes happen in the context of this intricate intertwining chain of inter-relationships and inter-actions at all levels, and medical judgment in the clinical decision-making process is necessary to recognize and work with all of these interactions.

1.4 Problem Statement and Research Questions

“A major part of the problem is the inherent obscurity, complexity, and irreducible uncertainty associated with human illness” (Croskerry, 2012, pp. 50-56). Trauma code is obviously an uncontrolled environment for at least a few minutes when any patient with highly varied medical conditions arrives in a Level 1 trauma center resuscitation unit. Under such circumstances, the clinical decision-making process in an uncontrolled environment is overwhelming (Gawande, 2002). Often trauma physicians have to make multiple decisions under extreme uncertainty and in real time, while the situation is rapidly changing and evolving. The timing of these clinical decisions helps to determine their value. Another factor in their value is their suitability to the situation at hand, given that the relationships upon which they are based may have more or less relevance to situation.

Medical schools, major academic centers, and medical practices provide physicians with the needed training in diagnostic reasoning, which helps physicians gather and group assessment data into meaningful sets in order to generate hypothesis about a patient. A major factor in this training, however, is that physicians for the most part tend to assume the presence of linear relationships between data and patients' disease. However, while these relationships are generally reliable, they will not help in determining the degree to which these relationships are able to explain the reported association when addressing the patient's unique problem. The reason is not because of problems with the accuracy or completeness of the data, but "because they are derived from the study of large and diverse populations" (Marinker, 2004, pp. v-vi). In particular, the inability to assimilate or incorporate subsequent or evolving data about that particular patient may be troublesome. In essence, "what can be claimed to be generally true for such researched populations cannot simultaneously be true for each of the individual patients included in these populations" (Marinker, 2004, pp. v-vi). Therefore, when physicians are confronted by actual patients, evidence derived from the study of populations can be less reliable, and the path between general medical facts garnered through large clinical studies and the specific application of those facts in individual cases becomes blurred. The rapid expansion of medical knowledge has lead to the daunting but crucial need for the physician to distill which information is valid and applicable to their particular individual patients, and how it is to be best applied in order to avoid active failures and latent conditions. Medical decision-making techniques help in deciding whether and how the results of a study apply to a physician's patients. A better understanding of diagnostic reasoning should enhance patient care outcomes.

Medical knowledge is expanding rapidly. For many professionals, learning to access, interpret, and apply this knowledge appropriately is a daunting but crucial task, and physicians are not immune to this problem. Under the pressures and stresses of the moment, this task can become very complex. For example, in one situation observed during this study the attending physician supervisor at a trauma center was required to attend to four incoming matters almost simultaneously: (1) an internal resident physician asking for instructions on how to proceed with a patient, (2) another attending physician reporting on a serious situation with a second patient that required the supervisor's immediate attention, (3) a telephone call from the EMS on an incoming patient, and (4) a radio call from another unit of the EMS system on a seriously injured patient on the way to the trauma center. This required four decisions about medical interventions that had to be made in less than two minutes. The overarching physician's approach was a decision model based on prioritization by concentrating on the radio and telephone calls first and then handling the in-house physicians expeditiously.

The research design of this study took into consideration the need to set boundaries and study only a few questions in depth. Based on the research methodology of real-time observations of trauma cases, boundaries were further limited by available resources, time constraints, and "limits in the human ability to grasp the complex nature of social reality" (Patton, 1987, p. 45). This research explored the following questions:

1. How do physicians make decisions when confronted with complex, stressful, and changing situations of trauma events?

2. Is it the physician's level of expertise that determines whether an intuitive judgment or an analytical approach should be taken to the various components of the clinical decision-making task while in the critical moments of the "golden hour"?
3. To develop an approach to understanding how physicians think while caring for a stressful trauma situation.

1.5 Summary

This chapter summarized and brought to light the importance an emergency physician play in trauma centers everyday situations. It covered in detail the important aspects of a trauma system versus a trauma center and the roles each play in our society. The major objective of this dissertation is to use complex adaptive systems ideas to provide an understanding of how physicians think when stressed by fragmentary data, multiple injured or very sick patients, and placed in very complex situations.

CHAPTER 2

A Review of the Contributing Literature

2.1 Introduction

This chapter presents an introduction to the material to be given detailed treatment in later chapters, that is, the application of the theories of complex adaptive systems and human judgment in hospital trauma centers, which receive a large number of trauma injuries. Trauma patients are those who have sustained a physical injury. Surgeons, in particular, use the term "trauma" to refer to the physical injury, whereas other medical providers prefer the term "injury." These injuries may be broadly categorized as penetration trauma (e.g., gunshot, knife wound) and multisystem trauma, such as car crashes, falls, and other events.

Trauma injury can be serious. Injury deaths worldwide place a significant burden on the world's work force. As shown in Figure 2.1, almost 50% of the worlds' trauma-related mortality occurs in young people aged 15 to 44 years old, the potentially most economically productive members of the global population. The World Health Organization estimates that trauma injury constitutes 12% of the world's burden of disease. Injuries have a substantial impact on American residents, their families, communities, and society. According to the Centers for Disease Control (CDC), during the year of 2005 a total of 173,753 injury-related deaths occurred (Besser, 2009). It is the leading cause of death in trauma patients in Western countries (Spijkers, Meylaerts, & Leenen, 2010). By 2020 it is estimated that more than 1 in 10 people will die from injuries (Fildes, 2008).

However, trauma is not always fatal. In 2006 an estimated 29,821,159 persons with nonfatal injuries were treated in United States hospital emergency departments (Besser, 2009). Severely injured patients can be expected to be at high risk for developing complications. The “reasons for this include the physiologic and immunologic impact of trauma (e.g., coagulation disorders, hyperthermia) and the frequent necessity of mechanical ventilation, immobilization, etc.” (Saltzherr, Visser, Ponsen, Luitse, & Goslings, 2010). The consequences of traumatic injuries can be extensive and wide-ranging. They can be physically, emotionally, and financially crippling, and in the case of disabling injuries, the consequences are enduring. For instance, as reported by the CDC in 2012 in the United States alone, more than 1.7 million individuals sustain intentional and unintentional traumatic brain injury annually, which typically entails long-term changes in functioning. Such complications are at the very least inconvenient for the patient, and they can lead to more severe negative consequences such as prolonged hospital stays, increased costs of medical care, and mortality. Almost 90% of pre-hospital trauma-related deaths involve brain injury. Global trauma-related costs are estimated to exceed $500 billion annually, not including costs related to lost wages, medical expenses, property damage, fire loss, and employer costs, among others (Fildes, 2008). The importance of research in efficiently generating medical evidence and diminishing the problem of injuries has been well described. In 1985 the Institute of Medicine report, “Injury in America: A Continuing Public Health Problem,” concluded that supporting injury research is necessary to substantially reduce injury rates. The World Health Organization (WHO) feels that organizations and groups involved in the care of trauma need to become more united and develop common messages with which they could collectively advocate. The WHO’s report emphasized a preliminary set of key resources that every injured person should have: (i) basic lifesaving care in the field and rapid transport to a site of definitive care; (ii) access to adequate, timely, essential care that is life- or limb-saving at hospitals and clinics; and (iii) access to adequate, essential rehabilitation services for those with disabilities resulting from their injuries (Shiffman, 2009). In essence, the report seeks ways to increase the political profile of trauma care by developing ways to utilize the determinants of political priority in order to position trauma on the global health agenda.

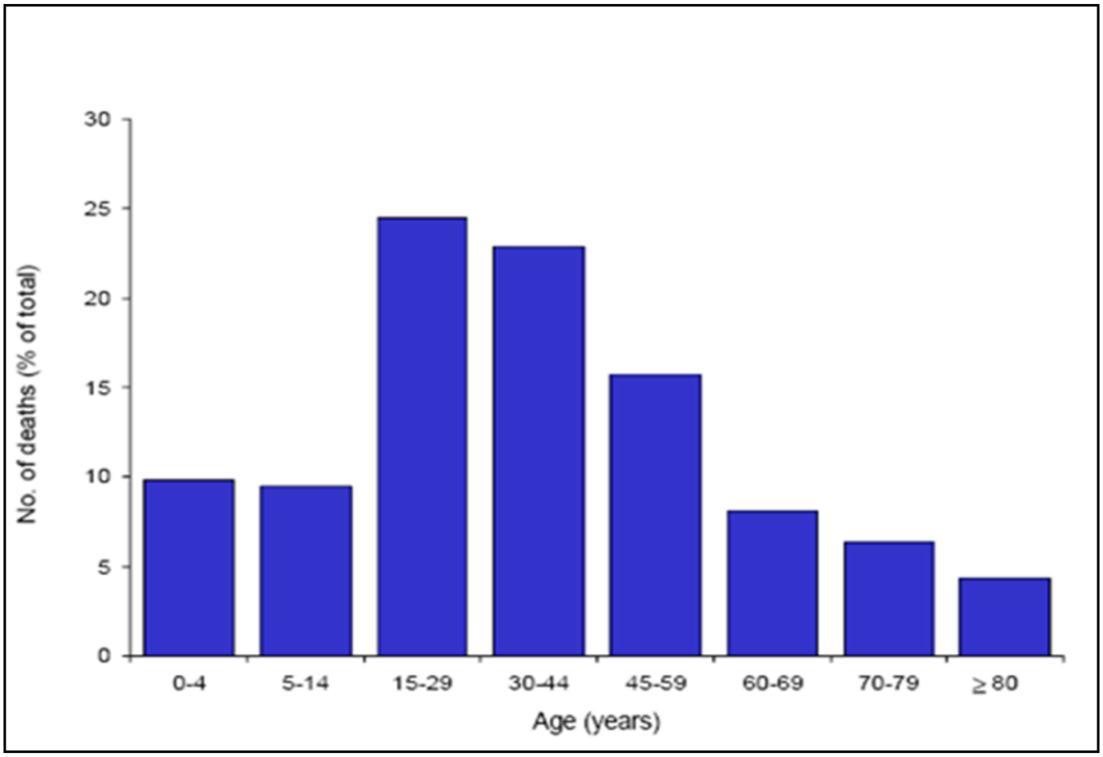

Figure 2.1. Age distribution of global injury. Source: (Peden, McGee, & Sharma, 2002).

Because of the diverse health effects associated with injuries, positive outcomes are often dependent on the availability of a continuum of providers from a multitude of health disciplines to provide patients with quality care, better life expectancy, functional status, and greater satisfaction. Patients arriving at trauma centers are placed in the hands of highly specialized teams comprised of 15 to 20 medical personnel, including surgeons, residents, registered nurses, medical students, and technicians. Most hospital providers of trauma centers have three separate teams to ensure 24-hour coverage. Studies have shown that the risk of death for patients cared for at a trauma center becomes significantly lower than when care is provided in a non-trauma center facility (MacKenzie, Rivara, Jurkovich, Nathens, Frey, Egleston, Salkever, & Scharfstein, 2006). This has been the fundamental belief and impetus that led the American College of

Surgeons Committee on Trauma (ACS-COT) to move forward its "Advanced Trauma Life Support for Doctors" (ATLS) program throughout the world to establish trauma center criteria for the care of the injured (Fildes, 2008). To be maximally effective, trauma center teams need not only to articulate their needs clearly, but also need to discover their members' unarticulated needs, innovate, and develop frequent, timely, and accurate problem-solving communication skills to effectively translate and disseminate information.

2.2 Interest in Complex Systems

The study of complex adaptive systems (CAS) these last few years has fascinated scientists from every corner of the world and across many disciplines in the physical and natural sciences, such as evolutionary biology, genetics, artificial intelligence, psychology, and mathematics. *The New York Times* on May 6, 1997, brought complexity theory to center stage when it carried an article by George Johnson entitled, "Researchers on Complexity Ponder What It's All About" (Johnson, 1997). In this article, the writer stated, "Some of the grandest phenomena, like the coursing of comets around the Sun, are marvelously predictable. But some of the most mundane, like weather, are so *convoluted* that they continue to elude the most diligent forecasters. They are what scientists call complex adaptive systems. Though made up of relatively simple units—like the molecules in the atmosphere—the pieces interact to yield behavior that is full of surprise[s]."

There are number of contemporary trends that are contributing to the growth of interest in complex systems theories and have been attracting a great deal of attention. One researcher of the complexity theory, Michael Cohen, (Cohen, 1999), provided at least three instances of this recent interest in complexity science. The first is that there are dramatic changes occurring in the structure and operational scope of business and government, and the list of challenges is long:

globalization, intensive local and global competition, process re-engineering, workforce diversity, quality improvement, and continual innovation are but a few. Second, it is common knowledge that we are in the midst of an information revolution, with the internet compressing space and time. There is awareness of the fact that prices for sensing, processing, transmitting, storing, and retrieving information are constantly declining at incredible rates. These changes allow for the exploitation of technology to couple activities that were previously disconnected in space and time, creating unlimited opportunities for the use of these new technologies to increase the sensitivity and inter-connectivity of one process to another. Finally, organizational entities are being created and dissolved at increased rates. It is noticeable from macro-level events such as the fall of the Soviet Union, the integration of the European countries, and the mergers of mega-size corporations, to micro-level events such as the rise of increasing numbers of temporary employees, outsourcing manufacturing and services, and virtual organizations that are here today and gone tomorrow. All these complex changes experienced daily “direct our attention to the formation and dissolution of an organization’s boundaries and to the forces that allow an organization to have value greater than the sum of its parts” (Cohen, 1999), that is complex adaptive system.

It is easy to confuse complexity with chaos; actually, it is even tempting to use the expression interchangeably in informal conversation to refer to a “chaotic situation” as being a “complex situation.” The management of traumatic injuries is such a complex, chaotic situation, involving interactions among hosts, agents, and environments, which together have lasting physical and psychological impacts. It is a science and an art that, like forecasting the weather, is always full of surprises. It is also full of potential. Murray Gell-Mann, the 1969 Nobel laureate in physics, is among those scientists who have become fascinated with CAS. He sees the potential for a much broader impact of complexity theory to all aspects of human endeavors: "Even more exciting is the possibility of useful contributions to the life sciences, the social and behavioral sciences, and even matters of policy for human society" (Gell-Mann, 1995a, pp. 316-312).

2.3 Basic Concepts of Complex Adaptive Systems

The changes occurring in many processes can be explained in terms of how complex adaptive systems organize, develop, and evolve. Levin (1998) has observed that it is easy to find books that discuss with varying degrees the specifics of certain systems as CAS. For instance, one author attempted a fairly general definition by stating that a complex adaptive system is an ordered state of the elements that make up an environment, exemplifying it with the state of liquid water, which is created by combining two molecules of hydrogen and with one molecule of oxygen (Miller, 1999). But it is another matter, said Levin, to find a formal definition, "as if investigators fear that by defining CAS they will somehow limit a concept that is meant to apply to everything" (Levin, 1998, pp. 431-436). Several researchers have nevertheless tackled the complex task of attempting to describe complex systems. Gell-Mann explains that "Complexity, however defined, is not entirely an intrinsic property of the entity described," as it depends to some extent on who and what is doing the describing (Gell-Mann, 1996, pp. 2-12). Thus, each proposed definition is somewhat unique, yet all contain overlapping features.

Broadly speaking, complexity results from the inter-relationship, inter-action, and inter-connectivity of elements within a system and between a system and its environment. Complex systems are systems that are comprised of many interacting parts that together have the ability to generate a new quality of macroscopic collective behavior, the manifestations of which are the spontaneous formation of distinctive temporal, spatial, or functioning structures (Qudrat-Ullah,

& Spector, 2008). Levin has offered a fairly general and flexible definition of complexity using three properties: “(1) diversity and individuality of components, (2) localized interactions among those components, and (3) an autonomous process that uses the outcomes of those interactions to select a subset of those components for replication or enhancement” (Levin, 2002). A more comprehensive definition of CAS can be stated as a collection of individual agents with freedom to act in ways that are not always predictable, and whose actions are interconnected so that one agent’s actions changes the context for other agents (Plsek, & Greenhalgh, 2001).

In each of these definitions, the form of a complex adaptive system is understood to reflect the ways in which its elements interact with one another. Some researchers of CAS (Chan, 2001; Gell-Mann, 1994; Holland, 1992; Mitchell, 2009; Nugus, Carroll, Hewett, Short, Forero, & Braithwaite, 2010) have begun to extract a common kernel from all of these definitions, that is, each one recognizes there is a similar “evolving structure” in complex systems, that these evolving organizations have certain design requirements and, furthermore, in seeking to adapt to changing circumstances, these evolving systems have demonstrated that their parts can be thought of as developing rules that anticipate the consequences of certain responses.

To say that such systems adapt is to suggest that they have the capacity to alter or change—the ability to learn from their experience. Gell-Mann points out that complex adaptive system actively search for regularities. They acquire information about their environment and their interaction with that environment, identify regularities in that information, then compress the acquired information into an organized collection of schemata or models and take actions based on those models (Gell-Mann, 1995b). Examples of CAS include trade balances, acquired immune deficiency syndrome (AIDS), genetic defects, ant colonies, human bodies, hospitals, trauma centers, and so on.

J. H. Holland, a professor of psychology and computer science at the Santa Fe Institute for Complexity Science and also the creator of the Genetic Algorithm, stated that the ability of the elements in CAS to adapt or learn is the pivotal characteristic of complex adaptive systems. More than this, they are adaptive not only because they respond to changes in their surroundings (learn) but also because they influence their environments to conform to their current organizational state (Holland, 1992). This is the evolutionary aspect of complex systems. Besides evolution, complex systems seem to share two other characteristics: aggregate behavior and anticipation. It is the aggregate behavior that researchers seek to understand and modify. Though to fully understand all of its ramifications, there is a need to understand how the aggregate behavior emerges from the interactions of the parts of the system (Holland, 1992).

A complex environment arises when situations or events occur that offer little or no predictable information, at which point learning and communication are required to fill the information gap in order to sustain the system. The assertion is made here that a trauma center should be dealt with as complex adaptive system because it is one in which low-information situations that require rapid learning and communication regularly arise. A trauma center is comprised of a set of elements that are interconnected and inter-related such that changes in some of its elements or their relations produce changes in other parts of the system. Moreover, the trauma center system, as a whole, exhibits behaviors that are different from those of the parts. The fundamental unit of the trauma center system is the patient. Each trauma case arrives with information limited to that which was communicated through radio or telephone by the EMS to the medical team at the trauma center. Considering each of these trauma cases as a sub-system of the trauma center, this information for the most part consists of the functional requirements that capture the intended behavioral parameters of the sub-system. These behaviors have been spelled out by the American College of Surgeons Committee on Trauma as the ABCDEs of trauma care—the services and functions (behaviors) to be performed, in the form of an algorithm that provides for a rapid survey and resuscitation of vital functions before the initiation of definitive care by the activated trauma team.

The job of the trauma team is one of securing these functional requirements of the patient sub-system in such a way that the information derived in doing so can drive architectural decision-making processes that create relevant mental schemas, which, in turn, translate into the formation of goals and their analysis and development during stressful moments. The structural design of the trauma case sub-system is created by the actions and interrelations of the team in using the information acquired from both the EMS and its own set of observations. These minimum functional requirements (the ABCDEs) serve to delineate the intended behavior of the sub-system (the patient) and allow for responding to changes that emerge from it, providing a basic frame of reference on which the entire team reacts. However, it is not unusual for lack of clarity surrounding these functional requirements to preclude the team from developing explicit goals. At these times, the trauma team must also draw upon intuition and judgment.

2.4 Medical Judgment in Clinical Decision Making

The literature of intuition and judgment in decision-making has grown immensely these last few years, covering both theoretical issues and interdisciplinary applications. A review of the literature shows that the clinical decision-making process for most specific medical procedures has been extensively and frequently described. However, it is hard to find studies covering decision-making processes for a trauma center medical team operating under the stressful conditions of caring for multi-trauma-injury patients. The medical team's pre-established protocols and algorithms may not factor in the element of human judgment in the clinical decision-making processes. This is because these algorithms are developed based on the procedural domain of medical expertise. Complex situations, however, bring massive amounts of challenging, problematic, and testing information that decision-makers come across, or even stumble upon, that helps them make their decisions. These decisions are "decisions typically made through gut feeling or intuition" (Yolles, 2006, pp. 237). Intuition and judgment have being around since the dawn of ages, as far back as Socrates (470-399 BC), Plato (427-347 BC), and Aristotle (384-322 BC). However, it has been only recently that researchers on decision-making methodologies have decided to study these most enduring disciplines in a formal manner and incorporate them in their processes as critical developments occur in this important competency area of decision making (Connolly, Arkes, & Hammond, 2000).

Classic models of decision-making generally assume static problem domains, rational analysis, and suboptimal human decision-making. The land of intuition is not one many scholars write about. "They prefer to describe a land where the sun of enlightenment shines down in beams of logic and probability, whereas the land [of intuition] we are visiting is shrouded in a mist of dim uncertainty" (Gigerenzer, 2007). However, intuitive judgment is bounded by "gut feelings" that arise during attempts to avoid misses and false alarms. This, undisputedly, is "the intelligence of the unconscious" turned loose on practical, real-time issues of interdisciplinary decision making. This intelligence comes strongly into play in trauma centers.

When an injured patient arrives in a trauma center, protocols to obey and algorithms to be followed generally take precedence in the process of caring for and even resuscitating the injured patient. These rules and procedures are starting points that are in effect long before the injured patient even arrives at the trauma center. Through radio communications, EMS and trauma center medical personnel are making two key decisions on how to bring a trauma event to a safe conclusion. First, there are decision-making events to get the patient alive into the trauma center. Second, there are decision-making events (based on certain pre-determined criteria) for deciding whether to code the case as either a Level 1 or a Level 2 trauma. Either of these two decision points will activate an appropriate medical team to be on standby for the incoming patient.

While in the midst of the trauma situation, the logic of mathematical models, a myriad of engineering technologies, and even the knowledge of evolutionary biology help trauma teams find a plausible solution for saving the patient's life. However, what is rarely observed are the repeated judgments, intuitions, and gut feelings of the leading medical team that bring about the successful outcome of the event. Logical scientific reasoning helps to bring success to fruition; but, not always is it solely because of the logic of scientific knowledge and the technology that is applied. Often it is the medical team's unconscious choices and decisions, not just their deliberate reasoning that makes it all possible. Everyone has such unconscious processes. Sometimes we are not even aware of making these kinds of choices or decisions. "The unconscious parts of our mind can decide without us—the conscious self—knowing its reasons, without being aware that a decision has been made in the first place" (Gigerenzer, 2007). The fundamental characteristics of medical decision-making while providing the best patient care seem to go beyond the technical, as if expert clinical judgment is generally of an intuitive nature. It is irrefutable that science makes up a great part of medical decision-making processes; but as the famous physician Atul Gawande pointed out, it is "also habit, intuition, and sometimes plain old guessing" (Gawande, 2002).

2.4.1 A case of intuition. The following case exemplifies intuition in trauma episodes and a surgeon's abilities to recognize patterns within a complex event. This case helps illustrate how intuitive decision-making works in the clinical setting, as well as showing methods to reduce complexity in the decision-making process by taking an incremental approach to the problem at hand. It is "The Case of the Red Leg" (Gawande, 2002). The case is one of those situations in which the absence of algorithms and protocols about what do drive physicians to make gut feeling, intuitive- medical-judgment decision-making. This is the story of one very complex decision-making event under extraordinarily uncertainty.

A 23-year old woman presented in the emergency department of the hospital with a red and swollen leg. The resident physician at the scene in the emergency department thought that it was probably only a bad case of cellulitis, a simple skin infection, and started the patient on intravenous antibiotic. However, because of the severity of the rash, he called on another physician, a surgeon, for a second opinion (perhaps due to intuition kicking in). The surgeon looked at the young woman. She looked fit, athletic, and almost young enough to be a teenager. There did not seem anything seriously ill about her, as she watched television. The young woman again told the surgeon the same story that she had already told the resident trauma physician, which was the same story she had a few days before also told to her private attending physician. It was a grand wedding she attended where she kicked off her shoes and went dancing barefooted all night. A tiny blister developed, which afterwards became an infection, and now she was in the trauma center in a lot of pain. Initially, the surgeon was about to concur with the resident trauma physician's diagnosis. But for unknown reasons, something popped up in the surgeon's mind (intuition, again): the possibility of one of the most horrendous diseases ever to befall a human being, a horrendously lethal type of infection known as necrotizing fasciitis. The tabloid media has called it a disease of "flesh-eating bacteria" and the term is not an exaggeration. Very little is known about the disease, except that it is highly aggressive and rapidly invasive. This disease has been associated with significant morbidity and mortality, rapidly killing up to 70% of the people who get it, with significant morbidity if an operation to remove the decaying and infected area is delayed even as little as 12 to 24 hours (Sudarsky, 1987; Wong, Chang, Shanker, Khin, Tan, & Low, 2003).There is no less invasive antibiotic or other treatment that can stop it.

Only about 500 to 1000 cases of necrotizing fasciitis occur in the entire United States each year, mainly in the elderly and the chronically ill (Gawande, 2002; Wong et al., 2003). How do you tell a young woman, full of life, just beginning her adult existence, that she possibly has this horrendous disease? It would be a hard sell, since, her fever had all but gone and the only signs of the infection were the red rash and the pain in her leg. The surgeon, however, had a gut feeling that told him to search deeper and, as he recognized the pattern, he “gained a sense of the situation” (Klein, 2004). He excused himself from the room, spoke with other physicians. Most physicians do not see this disease often, because it is not common; actually, some physicians fail to see it at all throughout their entire careers. And there is no test whatsoever short of a biopsy that will tell the two diagnoses, cellulitis or necrotizing fasciitis, apart. The scenario is thus completely unpredictable from patient to patient. The only way to know with any certainty is to go into the operating room, cut the patient open, and look inside (Gawande, 2002; Sudarsky, 1987; Wong et al., 2003). If it is necrotizing fasciitis, the medical team sees the destruction caused by the bacteria. If it is not too late, they must remove the affected area—including amputating limbs, if necessary—and hope to stop the bacteria from spreading to the rest of the body.

Within an hour, the surgeon had obtained the young woman’s consent for a biopsy of the affected tissue followed possibly by amputation of the affected leg. In the operating room, the biopsy revealed that indeed her condition was flesh-eating bacteria. To address this potential diagnosis, the surgeon had pre-assembled an impressive multidisciplinary team composed of surgeons, pathologists, radiologists, dermatologists, and the technological facilities only available in another hospital, all working in synchrony to save her life. The surgeon opted to try to save the leg via debridement of the infected tissue coupled with thoroughly washing out the entire area. For recovery, her doctors recommended hyperbaric oxygen treatments, which required transport to a nearby hospital for a two hour therapy, two times daily. After four similar operations to remove infected tissue, the leg seemed to be growing new tissue and healing.

Researchers of intuition and human judgment, such as Gary Klein, might say that the surgeon "had stumbled onto the phenomena of intuition" (Klein, 2004). To illustrate the importance of intuition, Klein uses a story he calls "A Baby in Crisis." The nurse in an intensive care unit was caring for an infant but "had missed the classic symptoms of sepsis, which seemed so obvious" (Klein, 2004). The supervising nurse, however, despite not having hands-on care of the infant, noticed the signs of the problem at a routine inspection, and her "intuition" told her that a more serious danger was facing the infant. Immediately, the supervisor sought help and information, which was met with the approval of the attending physician who agreed with the supervisor's diagnosis, decision, and treatment, therefore saving the infant's life.

Similarly, the surgeon in the necrotizing fasciitis case did not have any of the "classic symptoms" that could guide his decision-making process, because there are no such symptoms that will enable physicians to decide positively on the diagnosis of the disease. The pieces of the diagnostic puzzle were put together in the mind of the surgeon, who developed those pieces into a story that revealed the larger pattern. The ability to recognize visual patterns (i.e., the red leg) and auditory patterns (i.e., the young woman's account), and form them into a larger, recognizable, meaningful pattern are evidence of the great adaptive abilities of the human brain

(Gluskov, 1966). Because of his ability to recognize an obscure pattern by combining disparate sets of observations and information, the surgeon was able to create an image (a schema) of the disease that allowed him to assemble the multidisciplinary surgical team and to translate his “experience into action” (Klein, 2004). In addition to the limited information acquired from the trauma event environment, the surgeon had previously had an experience with another patient with the same disease.

The disease in this other patient had started with a scratch on the patient’s chest and escalated to the rest of the body, despite all the efforts of the medical team to eradicate the bacteria in an attempt to save the patient. The recognition of patterns helped the surgeon to capitalize on his stored representations of disease, by way of constructing mental algorithms for learning the pattern of various diseases. This, in turn, offered him direct access to the judgment and decision-making process. His judgment could not benefit from the system’s accurate description of the properties characterizing the trauma in order to arrive at a decision. Only his intuitive thoughts and gut feelings about the whole thing allowed him to make a judgment about what was going on under the skin of the young woman’s leg.

This series of events seriously contrasts with statistical approaches to events, where probabilities and likelihood ratios may provide some guidance in the diagnosis. But, as John Fox puts it, statistical numbers represent “a relationship between symptoms and diseases, but in abstract form.” They say nothing about the symptoms or the disease—whether it is just a symptom or a distinct disease, or whether the symptom is caused by a disease or just statistically associated with it. “Each number records the *scale* of a relationship but not its *sense*” (Fox, 1984). Intuition, however, can provide the sense of experiences. “Intuition is holistic and can reveal a remarkable degree of accuracy if the learning context has provided representative and valid feedback” (Plessner, Betsch, & Betsch, 2008). “The output of intuition,” observes Betsch, “is a feeling, for instance, the feeling of liking the entity or a feeling of risk” (Betsch, 2009). These amazingly accurate gut feelings or intuitions are often based on surprisingly little information. Researchers have shown that decision making can actually be improved despite severe time constraints and little available information (Gigerenzer, 2007).

Gut feelings are powerful means of communication of important pre-rational information and Gigerenzer (2007) uses this term to refer to judgment that promptly pops up in our minds, sometimes for no apparent reason, but with so much impetus that the decision maker feels compelled to act upon. Trauma systems, which are amalgams of medical personnel from different specialties who have learned unique formal algorithms (procedural domain of expertise) for diagnosis and treatment, rely on a combination of gut feelings buttressed by solid information from the medical team to produce positive outcomes for patients. Expert medical personnel are capable of attending to and extracting the most relevant cues in the trauma environment and can avoid attending to distracting or irrelevant cues that the learning context may also provide as feedback. If the initial gut feeling is proven correct, the physician’s expectancies should match the events with the solid knowledge-base of the assembled multidisciplinary team. Conversely, if intuition fails the surgeon, the surgeon can quickly use the team’s vast stored knowledge to notice the problem, take corrective action, and provide representative and valid feedback on the event.

In “The Case of the Red Leg,” a year after the young woman’s necrotizing fasciitis has been treated; the surgeon visited her family to check on her progress. He noted with satisfaction that the patient had recovered full use of her leg. His intuition, in short, had paid off not only in saving the young woman’s life, but also in saving her leg. The perceptual skills he had used to accomplish this feat included many of the intuitive decision-making processes: visual search strategies, signal detection, extraction of cues, and pattern recognition. This significant way of viewing a patient, who presented with what seemed at first to be a fairly straightforward and uncomplicated problem, made it possible to recognize the lethal disease.

For many complex clinical decisions such as the one just discussed, all the hard data in the world cannot surpass a lifetime's worth of experience that informs one's gut feeling, instinct, or intuition (Matzler, Bailom, & Mooradian, 2007). Researchers have struggled to understand human judgment and intuition by building mathematical models of how each item of information contributed to influence clinical decision-makers overall judgments. The consistent and amazing finding of these researchers has been that ridiculously simple mathematical models of disease did as well in study after study as sophisticated, experienced clinicians. The explanation for and implications of these results are still hotly debated (Connolly et al., 2000). In the trauma center as it is in life, "intuition is an essential, powerful, and practical tool," that we all use to "translate our experience into action" (Klein, 2004 pp. HIV).

2.5 Summary of Literature Review and Implication to this Research

The interest of this research lies in examining the complexity of decision-making processes in emergency medicine, and physicians' decision-making process under stress at all levels of trauma center units in hospitals. One way of exploring this is through theories of complex adaptive systems together with human judgment theories, which provide important concepts and tools for elucidating decisions that often seem ill-defined, fuzzy, and uncertain. In complex situations such as those of trauma events, the information that decision-makers have to help them make their decisions is often massive and difficult to handle. In the face of such complexity, it is often the case that decisions “are typically made through gut feeling or intuition” (Yolles, 2006).

The problem of decision making under stress has not been solved yet and more research is needed in the area of accurate description of physicians decision-making processes; however, researchers have developed theories that have greatly benefited those whose jobs are to operate in complex and challenging environments (Cannon-Bowers, 1998; Schraagen, & Schaafstal, 1999; Hamm, Scheid, Smith, & Tape, 2000). This study used Bayesian Classifier with Convolution and Deconvolution operators to study real-time, observed trauma events data to explain decision-making processes under tremendous stress. These topics are being introduced here but they will be fully discussed in chapter four. “Convolution is by far the most important operation that describes the behavior of a dynamical system” (Mendel, 1990). It “may be viewed as a self-organized learning process” (Haykin, 1994). Because physicians have blurred information and cues that are tainted by random environmental noise during injury-related events, making their information convoluted, they must de-blur (de-convolute) the observed data to find a best approximation of the real situation. Convolution is what causes the stress on the physicians’ rational decision-making processes. Deconvolution is the process of clearing out the extraneous noises of the physicians’ immediate environment to allow them to gain a clearer picture of real state of affairs and come to the correct diagnosis and course of action.

CHAPTER 3

Conceptual Framework

The American College of Surgeons Committee on Trauma (ACS-COT) has for over three decades published guidelines for trauma care. Books from the ACS-COT such as the Advanced Trauma Life Support for Doctors (ATLS) have outlined the general context and background for most particular actions and trauma events. In the following paragraphs, a general framework will be developed that distinguishes causes, sources, contents, and consequences of complexity in trauma centers, as well as different actors involved in the clinical decision-making processes. Decision makers in a trauma center (TC) know what they are trying to achieve but there are many unknown variables that make it unclear how to do so, in which case comes the need to judgmental or intuitive modes for making a decision. Patients in TCs present themselves with undifferentiated problems and symptoms hard to diagnose that require reasoning by analogy, intuition, judgment, and trial-and-error decision-making processes that poses real challenges.

3.1 Modes of Decision-Making

In this study, an attempt is made to operationalize complex clinical decision-making in trauma center units of hospitals in terms of the immediate impact of complexity on both the tasks and the actors involved in the trauma event. Figure 3.1 illustrates the nature of complex systems along three axes. The first, the x-axis, represents the continuum between facts and actions that are clearly defined or lend themselves to linear conceptualization and those that are more non-linear and conceptually fuzzy. The y-axis represents the continuum between situations and facts in which all are in agreement, to those in which various stakeholders may be in frank disagreement. Finally, the z-axis represents the continuum between extreme certainty and extreme uncertainty as complexity increases. These three dimensions of complex situations are at work in four identified domains: Rational (R), Political (P), Judgment or Discernment (J), Intuition (I). Each of these four domains of Figure 3.1 shall be discussed next.

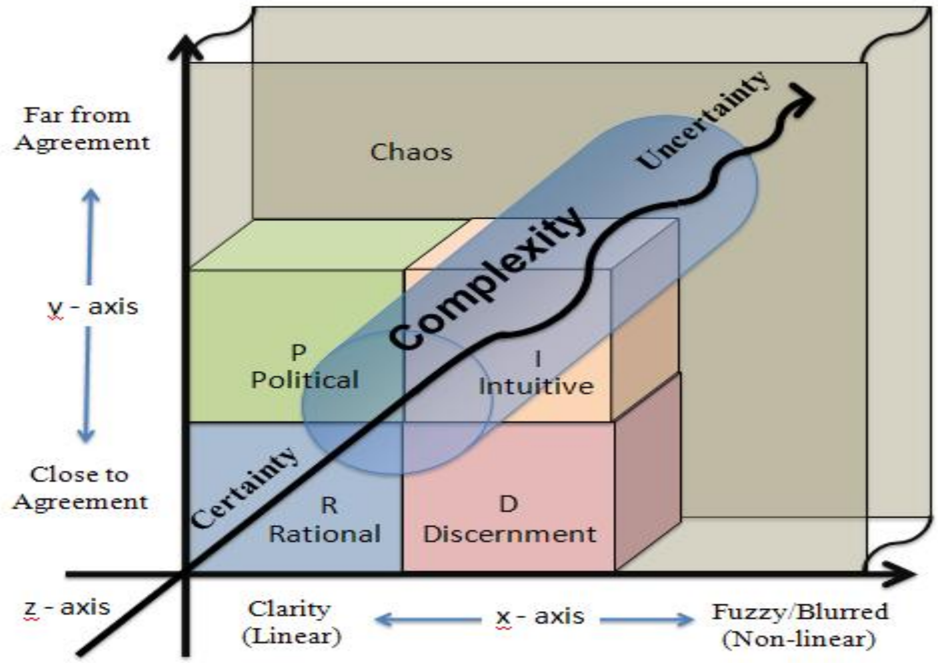

Figure 3.1. Concepts and fields of complexity.

3.1.1 Rational. Rational is decision making based upon facts regarding the object of focus (i.e., the patient), which specify what people ideally should do during a decision process. "Rational approaches are conscious, logical and planned, testable, and traditionally related to clear and quantifiable situations" (Yoles, 2006, p. 37). The rational domain of Figure 3.1 has the embedded notion of order that induces creation and systemization of information. This is the domain where decision makers do not raise questions of uncertainty or difficulty and there is no confusion whether they are dealing with the symptoms of a hidden problem or the problem itself. However, decision makers have to keep in mind that these decisions are taking place in dynamic and changing environments, requiring full information and knowledge. Rational approaches are sometimes inadequate for uncertain or ambiguous situations that cannot be rationalized as common pattern knowledge. The medical team's interactions provide common grounds for linking feedback and observations that is enhanced through rationalization.

The rational decision making process (RDMP) considers three characteristics: (i) descriptive, how people actually make decisions; (ii) normative, the process that would constitute rational decision making; (ii) prescriptive, tools that will encourage rational action in real life; in other words, moving the descriptive towards the normative (Robinson, 2004). There is strong desire to base decisions on rational grounds, which is corroborated by Paul Robinson that the desire for objectivity and rationality pervades the study of medical decision making (Robinson, 2004). Physicians go through the rational process to match the parameters acquired through experience, research, body of literature, schools, and so on. It means, in RDMP the decision maker has a value for the decision making process. If the parameters are known, everyone should reach the same conclusions.

3.1.2 Political. Political is decision making based upon intangible outside influences such as the perception of others and instructions of those in superior station or standing. Decision makers in most pivotal crossroad situations are burdened with conflicting objectives and must be cognizant of the constraints presented by the finite nature of human and material resources. The political process in trauma centers is ethical but normally exerts a determining or guiding influence on the behavior of the medical team. This is the domain of Figure 3.1 in which physicians believe that information matters in order to advance models to explain how their preferences are turned toward immediate evaluation of one procedure versus another. It is the domain for the evaluation and the structuring of cognition that result in a heuristic mechanism for evaluating new information. When new information is encountered, it interacts with relevant existing knowledge to form a virtually instantaneous assessment of the new information. And, this is a continuous and immediate process which occurs upon acquisition of the new information for which the decision maker will argue in favor and make an effort to fit it into the existing trauma case. It is the decision maker's prerogative to argue and make it fit to the situation; thus, the political decision-making process. The onus then falls upon the physician to determine how newly discovered data fits in to the developing scenario.

3.1.3 Judgment. Judgment (Discernment) is decision making based upon similarities observed between the current object of focus and previous scenarios with comparable circumstances while being aware of the subjective nature of judgment. It assumes that commonalities in decisions-making are perceived by all members of the team. The trauma situation can become difficult because it is not repetitive, outcomes are generally unknown for a few hours at least, and results are complex to measure. However, the objectives are clear, requiring subjective judgment. In this domain of judgment of Figure 3.1, the decision maker develops a view of the problem and proceeds to the modeling of it because how one sees the problem is individual and personal. The modeling of the problem allows others to visualize what happen in the decision-making process of someone making a judgment. This knowledge of judgment as modeling of decision-making process can be used to further understand how a decision maker under stress arrives at solutions to problems which prove themselves difficult to solve. In this domain, physicians rely on their library of pattern recognition in order to guide his or her actions to somewhat reduce the complexity of the task to arrive at a reasonable predictive probability. Judgment has associated with it the notion that situations can be intentionally molded to maintain an environment conducive to unconscious gathering of information and potentially revealing cues to a particular recognizable pattern. This approach of deliberate effort to manage the developing situation allows for adaptability to a changing environment.

Judgmental decision-making can then be conscious, unconscious, or subconscious through the projection of cultural attributes that are connected to emotions, experience, and knowledge. The physician's task is to be able to *mentally* read all cues and clues and make reasonable assumptions. The articulated judgments about some environmental state derived from physicians' perceptions, instincts, and interactions with emotions that eventually create transformation in that state. It is these organizations of perceptions, instincts, and interactions that convey to someone else what the physician has seen. And, it is the articulation of his/her judgments that makes problem's solutions available for discussion and reflection because perceptions, instincts, and interactions are organized in the context of immediate purposes and relationships. As seen in Figure 3.1, Judgment domain moves away from certainty and agreement (rational) to conditions of uncertainty and conflict, represented by the fuzzy or blurred area encroaching chaos.

3.1.4 Intuition. Trauma physicians are making intuitive decisions in every trauma case. In this intuition domain of Figure 3.1, physicians are using ad hoc mental models developed through years of experience and it occurs through physicians' pattern recognition and inductive reasoning. This is also the domain that shows that physicians do not know all the alternatives and all possible outcomes of the trauma case. However, through a quick and limited search to discover a few alternatives and the use of their own subjective intuition, a decision is made that satisfies the problem presented by the system. Physicians' knowledge and experience is clearly seen as playing a role of central importance in avoiding a chaotic situation. Isenberg (1985, 1986) suggested that decision makers' time and resources are limited and that even when computerized theories are available, they rely on subjective mode to make decisions. The use of this type of decision making by physicians happens because each trauma case is different, human beings react unpredictably and there is little direct access to knowledge about and control of the attributes endangering the patient. The principles that drive this domain are "why?" "what?" and" how? respectively, followed by pattern recognition and mental model simulation, which garner the internal power to exploit the opportunity. Intuitive processes help decision makers in their decision-making performance and their abilities to reflect on actions while performing them (Isenberg, 1985, 1986).

3.2 The Framework

In Figure 3.1, the relation between the states and the transformation is assumed to be continuous where the set of states may lie in a connected region. Thus, the region within the boundaries of Discernment (D), Intuition (I), Political (P), and Rational (R) are stable, though with each region showing a different landscape. However, the place where these three regions intersect gives rise to a complex region. Trauma centers operate at all times within this matrix of complexity, with each trauma case having a value that lies somewhere on each of the three axes and impacting each of the four domains. Given such complexity, clinical decision-making can be anything but a straightforward process. In Figure 3.2, "Framework for Clinical Decision Making," the Diagnostic Course of Action appears at the end of the mapping, but diagnosis and treatment actually occurs iteratively throughout the process, relying on representations of potential solutions. The framework in its simplicity suggests flexibility and transparency; but it is the evolution of the trauma event that fills in the details within that framework and creates complexity. That is, at each step of the trauma case, which is from the onset of the EMS critical report to the first assessment on to the second assessment, the team is intervening through interactions and interrelations among medical team members and the patient. These interventions are in the form of experts in airways, breathing, circulation, cardiopulmonary resuscitation

(CPR), and many other medical experts' actions. Therefore, this complexity occurs throughout these interventions or these constants in the framework in a fashion that may be imagined as a sort of helix. This helix has been drawn as a quadruple helix consisting of medical judgment, political and rational considerations, and treatment decisions, all leading to a final diagnostic course of action. One could imagine that the helix represents an ongoing mental process, and as one moves from the initial and secondary assessments to the diagnostic course of action, the combined factors create a complex, curved-yet-linear, three-dimensional structure of the helix.

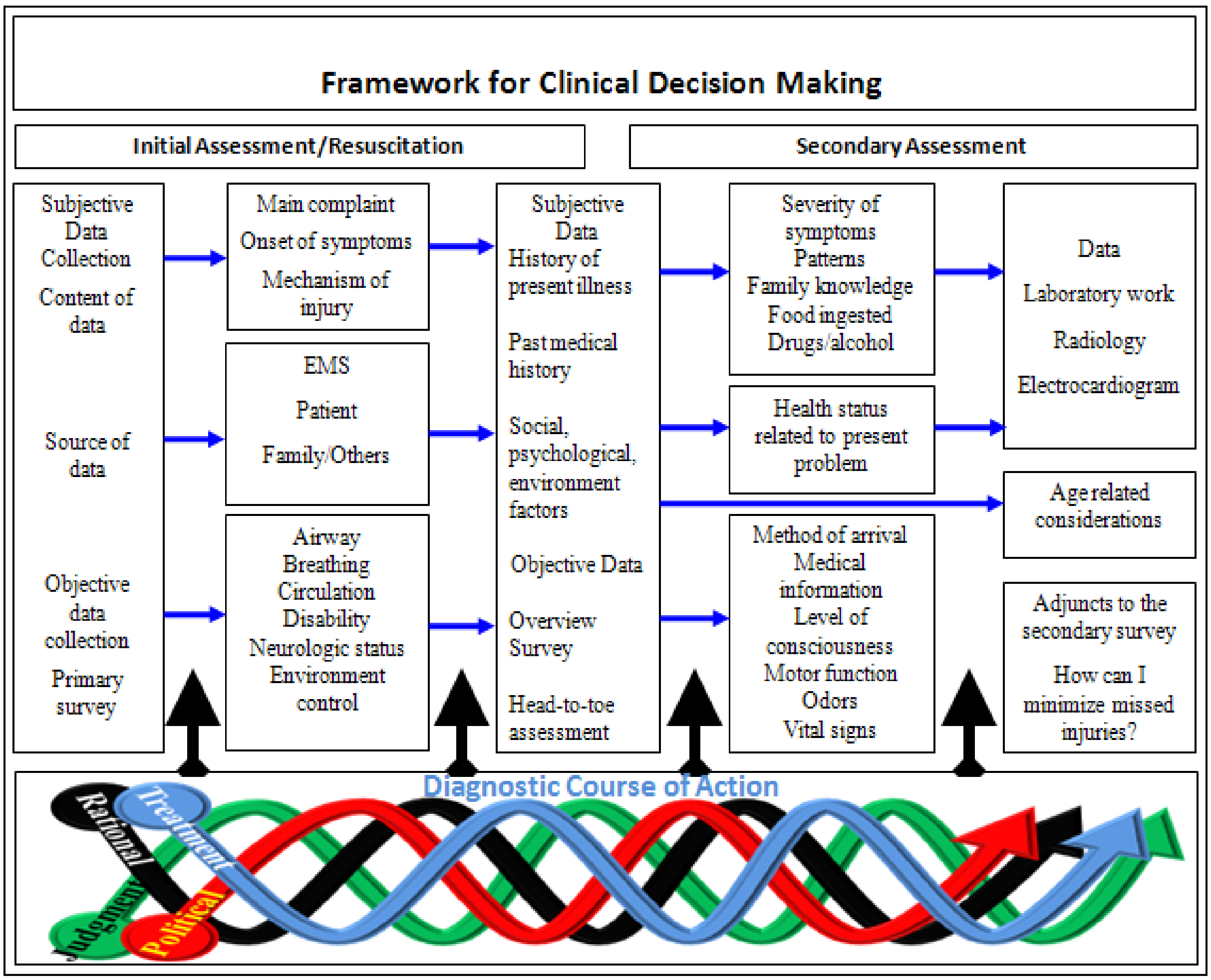

Figure 3.2. Framework for clinical decision making.

Ultimately, this is all about perception. This is about perception, data collection, and how people perceive the ongoing event. Simultaneously, it is about how they process this information.

At this level, data is a critical component. There is an initial contact with data that involves political, rational, and judgment decision-making. This contact includes the people handling the data as well as those perceiving it. There are three ways in which the data are treated and handled, which introduces an interesting form of uncertainty. At this point, complex decision-making is to be operationalized as a combination of all four aspects of decisions, such that it can be measured or expressed quantitatively. It can be stated that complex decision-making includes rational, intuitional, and political decision-making as the event unfolds. The medical team navigates the environment and how the team interacts with that trauma environment causes the team to decide its next move, which is supported by the feedback the team gets from the anticipatory tactile and auditory cues that in turn help the team move next, and so on.

In one sense, the trauma forces one to embrace a form of randomness due to the intricate folding of the state-space of the trauma system over the time of the event. The physician's task is to be able to *mentally* read all cues and clues and make reasonable assumptions. When physicians make judgments about some environmental state, transformations in that state must occur. A very basic example of how judgments change states occurs when one tries to navigate from one side of a dark room to the other. That individual is going to adjust in order to get their bearings. Throughout the process, the individual gets tactile and auditory cues, which are being fed into their sensory system. Intrinsically, there are different points in the diagnostic process: There is the initial assessment, and there is the secondary assessment, both of which work like gates in the information processing and decision-making system that eventuates in a diagnosis and a treatment plan. As gateways or transition points in the decision process, they get initial input followed by an initial vigorous push, and then a rapid increase in stimulus as the situation evolves.

Following this reasoning, at the intersections of the three steps in Table 1.1 (initial and secondary assessments and the diagnostic course of action) is an actual treatment, in which the arrows might be spaces where there is an activity that may lead to some type of decision making. Because a patent feedback loop creates the system that is out in the environment, and the environment gives it some sort of feedback, the system, when it is functioning properly, self-corrects. The trauma center operating as a system that is constantly getting information, reaches these points, these markers, these gates—and it changes. It can correct, but it can also over-correct. The medical team is always treating, never stopping, such that the conceptualized gates or markers get the system in motion. This treatment motion is symbolized by the arrows. The treatment motion is important in this model, and all decision cues along the way are qualified at every step. At the end of the decision making-process a cure or solution is found, or the patient dies.

There are at least three things that are simultaneously going on in the framework, which, along with some randomness or chaotic inputs, characterize the unknown. Because there are always chance factors, variation will occur regardless of the approaches taken by the medical team. If one thinks of the four domains shown in Figure 3.2 (political, rational, medical discernment, and intuition) dynamic factors in decision-making that are intricately tied, the complexity really shows. In that complexity a truth is revealed: There is no such thing as purely rational decision-making. One can always aspire to it, but there is no such thing as purely rational because no decision can be free of subjectivity or bias. Even if one attends to one's own subjectivity and potential biases the questions asked as a researcher are inherently biased because they are formed by interest. For example, the things someone else sees walking down the street versus what I see or what a third person sees might have something to do with what catches our eyes, which in turn is dependent on a range of factors from differing visual fields to differing stimulus thresholds. The concept of "bounded rationality" is used to designate rational choice that takes into account the cognitive limitations of the decision-maker (Simon, 1972). Decision makers in any specialty or profession try to do it, but it is often the case that it does not happen.

The next step may be to operationalize complex decision-making by either designing a construct that says "This is what complex decision-making means" or by searching the literature for an existing definition. An operationalized definition of complex decision-making is needed because chaos encroaches on decision-making and causes complexity. A search of the literature on this aspect of clinical decision-making has not yet turned out any work from other researchers. It is thus an interesting study because it can reveal how social, political, and even economic pressure can become centers of power from interested stakeholders. These factors combined in to the mix make rational decision-making straightforward, but then judgment and political decision-making variables also need to be factored in. It may be assumed that by this conceptualization of the model, rather than complex decision-making being somewhere in between, that complex decision-making is inherently a combination of the political, the rational, judgment, and intuition. Chaos is included because trauma centers are, or it can be at times, unpredictable and chaotic, in which the very uncertainty, unpredictability, uncontrollability, and dynamism of the environment reify the idea of adaptive capability of complex systems. Because of their adaptability in and evolvement with a changing environment, these dynamic networks that are of interest are often described as complex adaptive systems (Goldstein, Hazy, & Lichtenstein, 2010).

At this point in the research, it is not a matter of being right or wrong; instead, it is a search for a way to develop a theory such that the framework can be thoroughly analyzed. In order to achieve this, the goal is to define a construct of interest that will allow the development of ways to measure and observe the decision-making process. Therefore, the strands that go like a double helix, a triple helix, or even a quadruple helix as in a deoxyribonucleic acid macromolecule (DNA) strand such that political, rational, medical judgment and treatment decisions are each represented by one strand. We now add the unpredictable. Referring to Figure 3.2, it is when the three or four of these ongoing actions (the helix) hit the edges of chaos that they become complex. There is then this threshold of uncertainty where these edges come in and become complex, which generates disagreement.

3.3 Process Map of Trauma Center Decision-Making

Many of the issues confronting physicians during a trauma case require the ability to articulate thoughts and ideas concisely during stress. Figure 3.3 illustrates how a trauma center (TC) and its medical team engages in decision-making under stress that originates with the Emergency Medical Service (EMS) arriving at the trauma scene and transporting patients to the hospital, through the time that the trauma center medical team takes over the patient, and to the point where a proper diagnosis is reached.

Figure 3.3 shows the mapping of a complete trauma case event, which starts with the EMS personnel arriving at the scene of the event. During this period of time, communications between EMS and the TC is a constant. These are two-way communications as represented by the arrow until the injured or sick patient is delivered to the TC with an EMS critical report. At the time the patient is taken over by the L1TRU team, it is assumed to be a moment all convoluted or blurred by the physical condition of the patient, lack of historical information, the physicians' mindset, and the constraints imposed by the environment. It is the physicians' job according to experience and knowledge to de-blur his/her mental models. It is a monumental and an almost impossible task to understand and capture the process of what physicians are doing, saying, or thinking in the context of a healthcare trauma case.

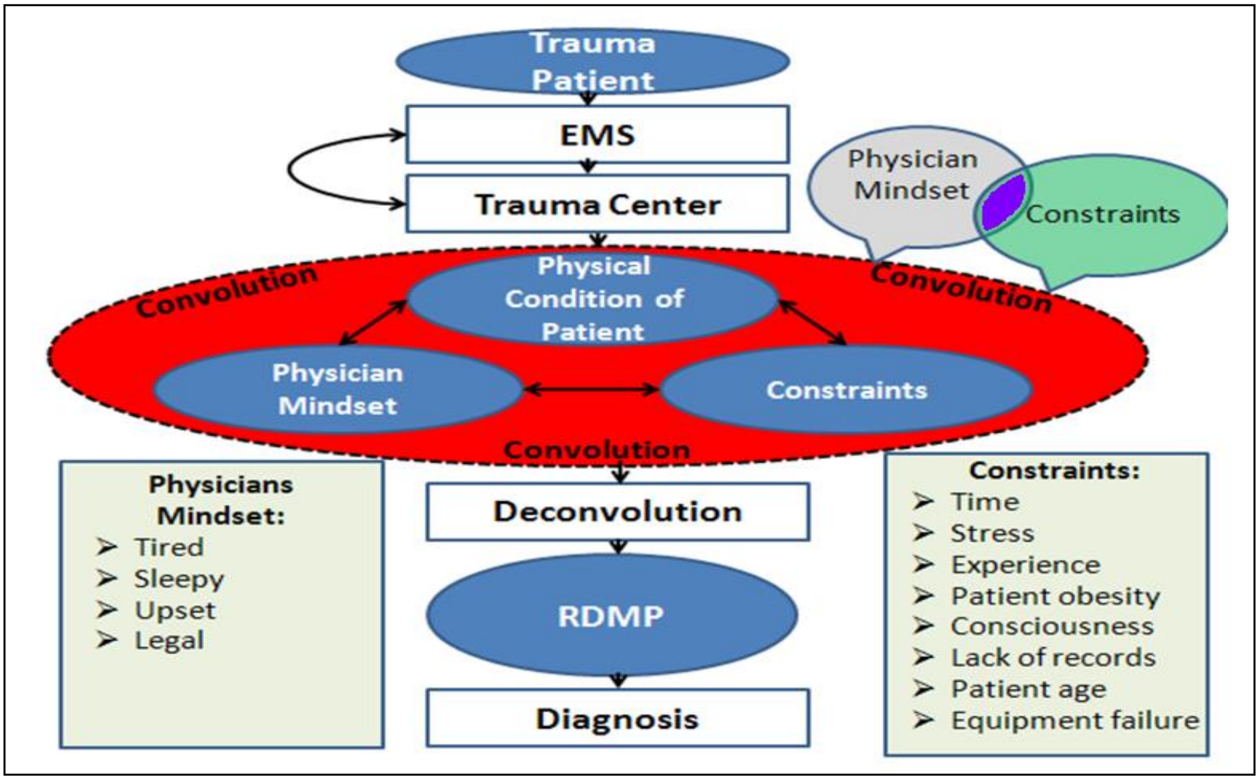

Figure 3.3. Process map of trauma center decision making.

This is a process in which physicians with a lot of experience go through the process more expediently compared to a novice physician. Once the mentally collected data are organized (de-blurred) and made sense of, physicians are able to return an approximation of the rational decision making process (RDMP) under stress, and have an initial diagnosis for the patient. Treatment then is outlined and the team works towards this common objective. Throughout the process, physicians work relentlessly and persistently with time-critical nature of certain injuries while continuously drawing upon their experience to provide optimal care to the severely injured patient. The successful outcome of the trauma event then becomes directly correlated to the physician’s experience and skills.

CHAPTER 4

Methodology

4.1 Research Design and Procedure

This chapter presents the methodology, including the research design and the procedures by which data is collected and analyzed for this study. The study is a combination of shadowing emergency medicine attending physicians (EMAP) during their daily shifts, observing emergency physicians in real-time trauma cases (referred to as "trauma code" by physicians) while situations are developing, reviewing transport emergency medical services (EMS) audiotapes of actual trauma cases in progress, and interviewing EMAPs during the shadowing observation period in the trauma center. The study site is a designated Level 1 trauma center based at an academic medical facility that treats approximately 3,600 trauma patients yearly. This healthcare institution has a multistate referral base and an air medical unit facility. The hospital's emergency department (ED) has an annual census exceeding 100,000 patients. The research and its data collection procedures were reviewed and approved by the Institutional Review Boards (IRB).

The model was designed on an X, Y, and Z-axis to allow for mapping decision-making processes and to look at the processes as medical team members reach certain benchmarks, or simply markers of decision-making. Every marker is somewhat alike in that the decision maker goes through a stage, which is a decision-making marker that records passing through a threshold such as the initial assessment, secondary assessment, blood pressure (BP), heart rate (HR), respiratory rate (RR), and so on. Lack of understanding of the challenges of these thresholds in the environment of acute care by non-medical researchers of decision making may lead to poor guessing of care givers' mental processes. Trauma centers medical teams are dealing with living systems that are complex with emergent characteristics that analytical models, attending only to local interactions and relationships of the system, fail to capture. As it was designed, the model may enable researchers to gain an insight into the well orchestrated cognitive processes of these practicing physicians while working with and treating living systems. The study attempts to explain the physicians thinking process while attempting to answer the questions of "How do physicians make decisions when confronted with complex, stressful, and changing situations of trauma events? Is it the physician's level of expertise that determines whether an intuitive judgment or an analytical approach should be taken to various components of the clinical decision-making task while in the critical moments of the golden hour? Thus, the nature and development of the model is an attempt to answer these questions. Further details about the model are outlined in the following section.

4.2 The Decision Making Model

The model designed for this study uses Bayesian classifier, convolution, and deconvolution operators. This model is designed to explain physicians' thinking processes while making decisions under stress during a trauma situation. This is shown in Figure 4.1, which is a model explicating physicians thinking process. Instead of just seeking statistical inferences, solutions are continuously sought until a familiar pattern emerges. Physicians want to achieve an approximation to a rational decision making while under the stress of a trauma code. In this model (1) data mentally collected is assumed convoluted; (2) Bayesian classifier generates a confusion matrix; (3) when accuracy is less than threshold, data is to be de-convoluted; and (4) physicians achieve decision-making under stress (DMUS). These decision makers in healthcare not only are faced with the stress of human beings body functions that need to be restored to their proper functional requirements, but they are also faced with many possible latent dilemmas (i.e., patients with AIDS, tuberculosis, hepatitis) that exerts tremendous pressure in the process.

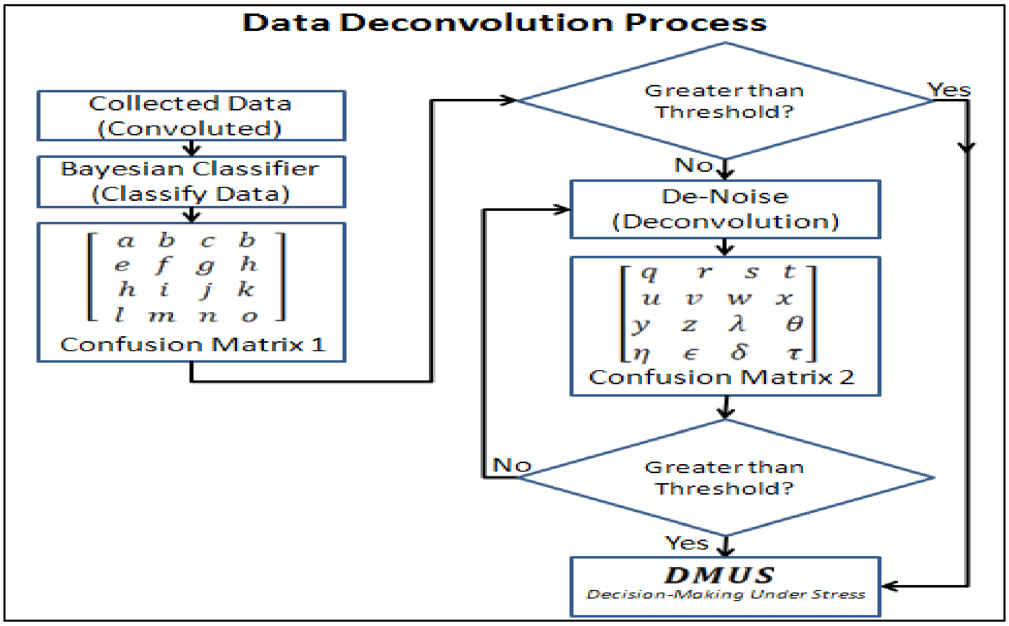

Figure 4.1. Data deconvolution model.

The environment of a trauma center is one in which physicians are constantly dealing with individual team members' cognitive processes and personal task work skills as well as information exchange and team leadership. The quantity and type of knowledge acquired by team members may influence decision processes. The structure of the physicians' cognitive processes during a trauma case, as shown diagrammatically in Figure 4.1, requires a strong knowledge base and experience for selecting the appropriate set of knowledge patterns to be activated in any given trauma situation. These decision-making processes are also influenced by variables beyond physicians' control, such as equipment failures, the surrounding environment, and material resources that may move physicians unsteadily to the edge of chaos (see Figure 3.1) or it may stimulate enough diversity to adapt to environmental demands in innovative ways. The EMAPs in trauma centers are constantly compelled to adapt in and evolve with a fast changing environment. It is in this state, the edge of chaos, where these physicians are most productive, in which their works result in maximum creativity that leads to innovations and new possibilities. In this model, the trauma team mental processes proceed through the actions of and interactions among its members' experiences, knowledge based medicine and the team's goals at hand as it reaches the edge of chaos.

Physicians are bombarded with a multiplicity of scoring systems that supposedly produce thresholds (see Figure 4.1) of decision making that might be used as predictors of potential mortality. As example, the Glasgow Coma Scale (simply known as GCS) purports to facilitate detection of early changes and trends in the neurologic status of patients. GCS is a simple method for determining the level of consciousness that is predictive of patient outcome (ATLS, 2008). Another example is the blood pressure (BP) scale for determining blood volume and cardiac output. As BP reaches low levels in addition to a patient having abdominal pain, physician's decision is to initiate surgery procedures. All these human and non-human variables create convolution in the mind of the physician's decision-making process. Therefore, on the onset of the trauma, the data mentally collected by these individuals are blurred or convoluted by many known and unknown variables while decisions are made at every fraction of a second of the process. The Bayesian classifier then is used to classify these decisions made during stress into the types of decisions occurring during the trauma. It allows for recognition of the number of decisions correctly made. Subsequently, BC originates a confusion matrix which determines the percentage of accuracy of the physicians' analysis. This percentage of accuracy is compared to the thresholds for that particular procedure or decision-making action. Accuracy percentage that is greater than the physician's threshold takes the process to the DMUS final result (see Figure 4.1). At this conjecture, novice versus expert physicians are different in their abilities to make decisions because the experts generally generate less mental iterations for each decision made during a trauma case.

Deconvolution operators are applied to these convoluted data to de-blur or de-convolute the data and to act as simulator of physicians' mental processes of arriving to a decision, and it can be viewed as an optimization of the process. It attempts to remove the distortion of the mentally collected data in the presence of noise by recovering a sharp version of the blurry input data, leading to the true diagnosis. Deconvolution doesn't act as crystal ball; and in decision making, it depends on the estimating abilities of the decision maker. Physicians still have to decide whether the de-blurred data is right or wrong and either perform other mental iterations for more solutions or act on the initial de-blurred data based on observations that suggest it is a correct decision. In essence, the de-blurred data become an approximation of the physician's rational decision making process, in which the output is a confusion matrix that offers the percentage of accuracy of the decision. Therefore, these results may explain the processes by which physicians make decisions under stress. Deconvolution then becomes the sorting out, the unscrambling of convolution that exists in the minds of physicians during those initial moments of trauma events.

4.2.1 Bayesian classifier. Classification is the problem of identifying or mapping to which group of categories an observation belongs, generally accomplished through the use of a training set of data containing observations whose features are known to the researcher. There are many classification algorithms in use by individual and organizational researchers, of which Naïve Bayesian classifier is one of them. For years researchers have been aware of the importance of statistical validation of published results, which have influenced the conception of an ever increasing number of classifiers. Today's computing power has facilitated the development of both new and hybrid algorithms. Here for example are some of the most commonly used classification algorithms:

- Naïve Bayesian classifier
- C4.5 statistical classifier
- CN2 induction algorithm
- Neural Networks
- Logistic regression
- Decision trees
- Bayesian networks
- Markov models

The details on these classifiers can easily be found throughout the literature of published journal articles and many books and textbooks.

Naïve Bayesian Classifier (BC) is a probabilistic classifier model based on Bayes' Theorem. The Naïve Bayes classifier greatly simplifies classification by assuming that characteristics are independent from each other given the value of a class variable. Therefore, it yields good performance in classifications, making it one of the most efficient and effective learning algorithm. One important function of BC is that of probability revision of the initial physician's guess (prior probability) based on new information from either research or experimentation to achieve a new revised probability (posterior probability) of the diagnosis. In essence, Bayesian classifier provides an effective way to approach many problems which decision makers need to identify solutions to problems that are not initially clear or logic but are solvable probabilistically. More important is that it allows researchers to come up with results without having to go through massive amounts of data that grows with the model.

The Naïve Bayesian Classifier (BC) model classifies the decisions made during the trauma case and provides the general framework to describe decisions that are made in the uncertain environment of trauma centers. BC operates by simply considering all of the characteristics of the variables being classified independent of each other, using information that is insufficient to completely determine the correct answer. In spite of its simple design and apparently over-simplified assumptions, BC has worked well in a multitude of complex real world situations (Charniak, 1991).

For the most part in statistical works, investigators use the classical methods of estimation that are based solely on information provided by random variables, focusing on how to extract information from available data. These methods essentially interpret probabilities as relative frequencies. Bayesian statistics represents statistical estimation as the conditional distribution of parameters and unobserved data, given observed data. An important difference is that in Bayesian theory, the parameters are viewed as random variables. The foundation of the Bayesian theory rests on subjective probability. From basic statistics, one learns two approaches of probability: relative frequency and indifference approaches. But, in many studies of probability, these two approaches are not applicable. In medicine where Bayes' theory is extensively used, physicians need to consider questions such as "What is the probability of this patient having cancer?" How likely is it that a patient has the flu?" "What is the likelihood of survival for this patient?" "What is the possible outcome for after surgery?" These are questions that can only be answered subjectively, always reflecting one's subjective opinion. Experienced physicians mentally review large amounts of clinical information about a patient to arrive at these clinical judgment points where these probabilistic questions arise to form predictive models. Questions of when, why, what, and how then permeate the analysis and are dependent upon four factors: (1) changes in the condition of the patient, (2) changes in the collected data, (3) scoring systems producing thresholds of decision making, and (4) organizational requirements. These factors influence the formation of subjective probabilities, which distribution then can be specified as prior probability distribution and reflects the researchers' prior assumptions about the parameter.

Once the prior probability distribution is specified (through experimentation and/or research), the posterior probability can be mathematically computed, and the investigator then can easily use it to make inferences about the population of the parameters. Posterior probabilities are nothing more than prior probabilities estimates of specific events of interest which were revised with the help of additional information obtained from sources such as samples, tests, laboratory reports, patient's conditions, communication among medical personnel, and clues from the environment. Given this new indicative sample information, posterior probability values are then mathematically calculated with equations provided by the Bayes' theorem to denote the outcomes of the trauma. In summary, the subjective prior probability is to be the inextricable partner of posterior probability in the Bayes' classifier approach to building models that combines prior knowledge with new information extracted from the experiment.

4.2.2 Convolution. In applied mathematics, convolution is a mathematical operation on two functions, say *f* and *g*, producing a third function that is deemed as a modified version of one of the two original functions. The convolution problem refers to the computation of the output signal *y(n)* given the knowledge of both the input *x(n)* and impulse response *h(n)*. Convolution is one of the most widely used operations in mathematics with applications in many fields, including medicine, bioengineering, electrical engineering, imaging, seismology, digital signal processing, probability, statistics, and many other fields. It complements well the Bayesian classifier model in that it satisfies each of the characteristics of the input of a system independently of each other. The fundamental assumption about the convolution input is that it is random and the values of the input are completely independent from one value of time to the next value (Mendel, 1990). Because of these features, convolution became a popular tool with scientists and it is used here in this research in combination with deconvolution operator for explaining decision making processes under stress. To this end, Matlab® software with its convolution and deconvolution functions is used in the model. Figure 3.3 shows a map for prototypical task situations in trauma centers and illustrates the complexity of the physicians' repertoire of mental models relevant to situation analysis that may easily become convoluted in their minds. Thus, the figure illustrates the potential for knowing how the physician mindset, the patient's physical conditions, and the environmental constraints affect the outcome of decisions. And, by understanding the way in which input factors are comprised of large numbers of tangible, intangible, known, and unknown variables" (EMAP-1), it seems reasonable to think that it should be possible to emulate physicians' decision making processes regardless of convolution in the first few minutes of the trauma code.

Under the stress of a trauma event, physicians have the challenge of time constraint, environmental noise, and other disturbances, causing their mental models to be blurred (convoluted). In the model, convolution is the actual data for the physicians' decision-making process under stress (DMUS), in which the function ***f*** is stressed. Stressing the function ***f*** is the convolution operation. For example, it is like adding lines to an image. It really blurs the image through the convolution function. However, physicians don't make decisions on blurred models. It has to be mentally de-blurred because physicians under stress have to make swift judgments because of time constraint to create a quick model which identifies what has been observed while the cognitive processes are blurred.

Experts in convolution (Sheth, & Rossi, 2010) argue that convolution based approach may permit a more efficient selection of the objects for which unbiased reconstruction and calibration are required. Convolution then becomes a formidable tool in determining a system's output from knowledge of a subjective and uninformed input and the system's impulse response. Because physicians know how patient (a system) injuries affect organ systems and understand that human physiology is comprised of balanced functions, it is possible for them to analyze treatment responses of the system. Thus, it is possible to determine what output results from a particular treatment action. In this case, convolution determines a system output from knowledge of its input. In convolution, investigators find it to be a tool to obtain a statistical picture of an overall situation.

4.2.3 Deconvolution. Deconvolution is a filtering process used to remove the extraneous noises to allow for understanding and visualization of physicians' decision processes, which should be an approximation of the rational decision making process under stress (RDMP). Deconvolution then becomes the unraveling of convolution (Mendel, 1990). The importance of deconvolution in this study can be thought of as similar as a telephone communication system. Peoples' voices can be easily distorted by the telephone system that exists between the mouth pieces at both ends. The telephone system smears out the voice sounds, resulting in interferences. Unless smearing is undone, these interferences make it difficult to understand the spoken words.

Deconvolution (and convolution) is used in real-time to invert the effect of the telephone system, allowing for clear, undistorted messages to flow from transmitting to receiving ends. It has to be accomplished in real-time to avoid unpleasant delays in the conversation. The deconvolution process in communication systems uses the same convolution and deconvolution equations called equalization. Physicians in trauma centers are continuously deconvoluting the real-time acquired data to make decisions about the system (patient).

In mathematics, deconvolution is an algorithm-based process used to reverse the effects of convolution on recorded data. The literature of deconvolution is extensive, which gives evidence of its importance in many disciplines such as in medicine, image de-blurring, seismic data deconvolution, communications, and so on.

4.2.4 The Matlab® program. A Matlab® program was created to run the data that explains the thinking process by which physicians make decisions. Deconvolution (referred to in Matlab® as de-noise function), convolution, and Naïve Bayesian classifier functions were utilized in order to achieve the results for this work. The program was created with objective of helping in the explanation of physicians' mental processes while under the stress of a trauma event. Naïve Bayes classifier classifies data in two steps, which are training step and prediction step. In the training step, using the training samples, the method estimates the parameters of a probability distribution, assuming features are conditionally independent. In the prediction step, the method computes the posterior probability of that sample belonging to each class. The method then classifies the test sample according to the largest posterior probability. Naïve Bayes function operates based on estimating $P(X|Y)$, which is, probability of features X given that class Y is known. This Matlab® function provides for the use of many distributions, including the normal and multivariate distributions. It uses less data than the other classifiers for accurate classifications, making it particularly effective. Deconvolution, or de-blurring, which Matlab® refers to as de-noise, is a mathematical operator greatly used by researchers of imaging, seismology, petroleum excavation, and many other disciplines. The objective is to take an event that is blurred or degraded by environment noises, such as physicians under the stress of a trauma patient, to capture and describe the distortions. Throughout the process, the decision maker really doesn't have a vision of what is in reality happening. What the decision maker has is vision as an image that represents what he/she would have if they had a perfect understanding of the event before them. In Matlab®, the functions include:

deconvwnr: Implements deblurring using the Wiener filter

deconvreg: Implement deblurring using regularized filter

deconvlucy: Implement deblurring using the Lucy-Richardson algorithm

deconvblind: Implement deblurring using the maximum likelihood algorithm

These functions can all be used to provide information about the noise to reduce the existing noise that blurs the decision maker's action.

4.3 Data

For the most part, data collection was based on site visits, individual interviews, and medical charts concerning trauma cases. The data were obtained from a Level 1 trauma center of a medical school in a major healthcare system. This data was a collection of 14 trauma cases, which are outlined in *Appendix C*. Of these data, two of the cases were not included in the study due to insufficient information; thus, twelve cases were identified that met the study criteria. The researchers followed the plan to go into the trauma center as the events were occurring and got the data first hand, real-time data collection of actual trauma events. It was all accomplished using the methods described in Section 4.1 (Research Design and Procedure). It included many days of shadowing attending physicians during a period span of two months (2012) in order for the researcher to familiarize with procedures and processes of caring for the seriously ill or injured patient in a trauma center. During this period of time, it was observed how physicians organized and made medical decisions in fourteen trauma cases and the identification of the variables needed for the decision making model. The second step of this data collection was to review EMS transport audiotapes. It was reviewed 51 days of audiotapes of communications with the trauma center from ground EMS and Helicopters EMS for Level 1 and Level 2 trauma codes for the mentioned period.

Table 4.1

Trauma Cases Observed in the Trauma Center

Patients Observed During Shadowing of Physicians		
	Mechanism of Injury	**Duration in Trauma Center**
1	Motorcycle Crash	06 minutes
2	Gunshot Wound to Lower Extremity	58 minutes
3	Multiple Gunshot Wounds	1 hour 11 minutes
4	Vehicle Crash	3 hours 47 minutes
5	Severe Knife Stab	29 minutes
6	Blunt Knife Stabs to Chest	18 minutes
7	Vehicle Crash	1 hour 08 minutes
8	Vehicle Crash	1 hour 31 minutes
9	Gunshot Wound	1 hour 23 minutes
10	Severely Burned	28 minutes
11	Blunt Chest Wounds	41 minutes
12	Vehicle Crash	28 minutes
13	Vehicle Crash	1 hour 14 minutes
14	Vehicle Crash	10 minutes

The final step on this data collection procedure was to review the medical records of 14 Level 1 and Level 2 trauma cases in order to gather the final data for the variables used in the model. Table 4.1 summarizes 14 of the trauma cases that occurred during shadowing and observation in the trauma center. This procedure, reviewing the medical cases, was also covered by the IRB, which authorized and approved the retrieval of 12-15 de-identified trauma encounter records. The request was approved, along with a data collection form onto which the information was recorded. However, the medical records contained all of the patients' identifiers. To bypass the problem, the IRB committee authorized EMAP-1, a physician, to extract these data and then destroy the medical records with any linking information, thereby, permanently de-identifying the data.

4.3.1 Method for data collection. The process of getting the observations was accomplished by observing and taking notes of the trauma event cases brought in to the trauma center. Each trauma (patient) event was considered an observation, one cycle, and each cycle representing one person as being input (arrival) and output (discharge from the trauma center). For this decision-making model experiment, it was recorded 14 (fourteen) of these trauma events in order to have a workable sample of how decisions are made in real time within the trauma center environment. Each trauma code was observed from the moment the trauma patient arrived at the trauma center (EMS hands off) until the time the patient left the care of the trauma medical team or to a maximum of 60 (sixty) minutes, whichever came first. The 60-minute mark was where a decision was made to stop observing and the trauma event was considered over for study purposes. Data were gathered on all these different events. The investigator looked at those different gates of the framework or those points of decision-making, whether it was the triage, the initial assessment, the secondary assessment, diagnostic course of action, and so on. Those gates or markers constituted the decision-making thresholds. In cases of potentially fatal trauma, exacting numeric values sometimes were discussed by the trauma team as the threshold and target for the posterior probability, once a test was recommended. These thresholds were determined based on benefit-risk analysis associated with each patient or treatment, and each threshold is individualized to each patient and according to the experience and knowledge of the physician. The data recorded for each cycle (patient) helped find out where the input was, with its starting and finishing points.

4.3.2 Procedure. There were many patients who arrived at the hospital and were either triaged as Level 1 or Level 2 trauma cases during shadowing of those physicians in the period of this study, from which events were observed as they unfolded and the data were collected. Table 4.2 is a sample of the data collection instrument**.**

Table 4.2

Sample of Data Collection Form

Trauma Case 13									
Time	**Blood Pressure**	**Heart Rate**	**Respiratory Rate**	**Mechanism of Injury**	**Oxygen Level Sa O_2%**	**Pupils L/R**	**Glasgow Coma Scale**	**Physician Decision**	**Observations**
22:32	134/102	102	19	1	94	3/3	8	4	Patient arrived by EMS. Vehicle Crash. Trauma team in place at beside. Primary and secondary assessments conducted. Patient was stabilized.
22:37	140/83	103	16	1	96	3/3	8	1	
22:43	140/90	102	14	1	96	3/3	9	1	
22:48	138/87	92	13	1	98	3/3	9	1	
22:53	140/83	98	19	1	97	3/3	10	1	
22:56	132/84	95	20	1	98	3/3	12	1	
22:59	142/92	106	16	1	98	3/3	12	2	
23:01	130/100	98	18	1	95	3/3	12	2	
23:10	124/79	94	15	1	95	3/3	12	2	
23:20	133/76	89	13	1	96	3/3	12	2	
23:25	135/89	93	20	1	95	3/3	13	1	
23:30	111/89	93	22	1	94	3/3	15	1	
23:40	122/81	93	18	1	95	3/3	15	1	
23:46	130/77	80	22	1	97	3/3	15	1	

Additionally, while observing the events unfolding, the entire scenario was mapped out from the verbal standpoint. Hence, the data was transcribed, encoded, and analyzed to observe how it fit in different scenarios, in real time as those scenarios were played out. It was real data that got transcribed. Table 4.1 shows an example of the data collection form in which the physicians' decisions were recorded with the patient's vital sign, as the trauma case progressed. For trauma cases of greater complexity, it was expected to see more of each of the four parameters of decision making going on because people are using their medical judgments or their intuition in the decision-making process as to whether to deal with the problem rationally, politically, or intuitively. The coding of those medical decisions was be accomplished by the physicians who handled the trauma case and immediately after the event took place. However, to get physicians at the moment the trauma case was over or as the case developed from arrival to discharge from the trauma center, while being the best approach, was not feasible. The alternative was to get a physician to review the medical files for the cases. This physician then assigned to each moment of the trauma event a number that related to the type of decision-making that, in his opinion, took place during the trauma situation, as follows: 1 (one) for rational, 2 (two) for political, 3 (three) for judgment, 4 (four) for intuition. These medical files were reviewed and judgments were used to make informed decision about what decision-making process was taking place at every moment of the trauma case.

4.3.3 Study design. The data consisted of eight attributes as shown in Table 4.2. The data for the fourteen trauma cases were entered into an Excel spread sheet, where two of the cases were determined to have insufficient information and subsequently eliminated from the analysis. Out of the twelve remaining trauma cases, eleven cases were chosen at random to be used for training of the data for the Bayes' classifier. One trauma case was used for testing. Referring to Table 4.2, one can easily notice that for each patient the time for the event was recorded as it evolved. After the training, the data was run in the program where de-convolution of the noisy data took place and it was performed according to the following procedure.

1. First, each line of data as those of Table 4.2 was considered one set of observation, which was tested individually against the trained data. Each line represents the data mentally

collected by the physician at a moment in time in which the patient is under the care of the trauma team.

2. Second, the first line of data with the second line of data was tested together, then the first, second, and third lines were tested together, and so on until the end of the trauma case. Each line is representing the collected information; hence, each of the next line builds upon the previous gathered information. Therefore, the last line represents both the final thinking process and final action of the decision maker.

4.4 Summary

In this chapter, it has been described the research design and its procedures. The site of the research for collection of data was a trauma center of one of the hospitals of the Wake Forest University Health Sciences organization. It was discussed the decision-making model and the approach that uses Bayesian classifier, Convolution, and Deconvolution operators to explain physicians' decision-making processes. Convolution is one of the most important operations describing a dynamical system. And Deconvolution is a mathematical operation widely used in large number of disciplines when researchers need an algorithm that performs well in severe noisy environments. The data were collected grouping and comparing several sources of information while shadowing physicians in a trauma center. Afterwards these data were reviewed by a physician before it was entered into the model, which validates the process utilized by the investigator to acquire the data. The review of the data was done from the moment of the initial contact with the patient to the moment of the transfer of the patient out of the trauma center.

CHAPTER 5

Trauma Center Physicians: The Adaptive Decision Maker

5.1 Introduction

Personal experience has proven to be a critical part of why seasoned physicians arrive at more accurate diagnoses that reflect the best available evidence for a particular patient's needs. Two questions about this decision-making process permeate the medical literature, **"**How do physicians make decisions?" and "How well do physicians make decisions?" The conceptually separable questions of "how" physicians make judgments and decisions and "how well" they make them have both become of greater interest to a wide range of people. The goal of this chapter is to elucidate "how" decisions and medical judgments are made under the stress of handling a trauma case , leaving aside the political, economic, ethical, legal, and sociological structural variations within which physicians and patients think and behave during complex events. The chapter was designed through a series of conversations with those emergency medicine attending physicians (EMAP) the author shadowed in the trauma center.

It has been said that it is difficult for one to understand another culture without understanding the language of the people in that culture. The medical profession has a very unique language and how successful one is in comprehending the intricate terms and metaphors of medical language might navigate well this challenging and demanding domain. The study interest is in how decisions and medical judgments are made in TCs. Through discussions with several EMAPs, an understanding of the subtle ways in which physicians practice medicine as well as what influences them to change course in any given medical situation is discussed in the following sections.

The research was conducted by observing (“shadowing”) several EMAPs in the domain of a trauma center (TC) during several eight-hour shifts for 15 days during a period of two months. During the period of observation, the emergency team was constantly busy: Lower-level physicians and staff were continually getting instructions from senior physicians, and procedures, the operation of complex equipment and incoming radio and telephone calls—and treating patients—were all occurring, often simultaneously. It was not possible to observe everything. This is due to the fact that the human observer cannot record everything that is going on in any given scenario. Humans are not movie cameras, and even a movie camera, with its limited field of vision, needs to be pointed in the right direction (Patton, 1987). To overcome some of the limitations of collecting data through observation, open-ended questions were asked of the participating EMAPs that not only helped in explaining some of the activities and actions that occurred within the TC, they also helped to provide a sense of the respondents’ frame of mind, experiences, thoughts, and backgrounds regarding emergency medicine. The questions focused on understanding the work of the physicians being observed, thus attempting to bring the physicians closer to the research being conducted while simultaneously allowing for the researcher to see and experience the physician’s perspective. The net result was a more holistic understanding of trauma care, with the caveat, nevertheless that interviewees are always reporting perceptions, and, for that matter, they are often highly selective perceptions (Patton, 1987).

There are in the United States 64 medical specialties; the physicians in this study chose Emergency Medicine (EM). For many, working in emergency medicine (EM) was valued as an opportunity to work with cutting-edge healthcare technology, make difficult decisions at a moment’s notice, and accept the challenges of a dynamic, complex, and fast-moving adaptive system. In addition, according to one of the physicians shadowed, emergency medicine is about having the knowledge base and the skill base to do things when presented with people who are really sick, regardless of what is causing the sickness. To some of these doctors, as was the case with EMAP-2, they found that the initial resuscitation and stabilization of a patient in distress was more interesting than overseeing that patient's long term care. To these EMAPs, a TC is a field of rich and complex medical problems, full of unpredictable outcomes that can only be understood by experiencing it. It is an environment where analytical and numerical solutions alone cannot solve every problem. They went into EM because of the knowledge that there would be a lot of varied and high-acuity, maybe even high-stress situations, and that their work might provide a template for research studies. They often had the ambition of reconfiguring knowledge gained from textbooks, from socially interacting with other expert physicians, and from their own experiences and using that cumulative knowledge to provide effective medical care to dynamic and complex living organisms. EM was something that was not a regular "office space to do the same thing every day" type of job. It was a place where one could work out of the hospital with ambulance services, police, and many others, on a wide variety of case scenarios. As EMAP-1 said, "Working in an Emergency Department is just not the normal job."

5.2 Predicting Outcomes

Recently, while discussing an article entitled "Trauma Intensive Care Unit Survival: How Good Is an Educated Guess?" (Goettler, Waibel, Goodwin, Watkins, Toschlog, Sagraves, Schenarts, Bard, Newell, & Rotondo, 2010, pp. 1279-128), Dr. Thomas Scalea, an EM physician, raised the following significant and pertinent questions regarding trauma care:

- "Why are we so bad in predicting outcome?"
- "Is it inherently that difficult?"

- “Are the scoring systems and predictive models just that bad, or are we simply incapable of being objective?” (Scalea, 2010, p. 1287)

These questions were presented to the “shadowed” attending physicians in this study. Their responses and comments were very similar to answers from Dr. Goettler given in response to Dr. Scalea. The main reason for the difficulty in predicting outcome, he said, is that there are so many variables that are intangible and that cannot be quantified. It is possible to see an extra set of vital signs, and the patient’s appearance also gives clues about their physical condition. But often physicians do not have a very good idea of what is going on and what needs to be done. Each patient is so different and there are so many variables that are unknowable that no one can really predict outcome very well.

> **EMAP-2:** It’s not so much difficult to predict that someone may have a bad outcome. The scoring systems I think work fairly well. It’s just that anything can happen to anybody at any point in time, so it’s hard to be 100% sure because not every model, not every person, is 100% accurate. If you were to come in from a [vehicle] crash and you had these four injuries, we could say “Yeah, he’s probably going to do fairly well.” Well, we can’t predict if you’re going to have a blood clot—throw that and die of a blood clot. I think it’s also not wanting to give up hope. If somebody comes in and they’re badly injured, you want to do everything you can for them. Obviously you know that they may have a bad outcome, but you want to do everything as much as you can for them. To the point where you know that it’s futile. And that may be in the first 5 minutes, or you may not know that until four or five days later.

> **EMAP-3:** It is difficult to predict the outcome for trauma patients because there are so many ways in which their bodies can get damaged and those things only manifest

themselves in a few areas that we can easily measure. Especially when the trauma patient first arrives to the hospital, all you really have are vital signs and usually a pretty limited physical exam. And so a lot of these scores try to take those things and the history of the injury and try to extrapolate that into a predicted survival. But that does not account for effects of the injury which may not be seen for a couple of hours but will turn out to be very significant.

EMAP-4: There are probably so many variables in each [trauma] case that it is hard to develop a rule, or a standard measure, that fits everybody. So, it may pertain to 92%, but that 8% are the ones that you miss or that require some gestalt.

There are many examples of health concerns that only become obvious with time following a traumatic injury. For instance, lung injury might not show up for hours. The downstream effects of ischemia and organ damage from hypotension will not be seen for hours. Even though the patient is ill, their injury severity score index at presentation might not be very bad. However, with time patients may get progressively worse because of these downstream effects. The patient who is transferred from another hospital where they initially presented with their trauma might arrive at the new TC much sicker simply because of these delayed developments, not necessarily because they were mismanaged at the first center. Because of these variables, physicians feel that diagnostic and predictive models are helpful but definitely do not completely describe what they find with patients after trauma. Trauma cases are always more than the sum of their parts. It is seldom that a single part of the trauma completely determines the nature of the whole. In short, trauma physicians are so bad in predicting outcomes because there is not enough data to make better predictions. More importantly, there are inherent physiological differences between individuals that may influence outcome. This inherent difference “will likely require genetic profiles to assess in the future" (Goettler et al., 2010). The number of variables that change from patient to patient, the inability to quantify them, and the non-linearity of the problems faced in the TC often makes each case very complex.

Sometimes, however, trauma cases are more well-defined. Unlike with less severe trauma, in very serious cases that are likely to result in death within 24 hours, the medical team generally has a good idea about the long-term outlook. But, from an ethical perspective, if no one from the family is present to give permission to stop treatment, the team must keep treating the patient.

For the most part, the question of the difficulty of diagnosis and outcome goes back to the problem of data collection. Intrinsically, in a trauma case the problem is that it is not known how difficult the case will be; thus, no one knows all the information that needs to be collected. According to EMAP-1, it is very hard to collect all the data that is needed in any given trauma case. To make matters more difficult, he also does not think that physicians know the data that need to be collected. EMAP-1 believes that there are many things that physicians do not know that "we don't even know we don't know." Many times medical decisions are made based on what is thought to be the path of physiology of a disease, with the expectation that the medicine will fit into the framework. However, the reality is that when physicians test the medicine to see if it works, a lot of times it does not because "we don't understand the disease as well as we think we do" (EMAP-1). Maybe one day physicians will be able to understand the reasons for this and find a solution.

Dr. Scalea's third question—"Are the scoring systems and predictive models just that bad, or are we simply incapable of being objective?"— has the answer within itself. If physicians have to try to be objective to give answers about most likely outcomes, then physicians are not naturally given to making decisions based on data. Decisions are made based as much on instincts and assumptions—what physicians think is going on—as upon pure data. In other words, physicians are using their skills and experiences. Predicting outcomes in trauma cases and trying to change them in favor of survival and health is inherently a human enterprise, however strong the scientific overlay might be. If this is true, Dr. Scalea's question is almost rhetorical.

5.3 Physicians and Pattern Recognition

The literature shows that physicians do rely on intuition and judgment, but by how much is still unknown. Dr. Atul Gawande discusses the fact that there is science in what physicians do; however, there is also habit, intuition, and the use of plain old guessing. He claims that there is a gap between what physicians know and what physicians aim for. As this gap persists, it complicates everything physicians do in TCs (Gawande, 2002). Several of the attending physicians who contributed to this study were asked to explain this "gap."

According to EMAP-3, the gap is the gap between what physicians would like to have happen and what physicians know that they can do. He explains that physicians would like to be able to look at a patient and know exactly what's going on, what will happen to them, and, with some certainty, how much care they are going to need when they go home. For the same reasons, physicians talk about not being able to know how sick patients are when they arrive at the hospital; physicians just don't know. There is not enough science currently available to determine the prognosis of patients in detail when they present at the hospital. Perhaps in the future such precision will be possible, but for today, it is only a dream. There is science in abundance and the medical world knows a lot more things today than in years past. As EMAP-3 admonished, "But, also it is very true in medicine that as we go along, we find out that things we used to think were true and scientifically justified turn out not to be exactly the way we thought they were." That is where the intuition and experience come in. That is where the art of medicine is located: in knowing that the science says one thing, but the science may not apply in exactly the way physicians think it should to this particular patient. There is always the potential that something else is going on with the patient. That is the unpredictability of the system.

> **EMAP-3:** I had a great case today where a patient was admitted to our observation unit for a urinary tract infection, and we looked through their stuff and were really suspicious of that diagnosis. It turned out that the patient had pneumonia. And that was just a matter of having a gut intuition that this diagnosis was incorrect, and examining the patient and deciding that it wasn't quite right, and then making a different diagnosis.

Physicians use a systems approach in order not to miss anything, but they do step out of that system when something unusual is found in order to make a critical judgment. Once something triggers this, physicians review the situation and try to put the entire picture together in an alternative way. That may be the reason why some of the physicians' work is not always systematically done. It is by putting it all together that they arrive at a critical decision.

> **EMAP-2:** In trauma resuscitation, the team is looking for exam findings. That's all that team is doing. The two people at the end of the bed are the ones making the judgment calls based on what they're hearing. So, you do trust the persons that are doing these things—that are finding what they're finding. For example, respiratory technicians are not MDs but, their expertise is airways and ventilators. That's all they do all day. So, if they tell me that this person has high airway pressures on the ventilator, I have to listen to them. And then I have to go figure out why. So, we rely on everyone to make good calls in terms of exams, and bring up findings that they're finding to the people who are actually making the final decision.

There was a physician who would say that physicians were supposed to be evidence-based and to rely on data and studies to make every decision. Formally, evidence-based medicine is defined as "the practice of making medical decisions through the judicious identification, evaluation, and application of the most relevant information" (Friedland, 1998, p. 3). However, it is not the reality in every case or situation. It is difficult to imagine physicians performing Bayes classification or some other type of symbolically complex analytical calculation every time a solution is sought to determine the best therapeutic option. Physicians react on intuition and at the gut level; consequently, often times their decisions are based on anecdote as much as on evidence. "Physicians rely on intuition a significant amount but also lean on experience," says EMAP-4. Physicians approach every situation in a similar manner, thinking about similar situations in which something bad happened while treating a patient in a new case.

Physicians tend to act on the knowledge they have gained from the worst-case scenarios they have had that were similar to the case scenario in which they are presently involved. Therefore, past experience and the current situation influence intuition and outcome significantly. The best example is seeing someone who has done trauma medicine for years and in the process he/she sees a lot of the outliers, a lot of abnormal cases. These physicians develop a different intuition than someone who has not done it for a long time. As a result, physicians are going to play it safe because they are going to think, "Okay, of all the patients I've had, which one was the worst? Okay, I don't want to have that happen," commented EMAP-1. It is possible that physicians are cognizant of the shortcomings of their own experiences in terms of that limited cohort of patients that they see in trauma centers. Physicians then are going to be risk averse and order many tests . Indeed, with traumas there are systematic ways of going through with resuscitation, finding injuries, and treating those injuries. However, even though trauma care has set protocols that need to be followed, it still requires lots of physician experience to discover the underlying cause of a problem, what has to be done, and how to design the next step. Physicians are big believers in script theory, which means to learn the way that the trauma or illness presents—the signs and symptoms—and once these signs and symptoms are recognized, they trigger the diagnosis. Pattern recognition plays a big part in coming up with a diagnosis and a diagnostic course of action.

In the best-case scenario, one can sit and think about all the knowledge and evidence one has or that is available about a situation. As one physician explained:

> **EMAP-1:** In most scenarios the physician doesn't have time to think that much. Most of what I do in Emergency Medicine I feel is pattern-based recognition. Every patient I see will fit into some pattern I already have in my head. And if they don't fit into a pattern, that's when I take a step back and start over and do more diagnostic testing. I get worried when they don't fit into my standard patterns.

Inductive thought plays an important role in the decision-making process. Inductively, recognizable events illuminate appropriately efficient paths of action, the knowledge of which stems from past experiences with positive and negative outcomes. This is one of the characteristics of complex adaptive systems that emphasize learning and innovation through adaptation. Learning is the process of recognizing these patterns, sorting through them, and deciding which one best fits the problem and, simultaneously, developing new patterns of recognition based on innovative judgment. Recognizing patterns brings to the physician's mind at once previous patterns of treatment or diagnostic courses of action that may be relevant to the trauma case at hand. Also, coming into play are x-rays, electrocardiograms, electroencephalograms, CT-scans and other laboratory tests that create a pool of information which support physician's patterns and potentially lead to the correct solutions or schemas. Trauma centers are modeled as networks of cognitive agents (physicians) seeking regularities in the form of schemas—the equivalent of mental models (Stacey, 2007). These agents store those schemas or representations as readily recognized patterns—in the form of rules—and then they act on the basis of those rules. Such pattern recognition is not static, however. The process of pattern recognition is complex but allows decision makers to unconsciously estimate required actions and fill in gaps based on their experiences to produce an understanding (Finkelstein, Whitehead, & Campbell, 2008). In essence, it allows decision makers to function with incomplete or limited information. The integration of novel information into established patterns gives rise to the emergence of novel patterns, new forms.

New patterns also emerge as a result of physicians using situational awareness, which clearly characterizes their experience of the dynamic changes in the TC environment. Situation awareness is defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in their near future" (Endsley, 1995, pp. 143). As EMAP-1 said, he gets worried when the pattern he sees does not fit into one of his library of patterns. He commits to an intervention when absolutely necessary to do so, but at the same time he remains open to the possibility that it is the wrong intervention.

There may be inherent flaws in the pattern recognition process because physicians may think that a patient is in a set pattern to start with, when the patient is really not; this is a potential source of errors. Additionally, in complex systems there are difficult-to-perform predictions due to ambiguities and novelties. However, using pattern recognition still makes it much easier for physicians to make decisions and make decisions much faster. Emergency physicians who have been doing this a long time have more numerous and more varied patterns in their heads to which to fit patient scenarios. As experts in their fields, physicians have a rich repertoire of mental representations and cognitive processes from which to draw possible solutions. Their performance measures do not usually retain the flavor of diagnoses and treatment plans based on the more time-invariant characteristics of cases. This is because any given trauma case does not require a specific time—indeed, it cannot have time limitations for its completion. Additionally, trauma cases are not dealt with so easily because there are no if-then rules for physicians in these situations; instead, there are structured mental models (pattern recognitions) that provide the framework for action. The complexity of these types of medical interventions may range from linear to very non-linear or that translates into a diagnosis and a method of treatment.

Trauma cases are characterized by complexities that depend on human heuristics permeated by habits, memorized behaviors, and cognitive strains for real-life solutions. These features are also an inherent weakness, because if the patterns are false and bias the physician to overestimate the prior probability of a disease or injury, then incorrect diagnoses and solutions could be chosen. Additionally, there might be an overloading of information and cues emanating from the trauma case that may exceed the physician's available mental resources for solving the problem at hand. The first encounter with the trauma patient signified that an unnerving gulf lay in front of the trauma team. The physician then assumed the dominant roles in solving problems during these trauma cases in which environments (i.e., humans, technologies) and constraints (i.e., patients' physical conditions) were dynamic. Through the trauma case, the physician has to deal with the effects of information overload due to the increasing complexity of the trauma. Therefore, this balance allows the EMAP team leader to ascertain the degree of uncertainty existing in the mind of team members at the time they have to make decisions in treating the patient.

Pattern recognition has become increasingly recognized as a pivotal factor in the process of using analytical techniques for decision making because it is a basic attribute of human beings (Tou & Gonzalez, 1974). It has been the subject of inquiry in many disciplines, including engineering and of course, medicine. As a facet of decision-making in these disciplines, this unique ability of humans to recognize recurrent themes and processes helps to set human beings apart as an exceptional instrument for analysis and action. When patterns are recognized, they not only allow physicians to update their initial model of the nature and severity of the patient's primary predicament but they also improve elicitation and communication of quantitative probabilities (Fischhoff, 2000).

5.4 Physician Decision Making

The latter part of the last century was marked by intense globalization in response to far-reaching political, economic, technological, environmental, and social changes, all of which had a strong impact on health care. In the United Kingdom, a report was written on the effect of globalization on health. The authors of this report (Murray & Dopson, 2000) stated that physicians have traditionally held medical judgment and decision-making in high regard and have been suspicious of attempts to explore them systematically with a view to making explicit their precise character. There has been in recent years a noticeable increase of attention on decision-making and medical judgment, not just from inside the discipline but also from outside of the medical profession. Why do physicians shy away from exploring medical judgment and decision-making systematically?

EMAP-1: There's so much that we don't know that we don't know. And I think many people come in and try to study the [clinical] decision making; but it's so complex and there's so many intangibles that it is a very difficult thing to quantify and look at from a quality-type basis. It's hard to methodize so many things that we do, or *how we do it, or how we make our decisions* [emphasis added].

EMAP-3: I think that they do. I think it's not true that they don't. I would say that everyone is rather protective of their own decision-making. No one likes to be told that the way that they make decisions is suspect, but we know that a lot of the ways we make decisions is suspect. There are a lot of cognitive errors in medical decision-making. That is a sub-area of interest for me, and so I am perhaps more familiar with them than other physicians. And so, we know that there are a lot of shortcuts we take with medical decision-making which lead to errors. But traditionally, the individual physician's judgment is held kind of sacrosanct. There was mystery in it and kind of you defer to that expert's opinion about the conclusion they came to. And short of some egregious violation of custom or something like that, typically physicians are allowed to decide whatever they want to decide.

Hamm and his associates did extensive work in this area of "how" and "how well" physicians make decisions and concluded that the question of what physicians actually do is obviously a matter for research yet to be determined because of the need to take account of the complex scripts which guide physicians' decision-making. These researchers have also concluded that more research is needed in the area of "*accurate description of physicians' decision-making processes*" [emphasis added] (Hamm et al., 2000). However, it is difficult to over-state the need for ways of evaluating alternative strategies for improving medical judgments and not just focus on the study of vignettes.

Emergency medicine is not the same as running a business that is highly structured around computer models. Such models allow for the evaluation of possible alternatives, where lists of the possible values of the various parameters are collected, the dimensions of the objective functions are created, and a series of analytical runs are performed using these collected values. For many of these business situations, interactions would not be needed because the majority of the problems encountered in daily transactions can be easily identified through previously specified reports. In the domain of emergency health care the problems are more often unstructured, ill-defined, *unique to each patient*, and complex in that the agents (i.e., physicians, nurses, technicians, and technologies) are dealing with living organisms whose pathophysiologies differ immensely one from the other. There is so much to know and so much to learn about a living organism. For so many decades, computers have been used to simulate and analyze physical processes rather accurately. However, there are so many systems of crucial interest to medicine that have so far defied any type of simulation because of the "many intangibles" and unknowns faced by the medical profession.

According to EMAP-1, researchers try to study decision-making in health care and are faced with a multitude of variables, many uncorrelated, and a level of complexity that is beyond full understanding by today's mathematics. Because the problems encountered in a TC are ill-defined and increasingly complex, they cannot be handled effectively through a computer-interactive problem-solving process. Unquestionably, computers have been used very successfully to simulate physical processes. However, physicians manipulating equations at computers, adaptively exploring space and time in an attempt to find the best possible solution or best diagnostic course of action for their patients is not the best approach to solving a problem when faced with a seriously sick or multiply injured human being. Instead, these medical professionals rely "on a very sophisticated information system" available to humanity, the brain, "partly because it possesses a superior pattern recognition capability" (Tou, & Gonzalez, 1974, pp. 6) for discovering and acting on the stressful demands of the situation. Another reason to avoid computer models is because physicians feel that such a systematic approach removes the cognitive and individual element of the decision-making process. Researchers in health care have surmised that the fundamental architecture of medical decision-making related to clinical diagnosis is a crucial element that has yet to be fully understood. Faced with time constraints and a lack of objective data, physicians default to previous experience or the most conservative path, even in the more serious emergency cases:

> **EMAP-4:** [In a trauma case,] a decision has to be made in the next two minutes, what do we do? Just do everything. I don't have the time to come back in an hour and reassess and gather more data because we are time-constrained and resource-constrained. Just do it now. It's all or nothing. It's a very binary decision. You either do it all right now, or you don't do anything right now. And that's somewhat how the decision is made.

Emergency physicians are constantly making judgments that require both technical skill and expertise and artful, nuanced intuition. The ultimate process cannot be entirely systematic. If a system could do it, then a robot could do it. Anybody could do it. Nevertheless, there are many ways in trauma care that the system is set up to remove a lot of the lower-level decision-making, in order that the physician does not have to deal with those things. Often trauma cases go wrong when those low-level decisions become high-level decisions that the physician is not used to making. They may get flustered because they are presented with things that they do not usually have to worry about, and then things go off the rails. When that happens, healthcare providers participate in mortality and morbidity conferences to review cases after the fact and see where things went wrong. Yet even in those cases, the medical profession typically does not criticize the judgment of the physicians who were embroiled in the case at that time unless it is felt that there was some obvious error that occurred. The mortality and morbidity conference becomes a tool for evaluating processes and outcomes at both the level of the individual physician and at the level of the trauma team, ideally leading to improvement in decision-making and processes.

Given time constraints and the lack of comprehensive data, physicians usually try to place their patients into a group of patients who were similar—a group that the physician has dealt with before. Once this placement has occurred, physicians will then pick treatments that seemed to have worked for those other patients and that they suspect will also work for the presented patient. If physicians are aware of any science that applies to the presented case, they will also typically try to apply that science, moving the selected treatment in one direction or another. A good example, provided by EMAP-3, would be a hypothetical case of a patient with massive hemorrhage. That patient would be very sick and there would not be a whole lot of time to get history or other data. The physician would be presented with a patient who is bleeding out and has weak vital signs, and he/she would be treating those things on the patient. But how each one might go about treating this patient could differ. The case might present a brand new set of data, suggesting that the patient might need whole blood transfusions, which in the United States means getting different blood components from the blood bank and then giving them back to approximate whole blood. "Historically, physicians would have just transfused a whole lot of red blood cells" says EMAP-3, because the patient needs a lot of blood. However, today the physician might order a whole blood mix and treat the patient as he/she would all patients who are massively hemorrhaging. However, as more data are gathered, the physician might need to adjust that treatment plan. During the ongoing process of data-gathering, new information might emerge that the patient is on anticoagulants. This would cause the physician to change the therapy to reverse the effects of the patient's anticoagulants. If other co-morbid things were discovered, the treatment would need to address those things as well.

According to EMAP-3, "Pattern recognition is a lot of what medicine is." That is one way physicians remove a lot of the low-level decision-making, by reasoning that "this patient has this which is like a lot of those other patients who had this." Hence, the treatment will be to do those things that are usually done for that known group of patients. Such an approach, however, leaves open the possibility that the patient is not like the known group, thus introducing a chance for error in the treatment. This brings us back to the patient initially diagnosed with kidney infection, which turned out to be pneumonia. This patient had symptoms that appeared to indicate pyelonephritis kidney infection and, as EMAP-3 pointed out, "quite frankly did not seem a lot like pneumonia, which it turned out to be." However, pneumonia can be like that sometimes, and there were a couple of pieces of data in the case that really should have made the physicians more curious about whether it was indeed a kidney infection (namely that the urine did not seem to be very infected). Despite this lack of fit between the expected pattern and the patient, the physicians categorized the patient into "fever, maybe urinary symptoms, seems kind of like urinary infection, didn't really seem like a lot else." As result, the book was more or less closed on that kidney infection diagnosis and the patient was started on the treatment that would correct that problem. On the following day the physician, upon seen the patient again, realized that the kidney infection diagnosis was perhaps not quite right, and pneumonia emerged as the correct diagnosis.

5.5 Unfamiliarity of Task Content: Analysis versus Intuition

Hammonds' Cognitive Continuum Theory considers the nature of, and the implications of, intuitive and analytical processes in decision-making. It states that the unfamiliarity of task content may lead to forms of reasoning that induce intuition in an attempt to place perception and deductive thinking in higher levels of decision-making. *Intuition* and *analysis* have been depicted in the literature of psychology as dichotomous rivals, where some eulogized one and criticized the other, diminishing the scientific value of these two concepts (Connolly et al., 2000; Goldstein, & Hogarth, 1997; Hammond, 2000). Highly analytical processes were posited at one extreme; at the other were highly intuitive processes. At the middle point of the continuum, there was an approximation of rational decision-making. Given this schema, the question is whether medical doctors are more likely to use analysis or intuition when they are unfamiliar with a task and whether the quality of a physician's reasoning depends on his/her use of analysis or of intuition (medical judgment).

Generally, said EMAP-1, all physicians trust their gut to a certain degree. The first decision physicians have to make is whether the patient is sick or not. It was observed during the "shadowing" of the physicians that unspoken decisions and diagnosis were made at every encounter with a patient. In a simple "Hello, how do you feel?" two or three decisions and a diagnosis were made. If the patient presented as overtly sick, then physicians divided their assessments into "We know what's making them sick" or "We don't know what's making them sick." Either way, if the patient was in the sick category, physicians were very careful and did a lot of analysis in order to figure out what was going on, according to EMAP-1.

If physicians look at a patient and do not think they are that sick, then the patient is mentally put into one of two categories. If the category is, "They're not sick, and I know what's going on," then physicians just get them out the door. If the category is, "They're not sick and I'm not sure what's going on," physicians will work them up and use a little more analysis. However, they will not devote as much attention to fact-gathering and analysis in these cases as they would if they thought there was a true pathological situation. As was explained during the shadowing:

> **EMAP-3:** Because of time pressure, they're [physicians] probably going to be more likely to use intuition. As for me personally, if I walk into a situation I am unfamiliar with, I am probably going to start by intuiting my way through it. And if I have time, I will probably start to look for science that applies to it. I may try to buy myself a little time with intuition and then go back to my desk and start to look up stuff to give me more direction on whatever we're going to do. But, I think most physicians rely on intuition initially because of *the time pressure*.
>
> **EMAP-4:** When there is objective data [like] vital signs, laboratory data, objective data becomes an analytical process. In the absence of those, it's an intuitive process. I think you would default first to analytical. Meaning looking for objective data, the EMS's story, the vital signs upon arrival—your objective data you can gather. If those are lacking, then it becomes intuitive.

Intuition and judgment are the first types of decision-making used when a patient is initially seen, leading to a decision about whether there is sickness or not. Once the patient's health status has been determined, then analytical and rational decision-making processes are used to figure out what is going on with the patient. In any situations encountered by emergency physicians, analytical processes (using quantitative data) are the first choice if data are available. As expressed by EMAP-1, "To ignore data in order to use intuition is not a good idea."

However, there are certain "gray area" cases where intuitive reasoning will trump whatever analytical reasoning says. That would be in the case about necrotizing facilities, in which every analytical tool said that everything was normal and there was no need to do anything extraordinary. Fortunately, there was some intuitive part of the physician's reasoning power that trumped the analytical part. All cases that confront emergency physicians probably fall on a continuum. On one end, the situation is obvious and the decision is easy. It is below the critical threshold for whatever decision-making is necessary. As emphasized by EMAP-4, "The blood pressure (BP) is low; patients need to go to the operating room. Heart rate (HR) or pulse is going down, the patients are dying." In this sense, decision-making is straightforward. Then there are situations that fall on the opposite end of the spectrum, where physicians look at the data and it does not take any intuition to know that the patient is fine, there is no injury, and there is nothing wrong. It is the middle portion of the spectrum, where the data has not yet approached any thresholds that trigger the need for a decision, forcing the physician to interpret trends in BP, trends in HR, trends in mental status, and seek out those extraneous other bits of information, such as mechanism of injury and EMS reports.

It is in this middle area of the decision spectrum where the need for intuitive judgment comes in—when the data are seriously incomplete or fail to match what the medical team is seeing. Often when physicians order a test, they expect to know the result. The test is a confirmation of their analytical reasoning about the case. If there is some discordance between what was expected and what the test shows, intuitive reasoning must be brought to bear. Either the physician's assumption was wrong or the data is wrong. It is at this point that a physician must say, "I'm looking in the wrong place, or my differential diagnosis needs to be broader because I am missing something." Failure to do so creates situations in which major signs get missed and cases are in danger of winding up being the subject of that week's M&M conference.

The question of whether the quality of physicians' reasoning depends upon their use of analysis or intuition depends on their experience. Physicians with significantly more experience have been demonstrated to possess greater intuitive reasoning skills. Intuition depends mostly on experience; inexperienced physicians, lacking the base for well-honed intuitive reasoning, typically misapply science-based reasoning. These novice physicians may not realize that they are applying certain kinds of scientific knowledge to patients for whom that information was not intended. Or, they simply do not understand the nuances involved in applying the analytical information they know and have been trained to use. As far as whether the analytical or the intuitive approach is inherently better, it is hard for a non-medical observer to know because it seems to never happen in a dichotomous way. Physicians never really apply intuition without also having used their analytical skills. By the time he/she becomes a physician, there is a significant amount of analytical information that novice physicians know and have acquired from both school and practice; this information is always informing their nascent intuitive approach.

> **EMAP-3:** It's kind of hard to establish that. I think it has more to do with experience than it has to do with the one approach over the other. Because I don't think it ever happens that way. There's never really a mostly intuitive moment, or a significantly mostly analytical moment. It's rare to encounter a patient to whom the scientific literature applies perfectly such that you feel comfortable that your decision is made really rationally in the absence of your own personal biases or intuition.

Physicians believe that decisions that turn out to be primarily intuitive are much better the more experienced a physician is. As expected, senior medical doctors make better decisions than junior medical doctors. Trauma surgeons compared to emergency physicians generally may make better decisions just because these highly specialized physicians have to deal with trauma cases in a more longitudinal fashion. Experience definitely plays a role in medical judgment, and it can be said that, generally speaking, intuitive decisions are much better with more experience

(Klein, 2004). However, the reverse is probably also true: Analytical decisions are probably better with experience because an experienced physician can recognize when an intuition does not really apply to the patient or the ways in which the science may or may not apply to a particular patient.

Compared to senior physicians, medical student trainees often get confused about science as it applies to patients, and they usually need some guidance from expert doctors in applying it appropriately. Sometimes these novices score major successes; sometimes they do recognize when the science applies. But many times they start to head down a path of doing things based on what the scientific literature says that really is not appropriate for patients because they fail intuitively to recognize that the patient does not really belong in the same category of patients to which the science applies. In commenting on an article published in the *Society for Academic Medicine* by an intern who wrote about his struggle with a patient's diagnosis, Dr. Karen Cosby from Cook County Hospital stated, "Unlike the clean, straightforward descriptions in textbooks, real patients come packaged with all sorts of challenges" (Cosby, 2011). Dr. Cosby further commented on the resident's excellent example of reflective writing with thorough details of his decisions and thoughts during the difficult trauma case. However, according to Dr. Cosby, the resident's analysis revealed how precarious the diagnostic process can be and how uncomfortable the process can become for physicians (Cosby, 2011). In the resident's article, he revealed all the decision complexity so familiar to trauma physicians, how he grappled with indecision, uncertainty, temporary loss of a sense of control, cognitive strain, his adaptation in and evolvement with a changing environment, and interactions with experts (Cosby, 2011; Caraballo, 2011). It was the struggles of dealing with political, rational, medical judgment, and chaotic decision-making processes all in one trauma case that produced the confusion and uncertainty in the event.

Looking at those four parameters (political, rational, judgment, or chaos) according to what the physicians are processing in their minds, there are certain situations where the physicians know there is very little or nothing that can be done to save a patient, but they are still going to work as hard as humanly possible because physicians focusing on Level 1 trauma patients know that is their responsibility. When patients show up in Level 1 trauma in the care of the EMS, they come in already defined by a limited set of information such as, this is a head trauma or a gunshot wound. The entire decision-making apparatus does not exist at that point. All that is observable are resource allocations given to the case (treatment bays, personnel, equipment, etc.) and what physicians are doing to focus on one outcome: to save the patient's life.

In an environment where there are new interns that have little or no experience and only rote familiarity with the kind of pattern recognition that can support his or her decision-making processes. Hence, the decision to hand a case over to an intern is a political decision by the EMAP supervising the shift, because any decision made by the intern might be fundamentally questionable due to lack of clinical experience. Another layer of the politics of decision-making arises when the EMAP must decide whether the intern's decisions stand or whether to step in with superior experience to change the decision. All of it falls in together in that triple helix that explains the physician's mental processes. The maturing of an intern is another entire study in itself and not the subject of this study.

Immediately the physician goes from intuitive decision-making to rational decision making. For instance, the patient seen by the physician presents with an obvious illness. The question, “Is it or is it not an illness that I have seen before,” is intuitive. The patient who presents bleeding from the nose and from the ears is obviously sick. The physician did not have to make any decision to determine that. Rationally, the patient is sick. At this point, pattern recognition becomes important. For example, if the patient presented having a swelling of the abdomen and low blood pressure, the patient most likely has internal bleeding. This kind of presentation is obvious even to a novice who has little clinical experience. Once the pattern “internal bleeding” is recognized, it becomes rational decision-making process (RDMP), because then the physician proceeds to discuss which tests to order, which action is more appropriate, or which decision needs to be made. It is a rational process because there is a protocol—a list of tests that are appropriate and available for each situation.

The decision-making processes that are happening are completely independent of the source of trauma. The physician goes through the process with one of the first questions, when he asks whether this person is sick or not. This is intuitive decision-making, but political decision-making is also folded into that. Every way a physician turns, somebody is watching over his/her shoulder, and everything that is done is recorded. Everything is recorded, somebody is watching, the supervisors are there, and these days everybody is reviewing security surveillance cameras, too. All this recorded information is getting reviewed. So, no matter the direction of any case, that physician is responsible for and will be held accountable for whatever happens. The political decision becomes a part of the overall decision-making process. The political gets folded into every decision.

Resource allocation does rarely come into play, at which point physicians can make the more finite idea of chaos come into play. But as the physician walks into a situation, he/she can immediately commence the intuitive or rational decision-making processes. If the physician is not asking these questions, then he/she has gone straight into RDMP because the evidence from what he walks in and sees is so straightforward. However, at the moment he/she asks the patient, "What is going on, today?" this is the hallmark of intuitive thinking, and it is clear that intuitively certain things have been decided. Based on these decisions, the pattern emerges in the mind of the physician.

5.6 Information Overload

In emergency medicine, especially where trauma is concerned, information overload can quickly become a crucial part of the physician's daily management of work. The dynamic environment of a TC requires the handling of many issues simultaneously. For example, during one of the observed shifts, EMAP#2 had one EMS case on the phone, another EMS case on the radio, an intern seeking help with a patient, and another attending physician handing over a case as his shift was over. All these situations were handled, almost simultaneously, in a space of less than two minutes. There was little time to combine information from many sources to estimate the value of a procedure in any given case. Many times if physicians are trying to do a procedure, it makes a simple procedure very complicated if they have to start over every time someone interrupts their train of thought. It requires rethinking of the problem, reformulation of their plans, as the train of thought vanishes, even if momentarily. Sometimes they forget to restart the process and what would have been a simple procedure becomes more complicated because it gets delayed and something else has happened to make the situation now more complex.

> **EMAP-1:** I think sometimes you just have to start over and re-verify what you were doing. I've been in situations in the past where you start a procedure and you start over because you're delayed, and then things evolve and the patient changes. And, now that things have changed, the procedure is no longer necessary. That has happened before.

It is not usually that difficult for physicians to combine information from many sources to estimate the value of a procedure, mostly because of experience. Having done it many times, physicians learn what is important and what is not important to the case. However, one physician felt that it is not always that easy.

> **EMAP-4:** I would say very difficult. I think that's why there is sort of an algorithmic approach to it, a checklist approach. We are not capable of keeping all these things in our minds; we have to have a checklist. I think that is sort of what the decision-making is: If you cross a certain threshold for a trauma patient, (i.e., they had a rollover MVA), they are going to get all the CT-scans. So, I would say difficult.

Physicians are looking for those thresholds of decision-making. As one of those decision-making thresholds is crossed, everything else ceases to matter, whether it is airway, breathing, circulation, or any other threshold. In the physician's mind, many questions are asked and answered: Can this patient go home? Can this patient stay? How sick are they? These data, cues, and information are all distilled down into a threshold. The decision-making process then turns into a binary decision-making mode, yes or no. CT scan: yes or no, OR: yes or no, ICU: yes or no. In reality, there are many other variables that physicians are looking for while treating the patient that may trump this seemingly simple process. But in the search for a diagnosis, when any of those thresholds are crossed, a decision is made. In a trauma case, if the BP is low, if they have significant abdominal pain, if they are not breathing, if their mental status is altered—each of those is a branch point binary decision.

For example, consider a trauma patient who was one of the observed real-time cases during the shadowing: a motorcycle accident. The patient's BP was low; he had a critical mechanism of injury and had severe abdominal pain. Based on these three variables (BP, mechanism of injury, and abdominal pain) the patient was immediately sent to OR. It did not matter what else the physicians would find afterwards, the decision had already been made and even if the patient's BP had come back up, the decision to send him to OR would have remained. There were no other data that were going to sway the trauma team from that final decision. Hence, there was no reason to look, no reason to even spend any mental energy processing other data, because the critical decision had already been made.

The nature of a physician's job is that they are always interrupted with large numbers of things all the time. They are often dealing with many different kinds of patients; all in a single work shift, and in the case of a teaching hospital, such as the site of this study, there are medical trainees to manage as well. Therefore, it becomes part of a physician's work load to just get habituated to frequent short interruptions to whatever they are working on at that moment; but they also learn to mentally return to their task as quickly as possible. In the setting of trauma, it is set up to usually batch those things. Hence, physicians can expect information to come at certain times, and they know what kind of information they are going to get at certain times.

When things go off the rails it is usually because the information does not arrive when it is needed, or it is not coming at the time it is supposed to come, or it comes once and then it comes again and it is really different information compared to the first time. Consequently, no information was obtained, because now physicians have two really different pieces of information. When information (i.e., x-rays, CT scans, laboratory reports and so on) comes when it is supposed to, things go really well, and it is not hard to integrate all of it into the trauma event. But when the timing of that information is incorrect, it can throw the entire team out of balance, forcing physicians to do more mental work to put things back together into the trauma picture.

> **EMAP-3:** In one way in trauma centers this [information overload, incorrect information, untimely information] is almost a failing or a weakness. It's a significant weakness of the trauma center model that things are so structured that when the structure fails, medical decision-making can fail because the MDs have significantly increased stress, and they start to misapply or misinterpret or fail to recognize that they don't have appropriate information. Then they start to make bad decisions.

There are almost an infinite number of things that can go perfectly right or can go just as perfectly wrong. For instance, a physician has a patient that needs to get a CT scan; however, the patient has to be held back because the scanner is already being used. Perhaps there are two trauma patients, and they both need a CT scan. Typically, physicians do not have to make the decision of which patient goes first, because there are not always two trauma events at the same time. But when there are, it adds another decision that must be made, because resources (the CT scanner) are scarce, which creates higher margins for errors. The physician might pick the wrong patient to go first to the CT-scan laboratory.

Another area where things can go very right or very wrong would be things that should be and are routinely easy, that almost always get done, but that sometimes do not get done. During this physician-shadowing process, a trauma patient was observed that did not have intravenous (IV) access established. Usually EMS paramedics can get at least one IV access into the patient, but sometimes paramedics cannot establish access. In this case, not even the trauma team could get an IV access once the patient arrived at the trauma center. This can be construed as a significant breakdown of the normal trauma process; to not be able to have IV access within a couple of minutes really throws medical decision-making, because at that point the Level 1 resuscitation unit is moving on to the primary survey. The team knows at that point that it needs to stop and get IV access. However, as physician commented,

> **EMAP-3:** The trauma resident physician is often thrown by that and they're trying to still go, but they're not sure if they should go along with the rest of the exam because we're still waiting for IV access.

That is why there are senior emergency attending physicians there, to keep the team together until the much-needed IV medication access is in place.

Physicians feel that trauma events per se are not very complex, but humans are complex; therefore, what happen in a trauma case is unpredictable because of the human factor. It takes very little to cause consternation, as in the IV case. These are cases that do not follow the normal model that physicians try to make them fit into. Physicians then find themselves dropping back into the intuitive decision-making mode, trying to categorize the patient according to other, similar patients and then applying therapies that seemed to work for those patients. Simultaneously, they are trying to resolve everything that is keeping the patient from fitting into the normal trauma role and to get the patient back on track to do the normal trauma-center things while taking care of whatever critical issue he or she has presented with.

The pattern recognition models that medicine in general and certainly emergency medicine follows help greatly with reducing the stress that is introduced by those complexities. As EMAP-3 explained, that is why novice trauma physicians often find these situations to be really stressful, because they just have not seen enough patients yet to have a mental library of people batched into these mental models. As a result, they get very uncomfortable when things do not go the way they are ideally supposed to go. They simply do not have anything to fall back upon for decision-making. It can be concluded that it is really something that can only be appreciated and understood by physicians who have been in practice for several years to realize how much one relies on this pattern recognition approach to medical decision-making.

5.7 Cognitive Demands

There has been increased recognition that real-world problems place extraordinary demands on decision-makers. More specifically, a Level 1 trauma resuscitation case places heavy cognitive demands on physicians. Classic models of decision-making processes generally assume static problem domains, rational analysis, and suboptimal human decision-making (Cannon-Bowers, 1998). These qualities are not characteristic of a trauma center, where problem domains are in constant flux, rational analysis is just one cognitive mode of operation, and human decision-making is expected to be optimal. Leading attending physicians are constantly making efforts to improve the decision-making effectiveness of medical teams and to discover the patterns of cognition at work— how the strategies and behaviors of physicians and other team members are adapted to the constraints and demands of the trauma case at hand—while under the stress of a Level 1 trauma case.

This research was conducted at a Level 1 trauma center in a teaching hospital of a medical school that maintains a faculty body of high-level trauma and emergency medicine physicians. These high-caliber professionals make up the Level 1 Trauma Resuscitation Unit (LITRU) of the hospital, and they all work side by side with the interns. Therefore, this LITRU may differ somewhat in its actions from other hospitals where a trauma patient is presented for care. The unit is activated at the time the EMAP makes the decision to consider the incoming patient as a Level 1 or Level 2 trauma (also referred to as Code 1 or Code 2), according to the set of criteria outlined by the hospital (refer to *Appendix A).* Before the patient arrives at the trauma center, the activated LITRU is positioned in place inside the Level 1 trauma bay, with each member of the team having his/her designated place according to their specialties and responsibilities. A hospital must have at least 16 kinds of medical specialists readily available for trauma care in order to be considered a Level 1 trauma hospital (See Table 1.1 of Chapter 1). There are two attending physicians who are generally the supervisors for the day's shift, one of which made the decision to classify the injured patient as a Level 1 trauma case.

The role of the two attending physicians is, in many ways, to not be a part of the trauma case. It is to stand back and look at the whole trauma event, look at all of the team members and what they are supposed to do versus what is actually happening. The attending physician concentrates on the patient not so much as a person but as a discrete variable in this system, and he/she attentively scans the system, searching for the spots where the system is breaking down and directing others to fix them before they become a problem. This distancing is useful, because the biggest chance for errors by those leading the code occurs when the physician becomes personally involved in managing the patient, putting their hands on the patient. There are other people to do that. Because there is so much information emanating from the event, the attending physician who is ultimately in charge of the trauma has to be outside of the event. This "hands off" procedure is true even for severe medical situations like those requiring CPR, intubation, cricothyroidotomy and similar procedures. The living organism is a system with parts that interact and interrelate with each other, resulting in one injured organ affecting a non-injured organ. Systems have functional requirements (FR) that help capture the behavior of the system. The attending physician is always aware of those requirements and is attentive to the behavior of the system as expressed by the ABCDEs functions, which the system is required to perform. Distancing enables the attending physician to take in the necessary information about the system piece by piece and feed it out again as the team needs it to make decisions instead of all members of the team having all of the information thrown at them all at once. This type of engagement with the trauma case enables the attending physician to distinguish between the baseline functionality requirement necessary for the system to survive the trauma and the features that differentiate the conditions of the presented system with those past experiences.

This trauma team approach recognizes that there are other, junior physicians to do the actual work of touching the patient to perform procedures or tests, and they relay information to the EMAP who is integrating it all and directing the trauma case. The process lets that EMAP be less distracted by each individual finding, whether normal or abnormal, and permits him/her to integrate all the pieces of information into a more complete picture of the patient. It has been documented that when the EMAP or the team leader becomes involved in the hands-on care of the patient, they easily get distracted or sidetracked into one aspect of the system. For instance, an EMAP who gets drawn into putting an IV into a patient is not functioning optimally as the case manager. If something else develops that is important to know, they may not realize it because their attention is directed elsewhere. Hence, to direct trauma cases, EMAPs have to be outside of the action, just like the director of an orchestra: in front of the events, looking at everything, and telling people what to do, including the nursing staff, so that things get done. This cognitive orchestration of putting all the pieces of the puzzle together underlies their decision-making process under stress.

An example of the kind of breakdown that can occur was given by this physician:

> **EMAP-3:** There was a trauma [case] not too long after you were there [shadowing the physicians] where all the trauma MDs, including the attending [physician] and myself, got dragged into the room because the patient was very sick and actually there were a lot of breakdowns in the system for that patient that probably contributed to a bad outcome

> for them because there was not anyone out there looking at what was happening and seeing the breakdowns as they were occurring. Everyone was in the room with their own little problems, and there were other, bigger system problems that no one really recognized because they weren't outside of the room.

These types of breakdowns in communications are resolved by assigning each team member a responsibility and then each team member strictly adhering to their assignment.

> **EMAP-4:** So I think that one important thing is communication of each team member's responsibilities. The person at the head of the bed is doing the airway, the surgery resident is doing the primary and secondary assessment. This nurse knows she's doing the IV, the other nurse knows she's getting a BP. Designated communication of responsibilities. If my job is airway, I know all I have to focus on is breathing. I don't have to take in all the other data, all that confusing stuff. I have a finite realm that I'm thinking in. Just the data that affects my decision to intubate [airway] or not is all I'm concerned about at that point.

For each trauma code, there is a person assigned to each of these critical areas prior to patient arrival. There's a person handling BP and a person getting IV access. If CPR is required, there is a person already designated to perform it. They all are pre-assigned prior to arrival of the patient.

The main thing the lead physician can do is to make sure each member of the team has the same goal and is working toward the same goal. However, during most trauma situations, things are very convoluted and very dynamic, and each member of the team cannot just keep doing their one task and not have to change that task.

> **EMAP-1:** If we're doing resuscitation and I suddenly decide that I'm not sure if this patient still has a pulse anymore. Now, I have to raise my voice, not yell, but raise my

voice and reorient everyone and say "Listen, I want a pulse check before we do anything else." And then, based on that pulse check, everyone will either continue what they're doing or completely reorient.

These are decisions in real-world settings. The framework for studying decision-making in TC is based on the theories of complex adaptive systems, where interaction, evolution, and novelty are ever-present within a constantly changing environment. Expert physicians periodically reorganize their knowledge base in order to accommodate much more information. This new, expanded knowledge base is the foundation for conceptualizing new recognizable patterns, as previously discussed. Expert physicians will store and retrieve information differently than novices do and use the information for fast decision-making as required by evolving situations. Simultaneously, they go through a conscious analytical process of exploring their existing mental models to match or determine which pattern is most appropriate to the situation at hand and determine a diagnostic course of action. After doing so, physicians as decision-makers can then see how it plays out in action.

The environment that physicians and their team members face consists not only of the patient placed in front of them, but rather what they all do as a team. Their interrelations and interactions are not static aggregations, but dynamic systems. Therefore, there cannot be just a single reaction to a single, given environment; rather, an expert team both reacts to and enacts the environment. Once enacted, the team can then break down that environment into separate events that can be easily explored and matched to each of the team members' pattern recognitions available in their mental models. As the team goes through the initial patient assessment, the available enacted environment may be a score of undifferentiated variables.

Sometimes, what is observed does not match any of the team members' patterns, and this can bring everything to a standstill:

> **EMAP-1:** There is a teacher from whom I've listened to many lectures and the famous quote he has is "Don't just do something, stand there!" Sometimes you have to let things develop and let things take their own course instead of intervening, because any intervention you may do might just make things worse.

That is a level of uncertainty physicians need to learn how to deal with throughout most of their professional careers. Indeed, in virtually all phases of their professional careers, physicians have lived with irreducible uncertainty in diagnosis, prognosis and therapy. But once a physician observes and collects all the information or cues and organizes them into a coherent set of variables, he is then more able to make the inference that some of these variables co-vary with other variables in ways that may be predictive. The physician then infers a connection among the variables during those seconds "standing there," simply observing. Physicians then become part of this complex environment, moving through this complex path, and actively learning complex tasks that take total focused attention and an extraordinary amount of cognitive effort. This information gathering about one's surround and about oneself and one's own behavior is what makes the trauma center and its cases a complex adaptive system (Gell-Mann, 1999).

5.8 Trauma Complexity

Many things were observed in the ED while shadowing attending physicians during their shifts. Three of those observations were: (1) Physicians adapt to constraints, pressures, and the complexities of the trauma case at hand; (2) Rational analysis cannot yield optimal solutions when the problem is ill-defined, information is ambiguous, and the situation is dynamic. (3) In complex situations, such as a Level 1 or Level 2 trauma event, the size of the input does not correlate with its output in a predictable manner. A very small action or observation by a physician may entirely transform the assessment and management of a patient's problem. Similarly, a large input may have very little effect. A question then emerges regarding the physician's response or mental schemas in these situations when faced with problems that are very complex. One physician recalled:

> **EMAP-1:** We're taught to step back to three main priorities in very complex situations, for instance a patient resuscitation, [and] to keep it very simple. It's **Airway**: make sure the patient can breathe. **Heart Beat**: make sure they have a good pulse. **Blood Pressure**: make sure they have a good blood pressure. You do your best to make a complex situation into three simple priorities. It doesn't always work; but often times when something is very dynamic and very fluid and things are changing rapidly, you have to step back to very simple priorities to be able to deal with a very complex situation.

Sometimes the complexity and the incongruity of certain situations may change the way physicians perceive the situation or act in solving a problem, making it possible for cutting-edge solutions to emerge. Trauma centers provide unique environments to interns as well as more experienced physicians for learning processes in complex skill acquisition. TCs provide a complex, shifting and emergent task environment. The emergent task environment is the consequence of a high level of local interaction between agents. For most physicians and especially for trauma physicians, one of their roles is to try to make sense out of the chaos of such environments. During a complex resuscitation procedure, all factors collected during the primary assessment are of a very critical nature and are to be dealt with swiftly, requiring immediate attention to correct major deviations from the norm and to avoid slipping into chaos.

Making sense out of chaos goes back to the simple and the complex: physicians have to try to fit very complex situations into very simple priorities. However, physicians' notions of the meaning of complexity and its opposite, simplicity, are not easily defined. As Gell-Mann postulated, it would take a number of quantities, differently defined, to cover all our intuitive notions of the meaning of these two concepts, as each quantity would be somewhat context-dependent (Gell-Mann, 1996). Simple priorities in the context of trauma include getting patients' *airways*, their *breathing* and their *circulation* stabilized, and if chest tubes are needed, providing them, giving patients fluids if needed, and trying to get a CT scan if patients become stable enough for the procedure. The essence of complexity is the way these priority patterns change with each patient and become vastly more complex, which takes physicians back to the pattern recognition concept. What are being prioritized are the A, B, and Cs, which stand for airway, breathing, and circulation; and trying to fit very complex situations into patterns that have been seen before, which, when it can be done, can really help simplify very chaotic situations.

> **EMAP-1:** It really calls for a lot of subjective thought, unfortunately, because it's not an objective method. Your personal biases could easily obscure your abilities to fit it into the appropriate pattern. That's one thing we have to be careful about.

What physicians, then, are trying to accomplish is to take these complex boundaries between orderly and chaotic behavior of the human body (system) and understand the factors that control its behavior during those short minutes of the golden hour from the point of the initial trauma. This tests physicians' empirical knowledge to its limits.

Typically, physicians in complex situations rely upon pattern recognition discussed in the previous sections, looking at the patient and interpreting all the available information in light of the kind of patient that they think they have in front of them. At the onset of the trauma code, physicians do a quick run-through of the data as the patient arrives. In looking at the patient, the physician mentally places him/her in a bin of the kind of patient that he/she is, then mentally steps back a little from the action to see the results. The problem is when things start to go wrong, problems emerge, and physicians fail to repeat that pattern recognition process and question whether the patient was put into the correct bin. Often when this happens, the data of the situation have changed but the physicians are involved in something else and have not recognized that changes occurred. In this regard one physician said,

> **EMAP-3:** That can be really stressful, if you don't realize that's happening and you recognize that the situation is going bad and you aren't really sure why. Because the patient seemed like this kind of person who should be better now because of the things that you did because they were [categorized as] this kind of patient. And so really, I think you just try to again pattern-recognition batch them so that you hope your intuitive decisions will be more appropriate and what kind of bin you put them into is kind of more of the scientific evidence based and experience based. That's where that applies initially. As you get more data you may apply more of an analytic approach to that patient, but mostly it's just intuitive.

One important observation made while shadowing the attending physicians was that it is unusual for leading trauma physicians to be far from agreement because one person is generally firmly in charge of the team. Unless the lead physician recommends a medical procedure that the team members think is really crazy, the team will usually go along. Typically, if the attending physician in charge does run into something that has the potential for disagreement, their training and experience allow them to take a minute to lay out the situation and get team members' input. Therefore, the leading trauma physician can usually move forward in a direction in which people have at least relatively significant agreement. Trauma physicians typically in chaotic situations move again into an intuitive model in which they are going to make decisions based on what is going to be good for that patient based on the kind of patients they are categorized as being.

The thing that helps trauma physicians the most is the experience of having dealt with a lot of really sick patients and complex situations where the diagnosis is not certain and the data is not certain. The attending physician provided the following comment:

> **EMAP-3:** Really the only way to do that is [1] *experience* in one way or another through [2] *simulation* or actually [3] *seeing patients*. In our model of medical education, we usually deal with actually seeing patients in a supervised setting. Where things get really difficult is when a patient never falls into a pattern and all you have is data that you can't model into some pattern and those are really stressful just because you have to deal with each piece of data without any structure and that is hard.

In this complex adaptive process of dealing with ill-structured problems that quickly move to the edge of chaos before the problem is solved, everything can also go back to the thresholds of decision-making already discussed. If the physician looks up and sees the patient's BP at 60 mmHg, regardless of the resources available the decision to send the patient to OR is immediate. There are certain critical thresholds that, when crossed, rise to the top so forcefully that nothing else matters. Trauma physicians then default to a habit/algorithm/stepwise approach to remove some of the thinking from the situation (i.e., ABCDEs, checklist). Having a checklist in place prior to encountering a patient removes any ad hoc decision-making. Physicians practice these decision checklists during their training in order to be able to default to them in stressful situations. Thus, what helps physicians in this complex environment in order to avoid chaotic situations are the checklists and some degree of experience in applying them. However, physicians are not certain what the mix of those two are or should be. The closer one gets to chaos, the more experience comes into play, because at that point things are moving outside the realm of what the checklist covers. Obviously, it would not be chaos if the decision-making checklist covered it. If there were a checklist available to cover the situation, it would still be falling under rational or analytical decision-making.

5.9 Determining Patients' Priorities

Emergency physicians are constantly involved in making decisions: whether to order a lab report, an x-ray, an EKG, or ordering one procedure versus others as a strong possible solution to the problem at hand. The *European Journal of Trauma* reported a case of a car accident where the occupant of the car broke the right clavicle and the tenth and eleventh ribs on the same side. The patient was admitted to the hospital, kept for 24 hours for observation, and sent home shortly after that. Two days later the patient was back in the ED with generalized abdominal pain associated with nausea and vomiting, which kept the patient in the hospital for five days. Initial ultrasound and CT scan did not result in discovering the problems, but subsequent CT scans and other tests revealed the problems: duodenal hematoma and blunt abdominal trauma. A more appropriate diagnostic course of action was then planned for the patient (Barry, 2006).

The prioritization of tests to determine the extent of injuries and detect them all is a constant in a trauma physician's life. Basically, any time a patient is a Level 1 or 2 trauma codes, based on trauma "rules" these patients are always going to get a CT of the chest, abdomen, and pelvis. The chest/abdomen CT administered in the above case would probably have detected the duodenal hematoma and blunt abdominal trauma the first time around. Perhaps not with 100% certainty, but with high probability. Physicians at the site of this study take virtually any patient who has received any type of severe injury (this case probably would have classified with a clavicle and two rib fractures) and practically without thinking get a CT of the chest, abdomen and pelvis. These types of injuries require following the protocols for getting all the tests. It is an effort to take complex situations and subject them to the same routine every time in order not to miss things like this.

There are situations wherein certain preliminary information directs a physician down one path of suspicion versus another diagnostically. It is a matter of medical judgment where physicians mentally categorize and count on prior decision-making schemas. In the presence of further data from the trauma event, the schema can supply descriptions of certain aspects of the real world, predictions of events that are likely to happen in the real world, and prescriptions for behavior of the complex adaptive system. By looking at two broken ribs and a broken right clavicle, deductively or intuitively it will be assumed that this patient could potentially be sick; therefore, this patient will get a lot of tests because this patient is significantly injured. Trauma physicians do not think about it, especially when dealing with a car crash as the mechanism of injury; they just do it. The human body in car crashes tends to sustain injuries not only directly from the impact but also from the combination of acceleration and deceleration forces on his or her body. Despite very little external evidence of injury, internally there might be serious damage and stress to tissues that will complicate the entire scenario.

These are the kinds of things trauma physicians must deal with when trauma cases first arrive. Sometimes it does not sound like a particular patient would need to be considered a trauma code. These patients are some of the many people who are in auto accidents yet who are nevertheless not trauma codes. In such cases, it is the mechanism of injury that becomes the main variable. It answers the question of how bad the catastrophe was that caused the injury.

Mechanism of injury is always regarded as one of the main variables to consider in trauma codes. Biomechanics plays an important role in injury mechanisms, especially in motor vehicle crashes. Physician understanding of the biomechanics of injury is considered of utmost importance in evaluating and treating trauma codes. According to the ATLS manual, the details of the injury event can provide clues to identifying 90% of a patient's injuries (Fildes, 2008). Any patient that had no abdominal tenderness and no external abdominal signs of trauma would not have had a CT-scan, which would be the test that would diagnose such injuries. According to EMAP-3, patients with broken clavicles and ribs are particularly known to be difficult to diagnose, but they are also relatively rare, so the case reported by the European Journal of Trauma is not really an unusual outcome.

This goes to the question of how much testing is appropriate for trauma patients, which was the initial question. Trauma physicians have to go with pattern recognition and previous experience to be able to recognize the exceptions to the rule. Patients that do not look very injured do not get a lot of tests. Yet many times there are conditions that the physician intuitively knows are exceptions to the rule, and more tests are requested for those patients. In all these decisions, physicians also need to weigh the potential harms of over-testing people by making diagnoses of conditions which are not important but for which they are going to receive a lot of extra tests. Consider for instance the following case:

> **EMAP-3:** I had a patient that other day, who a specialist had ordered a CT scan of the neck, which I thought was relatively unnecessary. And there was an incidental finding which was unimportant but probably led to a lot of extra testing to diagnose [something] that in fact is not important. That was a case in which the test probably was not necessary and the outcome of the test was not good for the patient. And, then there is the actual

expense of extra testing, which is not insignificant. We, as custodians of the health care system, have to realize that. And then the harms, potential physical harms of the tests—which most of these are radiation-based studies, and many of them involve contrast dye, which is potentially bad for your kidneys. So it's not a small thing to decide to do them.

In a trauma center, especially for Level 1 and 2 trauma codes, a lot of those decisions have been decided before-hand for the trauma physician. A Level 1 trauma code is always going to get these kinds of laboratory studies and then extra ones if, in the physicians' judgment, the extra tests are needed. For the trauma center environment, the usefulness of these tests has already been decided by the medical profession, as represented by government agencies, the American College of Surgeons, the Medical Association, and the physicians as a group. Physicians may decide to make exceptions, but generally speaking those tests are going to happen. It is decision-making involving discordance between what physicians are seeing, what physicians expect to find, and what is actually found that triggers the physicians to go down a different diagnostic path.

5.10 Trauma Gestalt

An Emergency Department (ED) in a healthcare system also houses trauma centers (TC), with all of their ramifications for staffing and care. It has to have physicians and nurses who are trained to work in an emergency department and to take care of sick patients with any type of illness and any age group. Therefore, EM physicians cannot be an expert on only one kind of medicine, such as pediatrics, orthopedics, or any of the other 63 specialties. These physicians have to be able to deal with all types of problems, at least enough to get patients stabilized, do an initial or secondary assessment and get the initial diagnostic process going. The ED also has to maintain that infrastructure in readiness 24 hours a day; it cannot just be part of the day. It must also have enough ancillary resources to allow the physician to do the appropriate diagnostic testing, and physicians (not just emergency physicians) who are willing to come in on call and see a trauma patient 24 hours a day. The healthcare organization must maintain on the premises or on call a surgeon and a fully equipped operating room to take care of those patients.

The main factors that make an ED program with its trauma centers very successful are money and other resources. It is of utmost importance to have the CT scanners, x-ray equipment (both portable and non-portable), well trained RNs and an educational infrastructure to teach the nurses and the physicians. It is necessary to have the ability to reimburse physicians well enough that they want to stay up in the middle of the night seeing very sick patients. And there has to be the whole hospital infrastructure to support all of that. Trauma centers, then, require a lot of training and resources—and serious commitment from their leadership.

At the site of this research, the organization and support was visible in every aspect of the ED. The major strength was that the hospital puts a lot of resources into the trauma system. There are a lot of committed people, and there is a lot of really good training for all the medical personnel. The weakness is that the whole health care system is changing so quickly that it is uncertain whether the present amount of resources is still going to be available to put into the system and continue to make it function well enough to respond to future demands. The ability to keep up with the present volume of sick patients that are seeking services is in balance at the moment; but, hard times are anticipated if the present level of services will be required into the future. The whole process of health care reform, changes in the healthcare economy, and the stability of the global economy are going to dictate the direction trauma care will take.

To compound the problem of caring for the injured, there are the malingering patients consuming ED resources. It is hard to tell who that patient is who is malingering. He might be malingering; he might be someone who is really sick. There have been mistakes made before where the medical team determined someone was malingering but they turned out to be sick and the outcome was not good. The alternative is to take everyone seriously, regardless of appearances, no matter what the problems or complaints, which is one of the hard parts of medicine. The ED personnel have to assume they are sick.

Generally, the program affects everybody in a positive way. It gives physicians, nurses, technicians and staff immediate feedback on their failings as well as encouragement for jobs done well. It provides constant training and a system to fit into. The members of the program are respected because the results achieved are not coming out solely from the physicians or trauma surgeons or the nurses or the x-ray technicians. The results are achieved by everyone working together in the trauma system. Going back to the initial paragraph as to why these professionals chose EM as career, the biggest reason they work in a trauma ED is that they get to work with a team of very highly educated people—highly educated nurses and doctors. In contrast, in a clinic they would be working by themselves in a lot of ways, instead of working as they are now with a large team of very smart, assertive people.

One of the most significant problems in trauma medicine is that a lot of trauma management has become non-operative. In other words, for many trauma patients an operation is not needed. “For a lot of abdominal injuries and chest injuries that currently we manage through other methods, you used to have surgery,” says EMAP-3. Yet the current trauma center model relies on the immediate availability of surgeons. One of the problems created by this expectation of surgical management is that there are significant rural areas that do not have immediate availability of trauma surgeons, so those patients need to be transported to a trauma center in a timely manner. This involves either helicopter transport or ground ambulance transport. In any case, the movement to a treatment center from outlying areas is prolonged. EMAP-3 pointed out that, "There is a need to kind of decide better how to decide when surgeons are needed and also if there is a better way to move patients to trauma centers, or to move trauma centers to the patient." Three questions of crucial interest emerged:

1. Is it more appropriate to really make an effort to have trauma surgeons in outlying areas that may not have every other resource available but could do initial surgical trauma management?
2. Do surgeons have to be in tertiary centers with every subspecialty available?
3. Is that really what a trauma center has to be?

These are questions of crucial interest for future research in trauma medicine.

The trauma center and the ED where the shadowing and discussions with all physicians took place have a commitment to high-quality clinical medicine and teaching. The hospital school works hard to make sure the physician residents are the best all around, teaching professionalism and clinical competence as ED residents as well as hospital residents. The volume of patients, which exceeds 3,600 trauma cases and more than 100,000 emergency cases yearly, makes these physicians truly excellent professionals. The ED takes lots of referrals from neighboring states, "so we see lots of weird things," says EMAP-3. It is just natural in the development of cognitive processes that when one sees "lots of weird things," the pattern recognition repertoire gets bigger. Another important strength of this ED is that it has high-quality ancillary staff (i.e., nurses and technicians). For instance, the ED maintains true, fully trained charge nurse positions. The charge nurse is in charge of trauma codes, working side by side with the attending physician who is heading the ED for the shift. The triage nurses group is made up of the more experienced nurses who are specifically trained to triage. EMAP-3 explained the importance of the triage, “You want those nurses to be experienced because, again, they are also going to make intuitive decisions about patients that may not necessarily be supported by the data about how sick that patient is.” It is crucial for these triage nurses to have an informed patterned recognition buffer to make those at-the-edge decisions.

The study site is a fairly typical, traditional ED in that there is a significant amount of ambulance-based traffic and a significant amount of walk-in traffic. This is also an academic ED in that there are resident trainees who see the vast majority of these patients under the supervision of the attending physicians. The emergency medicine attending physician (EMAP) almost always does a more limited evaluation then they would do if they were in private practice. This is acceptable and necessary for the training of the residents. While from the patient’s perspective, it would be ideal to see just one physician at the level of an attending physician, every EMAP sees to it that patients get that level of care, even when they see the resident first.

5.11 Chapter Summary

This chapter covered a very large number of topics that are crucial to decision-making in an environment where decision makers are under stress. It covered a wide range of topics, ranging from pattern recognition, clinical judgment, and exploring decision-making systematically to information overload, cognitive demands, and the complexity of trauma events from the standpoint of complex adaptive systems. Observations, shadowing, and open-ended questions were the tools used to understand how physicians make decisions in the stressful environment of trauma centers. These tools provided a unique way to understand medical decision-making processes and how physicians approach the very difficult task of saving someone’s life when only little or partial knowledge is available at the onset of the trauma event. These EMAPs demonstrated the ability to make broad but fundamental decisions regarding a sick or multiply injured human being. Trauma physicians know what they want to achieve and how to focus their knowledge and experience on the event at hand.

Physicians, as expert decision-makers in their fields, are predisposed to make clinical judgments implicitly as well as being inclined to make decisions and clinical judgments on a more intuitive basis. Of paramount importance is pattern recognition, which helps physicians in solving difficult problems when all that is available are data that cannot be easily modeled, making the situation truly stressful. Physicians store those patterns in the form of precepts and they act on the basis of those precepts by somehow forming inner mental representations of outer reality, then acting on the basis of those representations. Thus, experience helps physicians in this complex environment to avoid chaotic situations. The closer physicians get to chaos, the more experience plays a role in problem-solving. In making sense out of chaos, a trauma team goes back to the simple and the complex by fitting very complex situations into very simple priorities, such as the ABCDEs. A Level 1 trauma resuscitation case places heavy cognitive demands on physicians because TCs are complex, shifting and emergent task environments. An increasing emphasis is placed on physicians' performance in complex situations, requiring improved communications, teamwork and coordination. The unpredictability of trauma systems and the difficulty of collecting needed data were stressed because there are so many tangible and intangible, known and unknown variables. Physicians in trauma centers exercise great leadership because they care about emergency medicine very deeply. In the process of caring for the very sick or seriously injured, these physicians exploit many types of information processing for effective strategies to come up with plausible decision-making solutions for the patient's problems, contingent on task demands and often adapting to new directions.

CHAPTER 6

Results and Discussion

6.1 Introduction

In this study, data was collected for a total of 17 trauma cases; five of these cases were excluded due to insufficient performance data. Of the twelve cases chosen, data from ten of these cases were used to be used in the model for "Decision-Making Process Under Stress" for a training process. Two of the cases were used for the actual classification for the likelihood that an observation belongs to one decision-making class or another. The resulting output was the generation of a confusion matrix (CM) by means of the Bayesian classifier and a process graph using a deconvolution operator. Both were derived with parameters that modeled the cognitive performance of the physicians' decision-making processes.

The two trauma cases were selected and used in the model "Decision-Making Process Under Stress" (DMPUS) for achieving the greatest understanding of how physicians make decisions under stress. The cases were discussed for verification of the results with a physician at the trauma center site. The results align very close to how physicians think during trauma events, giving a better insight into how physicians make decisions.

1. Case 1: The patient arrived at the trauma center transported by EMS, with multiple gunshot wounds to the lower extremity. The trauma team was around the patient at the bedside, simultaneously evaluating to determine the type and extent of injury and subsequent management of the region of the body that was injured, the organs in the path of the penetrating bullet, and the velocity of the bullet. Technicians with portable X-ray machines were called in for x-rays.

2. Case 2: The patient arrived at the trauma center with chest stab wounds with an unknown size of knife. It was not possible to immediately assess how deep the wounds were and whether vital organs had been punctured. Although the patient's condition initially showed marginal improvement, when reassessed by the emergency physician the impression was that the patient was not improving. Further history was taken and after more trauma center care, the patient was transferred to the operating room to be cared for by trauma surgeons.

During the study period, physicians were observed while attending to critically injured or extremely sick patients in the trauma center. As patients arrived, physicians were formulating decisions and plans of action. Throughout Case 1 events, gunshot wounds, many decisions were made in split seconds. Some decisions inherent to traumas like Case 1 must be made rapidly and executed promptly. These decisions, which must be made in the midst of immediate stressors, may be outlined as follows:

1. Mechanism of injury – bullet entrance and exit sites
2. Bullet caliber and velocity of the projectile
    a. High-velocity wounds may cause increased damage lateral to the track of the projectile due to temporary cavitation
    b. Care must be taken not to underestimate the amount of energy delivered in high-velocity wounds.
    c. Appropriate actions must be taken to prevent missed injuries.
3. Internal bleeding
    a. Must take blood pressure very often
    b. Attention to patient's abdomen as to whether it becomes taut

c. Attentive to temporary cavitation

4. Additional injuries based upon

   a. The length of the projectile's path

   b. The greater kinetic energy

   c. Linear or nonlinear trajectory of the bullet between entrance and exit

   d. The possibility of ricochet off of bony structures

   e. Possible fragmentation of bones creating secondary projectiles

   f. Vascular problems

5. Patient's medical history

   a. Importantly, is patient on some type of blood thinner?

6. Visually identify sites of major external bleeding.

7. Continuously visually assess the extremities for color and perfusion, other wounds, deformity, swelling and discoloration or bruising.

8. Assess four important body organs/systems

   a. Skin

   b. Neuromuscular function

   c. Circulatory status

   d. Skeletal and ligaments integrity

9. Review for other musculoskeletal injuries

10. Examine for limb-threatening injuries

    a. Possible major arterial vascular injury

    b. Need for immediate consultation with a surgeon

11. Securing blood from blood bank if needed

12. Is the shooter in custody?
    a. Should ED be locked up?
    b. Is the medical team safe?
    c. Should hospital security or the police be called?

These are many of the decisions made during a trauma event of this type, because the type of surgical procedure that may follow is definitely influenced by these decisions. There are many types of medical and other decisions taking place at these times, and, depending on the patient's physical condition, stage of illness or age, there might be a set of different decisions. This differential decision-making process is the substance of developing trauma codes.

In Case 2, a series of decisions were formulated by physicians that included many of the same decisions as those necessary for gunshot wounds, as well as some decisions inherent to penetrating knife wounds to the chest. Physicians were making decisions on how to stop the bleeding, as in Case 1. However, they were also engaged in how to ascertain that internal organs were not affected and, if they were affected, what line of action might be taken to correct or minimize the problem. Among these decisions are:

1. To seek the account of EMS or witnesses who can provide details of the incident, because this information helps in predicting injury patterns
2. Developing an unusual index of suspicion about what affects the patient
3. Determining whether the patient has any hemodynamic abnormalities
4. Early and immediate surgical exploration (laparotomy)
5. To see whether there was puncture of the pleura
6. Lung puncture
7. Whether to bring in respiratory technicians

8. Determine whether a CT-scan or X-ray is needed. Will they be revealing in this particular trauma case?
9. Whether to do more evaluations or transfer the patient to a more appropriate level of care for severe injuries that have already been identified

There are also many other decisions which are common to both cases that can or seem to be procedural and almost automatic, but they are not. These are decisions regarding when to record vital signs, such as blood pressure, level of oxygenation, heartbeat, respiratory rates, body temperature and environmental temperature, as well as who will collect this data, and the assignment of a CPR expert to be present throughout the assessment period, among several others. At the least, these seemingly merely procedural decisions will increase the noise of the environment, causing physicians to have to deal with a lot more distraction and information. In addition to the procedural domain, physicians in trauma centers also have to deal with the affective domain, that is, all of the emotions emanating from medical staff, patients and relatives of the patients. These are environmental noises that convolute decision-making processes; they can easily blur the physicians' minds.

In terms of simulation output, the two cases were different in the manner in which the physicians handled each case. The physician's course of action initially can be easily followed because it is very procedural: x-rays are ordered, wounds are cleaned, first and second assessment as required in trauma codes are performed—and all with clockwork precision. These procedural actions are automatic, "tangible, well defined, and teachable" (Croskerry, 2000) and seem to be achievable without much thought, relying chiefly on training, experience, and prior authentic rehearsal of textbook techniques.

This study, however, was trying to make sense of the decisions as being rational, political, judgmental or intuitive – as defined in Chapter 3. While technicians was taking and developing x-rays and bringing the resulting reports to the physician for analysis, the physicians were making many decisions for the patient in the meantime, which might fall into any of these four decision categories. The process never stops because it cannot stop until the patient either is stabilized or has expired. Dr. Patrick Croskerry, a scientist and an emergency medicine medical doctor, wrote about three domains of expertise in emergency medicine that are required for effective performance in trauma situations, referring to these domains as procedural, affective and cognitive. His writings about decision-making in emergency medicine draw a sharp distinction between the three and attention to the fact that it may appear to outside observers, "as well as to many within the medical profession," that the procedural is the most important of the three domains. However, his assertion is that most of the emergency physician's time is engaged in "cognitive behavior" through actions and interactions with other medical personnel (Croskerry, 2000). The assertion in this study is that these cognitive behaviors define physicians' decision-making processes as being intuitive, judgmental or political.

6.2 Results

The model "Decision-Making Process Under Stress" generated a confusion matrix and a deconvolution graph for each of two different study conditions applied to each of the two trauma codes. There were a total number of 101 of four decision-making types in Case 1, of which 61 were classified as rational, eight political, five judgment, and four intuitive decisions made. It resulted in 75.09% accuracy for all decisions made during the trauma case. In Case 2, the results were similar in that there were 68 rational, 7 political, 1 judgment, and 4 intuitive decisions made. The resultant numbers from the CM that used data from the eight variables have been summarized according to Case 1 and Case 2. Table 6.1 gives an outline of the time sequence of events for “Case 1” and “Case 2” regarding each “decision-time-interval” (DTI).

Table 6.1

Sequence of Events of Trauma Cases 1 and 2

Decision-Time-Intervals			
Case 1		**Case 2**	
Gunshot Wound		**Knife Stab**	
Time	**DTI**	**Time**	**DTI**
04:39	DTI-1	03:10	DTI-1
04:44	DTI-2	03:14	DTI-2
05:01	DTI-3	03:18	DTI-3
05:06	DTI-4	03:20	DTI-4
05:37	DTI-5	03:24	DTI-5
		03:28	DTI-6

6.2.1 Trauma Case 1 – Study Condition 1. The first study condition used sample data collected for the eight variables on a “moment-per-moment” basis in trauma Case 1, referred to as “decision-time-interval” (DTI). For each DTI, the data was run through the Matlab program model. During Case 1, there were five moment-per-moment decision time intervals, each referred to as DTI-1 through DTI-5 (see Table 6.1.) For the first study condition of Case 1, Figure 6.1 provides the results of all five confusion matrices (CMs) that include the percentage of accuracy of all decisions made by the physician during the golden hour of the trauma code.

Confusion Matrix
Decision time Interval 1
Accuracy: 74.0%

	R	P	J	I
R	64	2	1	4
P	6	3	2	1
J	1	0	4	0
I	6	1	0	6

Confusion Matrix
Decision time Interval 2
Accuracy: 76.0%

	R	P	J	I
R	66	1	1	3
P	6	6	0	0
J	2	0	3	0
I	8	0	1	4

Confusion Matrix
Decision time Interval 3
Accuracy: 71.2%

	R	P	J	I
R	63	4	1	3
P	3	8	1	0
J	2	1	1	1
I	9	2	0	2

Confusion Matrix
Decision time Interval 4
Accuracy: 76.0%

	R	P	J	I
R	69	0	0	2
P	10	1	1	0
J	1	0	4	0
I	7	0	1	5

Confusion Matrix
Decision time Interval 5
Accuracy: 77.9%

	R	P	J	I
R	69	1	0	1
P	7	4	0	1
J	1	0	4	0
I	9	0	0	4

Figure 6.1. Confusion matrices, Trauma Case 1, Study Condition 1.

These CMs are based on the Bayesian classifier which gives fairly accurate probabilities of likelihood that a decision was correctly made, assuming relevant variable inputs are known. In other words, it allows researchers (physicians) to combine new information, or data, from the noisy environment with their existing knowledge or expertise, which in turn provides a better approach to problem solving and better decision-making.

Figure 6.2 gives the deconvolution graphing output for each DTI for the first study condition of Case 1, describing physicians' cognitive behavior during a trauma from a cognitive engineering approach. These graphs represent the evolution of the physician's thinking process for each moment of the trauma code, which is an approach to developing and evaluating a physician performance measurement system that leads to effective decision-making outcomes. Variations in the physician's decisions are conspicuous on the deconvolution graphs and are determined by experiences, preferences, choices, influences and a number of other human and non-human factors dictated by certain mechanisms such as emotions, environmental noises, physical condition of patients, and so on. The graphs of Figures 6.2d and 6.2e show that the medical team experienced a period of relative stability in which the next actions could be reasonably predicted, with perhaps little from the environment influencing the medical team's actions. It was only when environmental noise and increased information changed at a pace greater than the physician's decision-making threshold that the team encountered critical points that forced decision-making accuracy to be reduced.

These graphs represent the variation in the physician's thought processes via the upward and downward movements of the graph lines, which establish its erratic nature as decisions proved to be stable or unstable. This was caused by the fact that trauma physicians do not have time to look for all relevant information and weigh every bit of information to decide on a course of action when every split second counts toward saving patients' lives. Moreover, these variations in essence illustrate the stressful moments of the trauma code; as the graph lines show, stress is never completely eliminated. The complexity of the system brought about by the team members' interactions and relationships were compounded by the team members' individual and collective behaviors that changed as a result of their involvement with the environment, created critical moments during which decision processes slowed down, even if just for fractions of seconds. Trauma physicians do not face a problem domain that is clearly bounded because human patients are individual systems that react differently one from another; therefore, each trauma case is unique and even ill-structured presenting a series of novel problems.

Figure 6.2a illustrates that the incidence of the percentage of correct decisions at the onset of the trauma was 69%, which with some variations reached a peak of 77%, finally stabilizing at between 75% and 76% when the physicians de-blurred and made different decisions. Throughout Case 1, in the remaining graphs of Figure 6.2 (b, c, d, and e) decisions run from 66% to a peak of 81% moment-per-moment as the trauma code progressed.

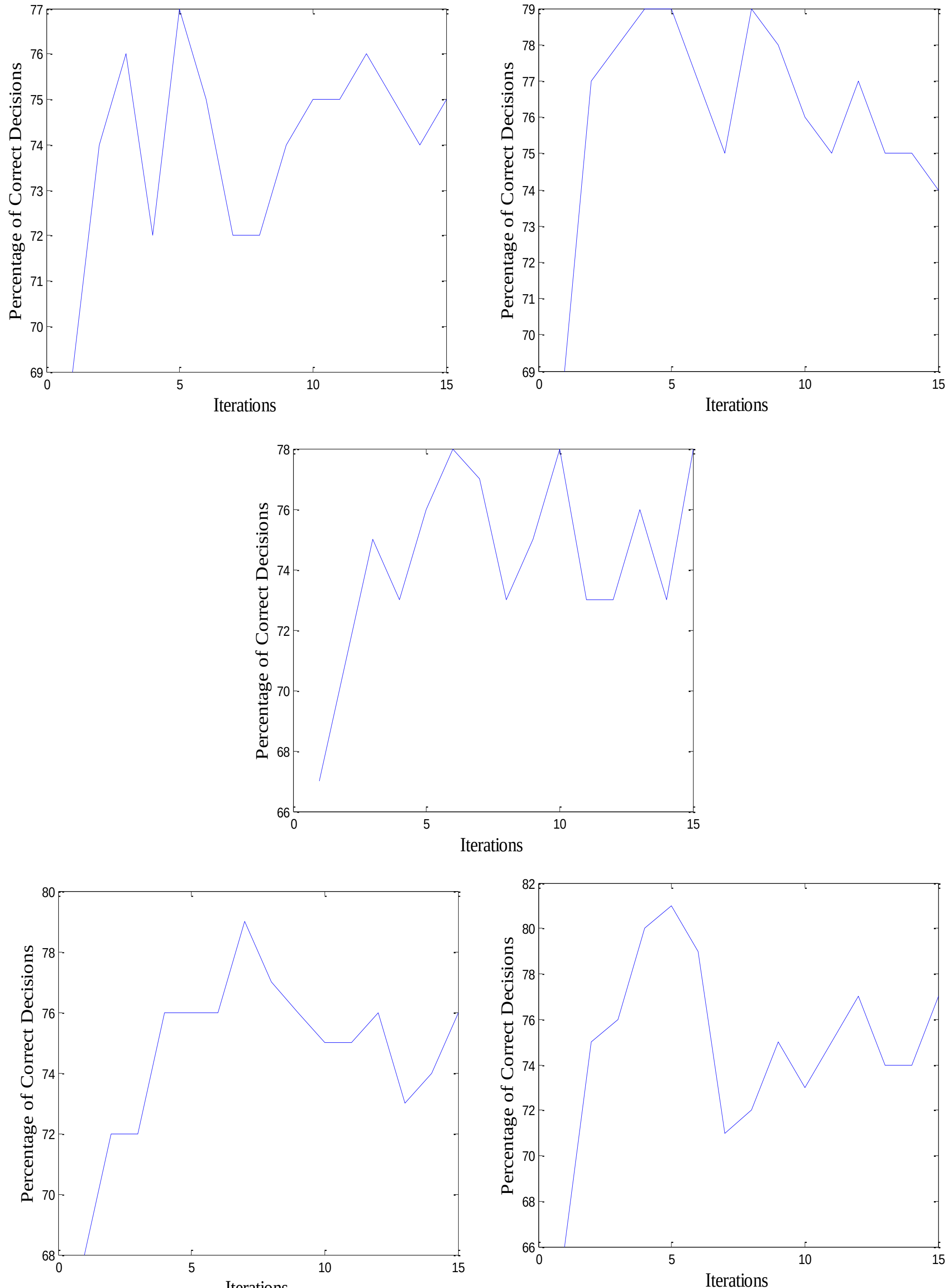

Figure 6.2. Deconvolution graphs, Trauma Case 1, Study Condition 2.

In the first CM of Figure 6.1, the actual physician's decisions show 64 rational decisions that were correctly classified as rational decisions, two rational decisions that were incorrectly classified as political, one rational decision incorrectly labeled as judgment, and four rational decisions incorrectly marked as intuitive decisions. The next row of the same CM shows three actual political decisions correctly classified as political, six political decisions incorrectly marked as rational, two political decisions incorrectly marked as judgment, and one political decision incorrectly labeled as intuitive. The third row of this CM shows four judgment decisions that were correctly classified as judgment, one judgment decision incorrectly labeled as rational, zero judgment decisions incorrectly labeled as political, and zero judgment decisions incorrectly labeled as intuitive. In the last row there were six intuitive decisions correctly classified as intuitive, six intuitive decisions marked as rational, one intuitive decision marked as political, and zero intuitive decisions that were marked as judgment. Consequently, in Figure 6.1, the CM system correctly predicted 64 rational decisions, three political, four judgment, and six intuitive decisions, for 74.0% accuracy. Following the same reasoning outlined above, the remaining four CMs of Figure 6.1 show 76.0%, 71.2%, 76.0%, and 77.9% accuracy. The rise in accuracy is due to physicians de-blurring their thought processes and making different decisions, bringing the percentage up to 77.9% from the previous lower level. These results have been graphically summarized in Figure 6.3.

In this summary of the five confusion matrices for Case 1 reflected in Figure 6.3, each bar of the graph depicts the percentage of accurate decisions made by the physician during the trauma case and correctly classified by the Bayesian classifier. In decision-time interval one (DTI 1), the percentage of accuracy was 74%, and this accuracy increased to 76% during DTI 2, just to hit a critical decision-making point in DTI 3, as shown by the decrease in the accuracy rate of almost five percentage points, down to 71.2%. As physicians de-noised their thought processes in DTI 4, it bounced up to76% and then leaped up again in DTI 5 to 77.9% accuracy.

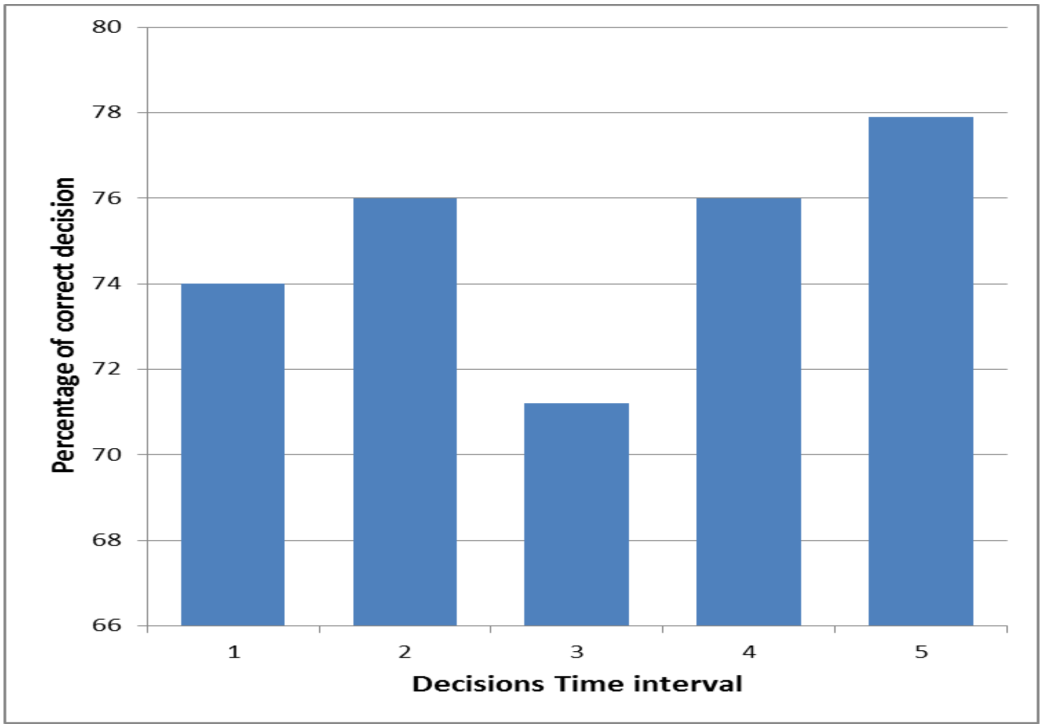

Figure 6.3. Summary of confusion matrices, Trauma Case 1, Study Condition 1.

Accompanying the summary of confusion matrices in Figure 6.3 are the deconvolution graphs presented in Figure 6.2, in which each of the five line graphs represents the physician's thought process for a moment during the trauma to arrive at a decision. Figure 6.2a shows a process that is unstable. This graph shows variations throughout the 15 iterations; but, it also shows that the deconvolution process reached an optimum at 77% of de-noising development during the first five iterations. However, the process stabilized at iteration ten, where it reached an optimum of 75% of de-noising. In Figure 6.2b, the results are perceptible as physicians approached the next moments of the trauma code with the first four iterations showing de-noising results of 79%. Again, the process reached a critical decision-making point and environmental noise brought the process to a lower level of understanding that reached 75% at 11 iterations and 74% at 15 iterations. The results of Study 1 helped in developing a more comprehensive understanding of the complexities underlying decision-making by trauma physicians.

6.2.2 Trauma Case 1 – Study Condition 2. The same procedure was followed for Study 2 of Case 1, but, the data used were "moment-upon-moment," meaning that the data for DTI-1 and DTI-2 were entered together in Matlab to create both the confusion matrix and the deconvolution graph for those two decision time intervals. Next, it was the DTI-1 with DTI-2 and DTI-3 sample data which were entered together in Matlab. It was continued in this manner to the end of the golden hour of the trauma case, always adding one more moment-per-moment (DTI) of the sample data to the end of Case 1. The resulting confusion matrices are shown in Figure 6.4, and the deconvolution graph outputs are shown in Figures 6.5a thru d.

Confusion Matrix
Decision Time Interval 1-2
Accuracy: 75.0%

	R	P	J	I
R	66	2	0	3
P	7	5	0	0
J	2	0	3	0
I	7	1	1	4

Confusion Matrix
Decision Time Interval 1-3
Accuracy: 73.1%

	R	P	J	I
R	65	5	1	0
P	4	7	0	1
J	1	0	3	1
I	11	0	1	1

Confusion Matrix
Decision Time Interval 1-4
Accuracy: 73.1%

	R	P	J	I
R	68	1	1	1
P	8	3	1	0
J	3	0	2	0
I	9	0	1	3

Confusion Matrix
Decision Time Interval 1-5
Accuracy: 75.0%

	R	P	J	I
R	61	6	3	1
P	4	8	0	0
J	0	0	5	0
I	4	3	2	4

Figure 6.4. Confusion matrices, Trauma Case 1, Study Condition 2.

Figure 6.5d is a graphical representation of the entire trauma event (DTI-1 through DTI-5), at which point the physician had full knowledge of the entire case. It can be compared to Figure 6.5a, at which time the physician had only partial knowledge of the trauma code.

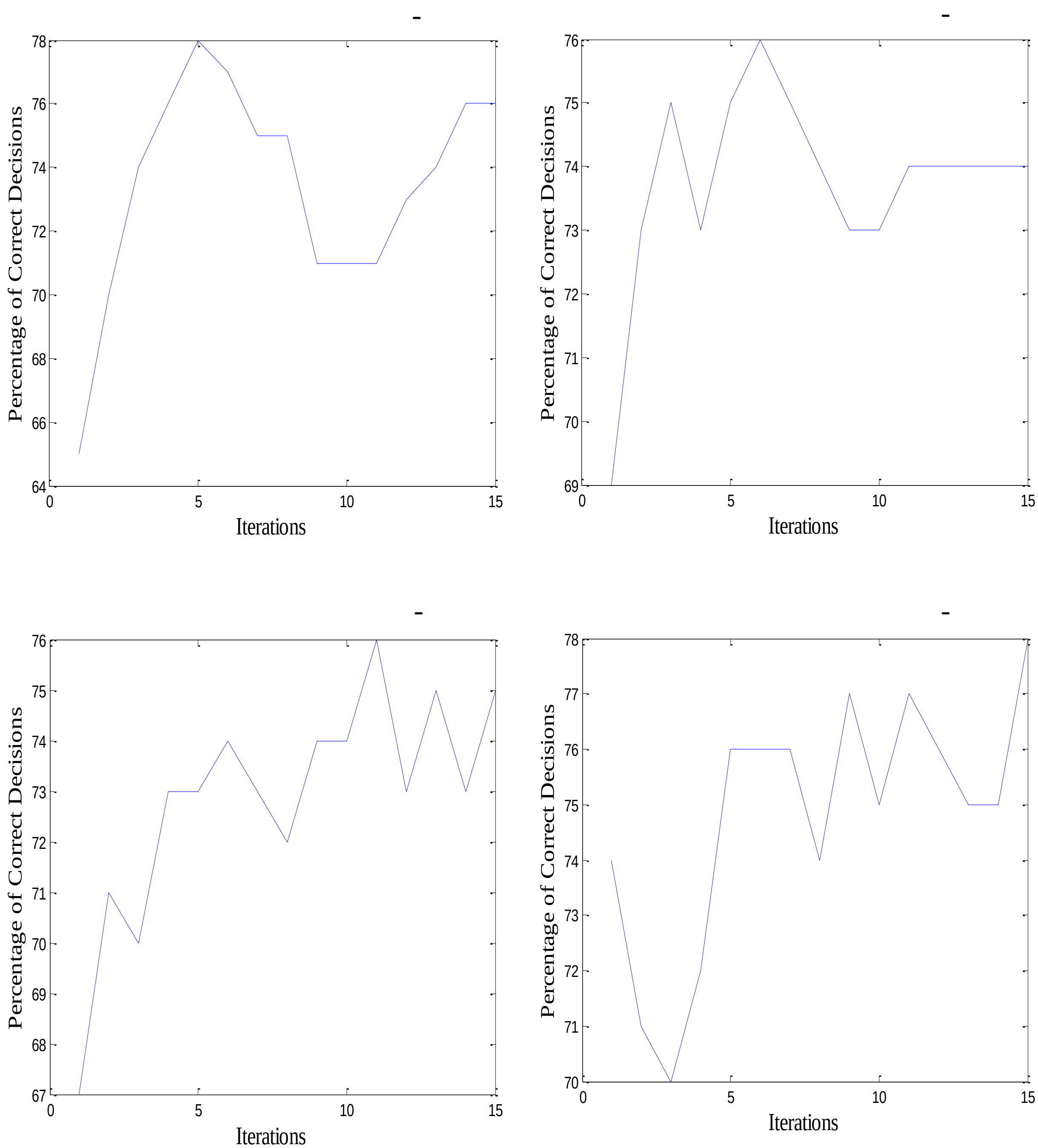

Figure 6.5. Deconvolution graphs, Trauma Case 1, Study Condition 2.

In this study, two of Case 1's participants, the CMs reported in Figure 6.4, have been summarized in Figure 6.6, where the accuracy rates were graphically compared to achieve a greater understanding of the decision maker's cognitive processes.

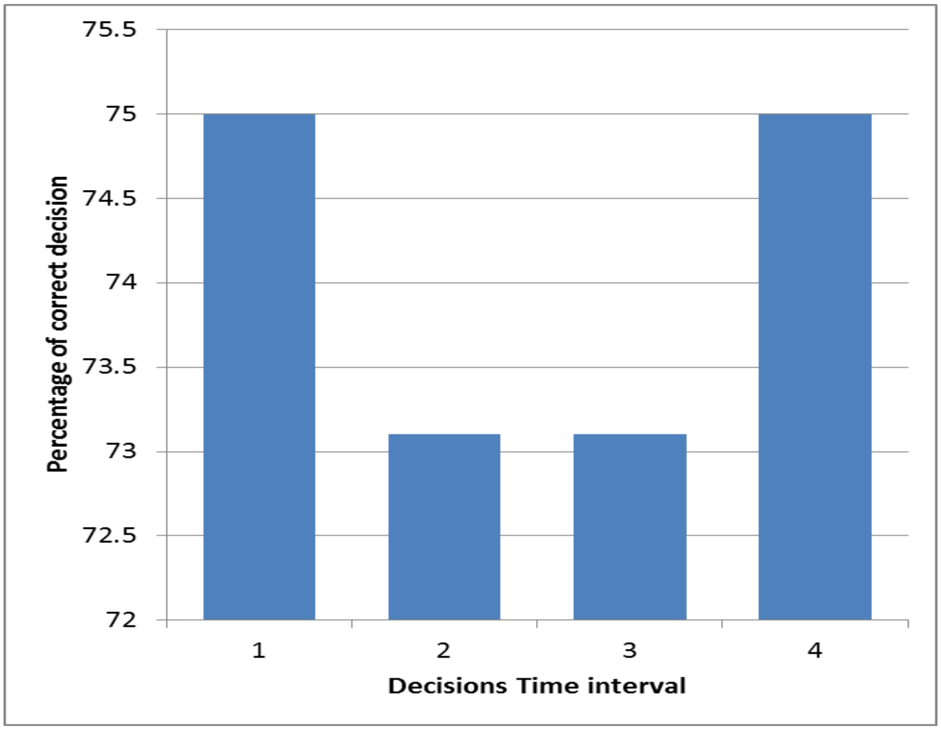

Figure 6.6. Summary of confusion matrices, Trauma Case 1, Study Condition 2.

As shown in Figure 6.6, the accuracy of decisions made changed from 75% at the beginning of the trauma code to 73.1% mid-way stabilizing in the end at 75% accuracy. This 75% accuracy can be compared to the deconvolution graph of Figure 6.5a in which the percentage of correct decisions reached a peak of 78%. It is evident that the decision makers encountered critical points, forcing their thinking processes to slow down in order to manage de-blurring and an opportunity to make different decisions. The physician reached a slow moment in the decision-making process creating convolution at what seems to have been a critical point, while entering the next moments of the trauma, as shown in DTI 1-3 of Figure 6.5b. Critical points are serious indications of a time of struggle and differences of opinion, and they may indicate periods of cognitive disagreements among the medical team members (Goldstein, 2010).

However, critical points offer the medical team unique opportunities for successful transformation of the event through complex interactions, relationships and innovations that help to define strategies for dealing with novel situations. This critical point caused a reduction in the percentage of correct decisions to 73.1%. The convolution could have been the result of higher environmental noise that required the physician to heavily focus attention under stress, perhaps because of novel knowledge characterized by the development of new patterns. Critical moments such as these often happen in trauma situations as the pace of events and the nature of the trauma require physicians to interrupt any on-going cognitive activity in order to address a more critical developing situation. Performance was markedly impaired for a few iterations, showing a steady decline to continue into the DTI 1-4 of Figure 6.5c before deconvolution took place. In addressing this new state, the deconvolution or de-noising during DTI 1-5 reached an optimum of 75% to allow physicians to make decisions with clear minds as observed in the last CM of Figure 6.4. The last two deconvolution graphs, (c) and (d) of Figure 6.5, provide clear evidence of thinking process improvements and the physicians' ability to achieve higher performances while under stress. This higher performance is shown in the significant results of Figure 6.5d, in which the entire trauma event (DTI-1 through DTI-5) is depicted to represent the physician's full knowledge of the entire case as the medical team reached its optimum. In this period of time, there was steady de-blurring and variations on the decision process occurring throughout the 15 iterations, always, however, improving decisions and experiencing steadily upward stabilizing adjustments.

The accuracy of a decision is compared to the physician's thresholds for that procedure, decision-making action, a particular disease, or an injury of the patient. An accuracy percentage that is a good approximation of the physician's threshold for the situation takes the process to the DMUS final result (refer to Figure 4.1 of Chapter 4). This is the physician's initial guess as to the diagnostic course of action. Assuming the resulting percentage of accuracy is reasonably within the physician's threshold, the decision process is completed and the physician has reached the decision under stress.

The important points observed for Condition 1 of Case 1were in the results of the deconvolution graphs. As shown in Figure 6.5a, the percentage of correct decisions went from 65% to 78% in five iterations and reduced to around 71% in four more iterations, stabilizing itself at 76% after four more iterations. In other words, there was a critical moment in which the medical team came in contact with some critical information that blurred the physician's thought process, causing the decision-making process to slow down or be too noisy to decide the course of action, and this lasted for six iterations.

Additionally, the graphs of Figures 6.5a, c, and d show similar reactions where decisions went up from 67% to 76% with some variations that brought correct decisions down to 73% before springing up and stabilizing again at 78% after the physician's de-blurring. Something happened that raised the physician's decision process to a different level. When little or no variation is observed in the graph lines, it means that the decision of the physician has reached its optimum because there is little variation between the physician's decision and the Bayesian classifier. Physician decision-makers have been trained in specific construct systems that enable them to view in many dimensions the problem or situation which their medical team is facing. It is important is that these constructs are adaptive and not static, since trauma physicians are part of a complex adaptive system that must be able to adapt in and evolve with a changing environment. As discussed in the previous sections, these constructs are, for the most part, confirmed by a pattern recognition process that matches the situation at hand with those in the physician's mental library of pattern recognition.

The confusion matrices of Figure 6.4 were summarized in Figure 6.6 for an easier interpretation of the decision-making process for Study 2 of Case 1. Evidence regarding the decision-making activities of these physicians is indicated by the percentage of accuracy achieved throughout the trauma.

6.2.3 Trauma Case 2 – Study Condition 1. The second trauma case was several minutes longer in duration. The same procedure outlined for Case 1 was applied for Study 1 and Study 2 of Case 2. The results for Case 2 were six CMs for Study 1 and five CMs for Study 2. This is illustrated in Figure 6.7 and Figure 6.10, respectively. Further, the resulting deconvolution graphs for Study 1 and Study 2 of Case 2 are shown in Figures 6.8 and 6.11, respectively. This combination of CMs and deconvolution graphs is important for making sense of the physician's thinking processes, because it is a strong way to visually depict the decision-making process. It allows for rapid comparison of the physician's mental models with the reality of the trauma situation. In Figure 6.7 of Study 1, note the robust results of all six CMs. At the start of the trauma code, the physician's accuracy was 75% in the first "decision-time-interval" (DTI-1). The accuracy improved as the trauma code gained momentum, reaching 77.9% during the next DTI-2, and improving once more to 82.7% in DTI-3. Physicians encountered some critical moments during the next two intervals as accuracy dropped 7.7% to 75%. However, accuracy went up to 78.8% in the last CM. These CMs for Study 1 of Case 2 have been graphically summarized in Figure 6.8. The deconvolution graphs of Figure 6.9 demonstrates the ability of the trauma medical team to approach complex situations, raise new questions, use proximity, time, and perceive the consequences of actions taken.

Confusion Matrix — Decision Time Interval 1 — Accuracy: 75.0%

	R	P	J	I
R	65	3	0	4
P	5	7	0	0
J	1	0	3	0
I	9	0	0	3

Confusion Matrix — Decision Time Interval 2 — Accuracy: 77.9%

	R	P	J	I
R	64	3	0	5
P	5	6	0	1
J	1	0	2	1
I	2	0	1	9

Confusion Matrix — Decision Time Interval 3 — Accuracy: 82.7%

	R	P	J	I
R	68	1	2	1
P	3	8	1	0
J	1	0	3	0
I	4	1	0	7

Confusion Matrix — Decision Time Interval 4 — Accuracy: 76.0%

	R	P	J	I
R	68	2	0	2
P	7	4	0	1
J	2	0	2	0
I	6	1	0	5

Confusion Matrix — Decision Time Interval 5 — Accuracy: 75.0%

	R	P	J	I
R	65	3	2	2
P	6	6	0	0
J	2	0	2	0
I	7	0	0	5

Confusion Matrix — Decision Time Interval 6 — Accuracy: 78.8%

	R	P	J	I
R	69	2	0	1
P	7	5	0	0
J	0	0	3	1
I	5	0	2	5

Figure 6.7. Confusion matrices, Trauma Case 2, Study Condition 1.

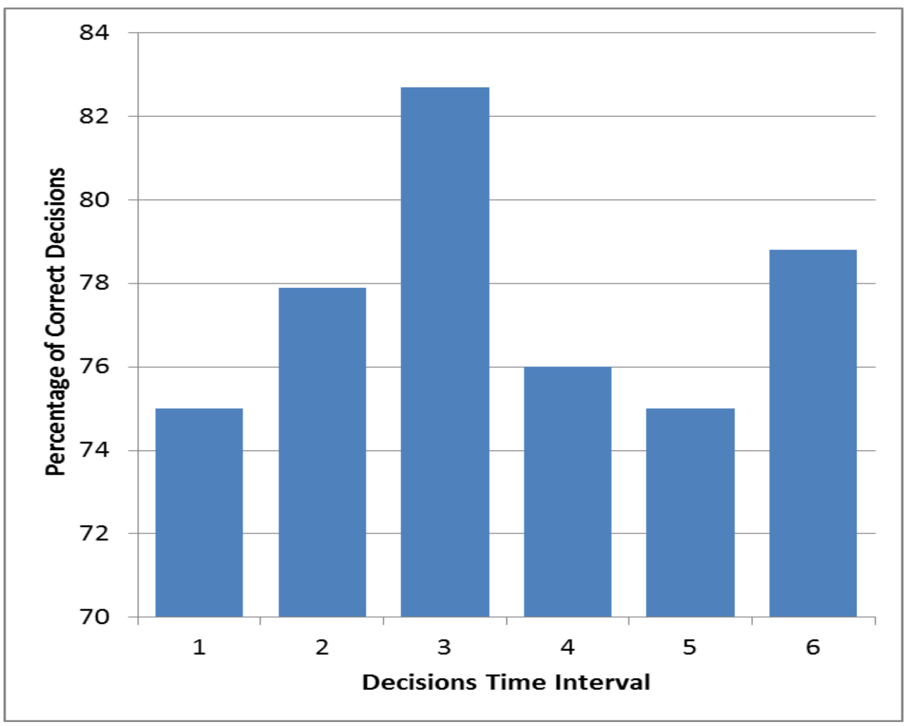

Figure 6.8. Summary of Confusion matrices, Trauma Case 2, Study Condition 1.

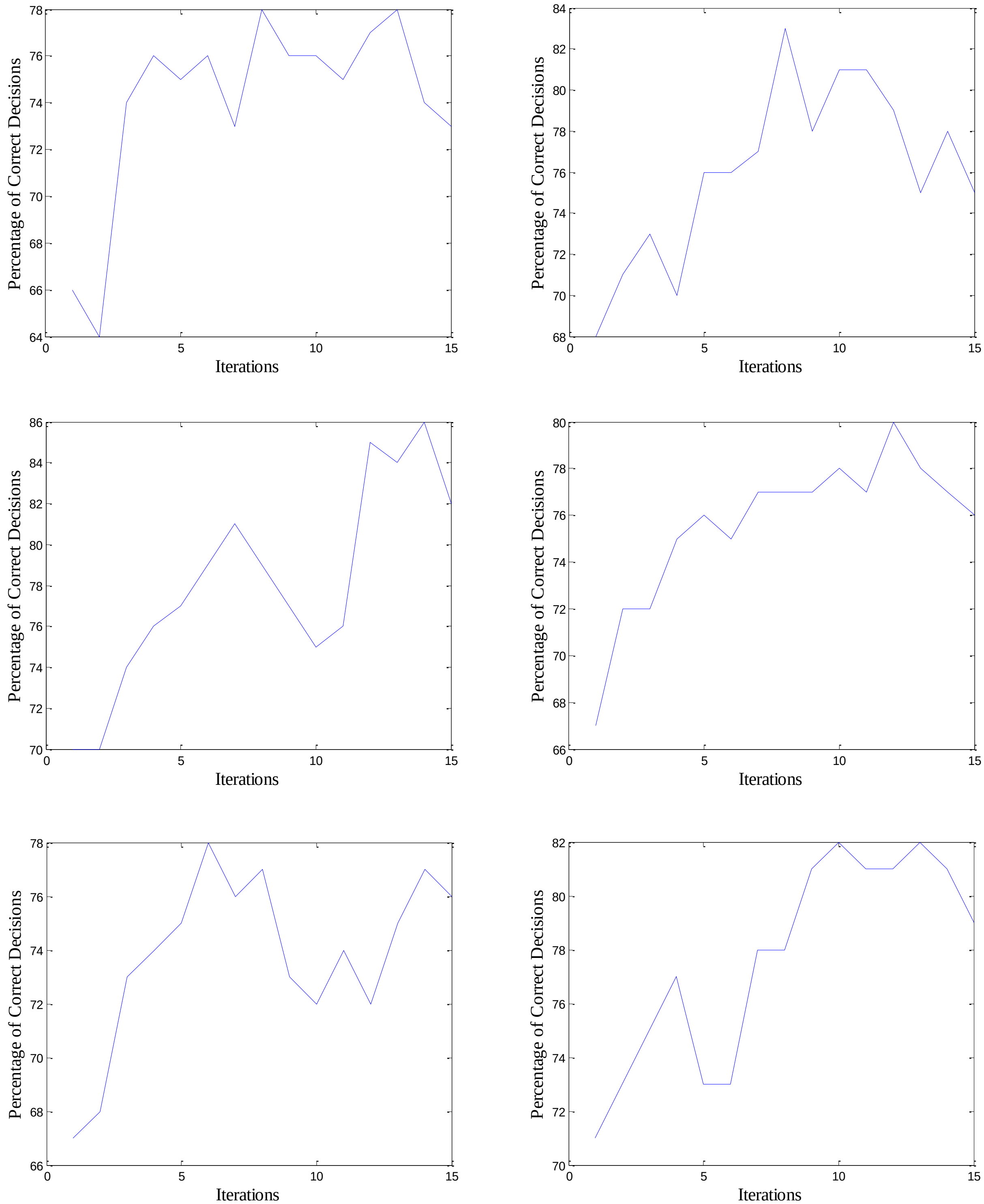

Figure 6.9. Deconvolution graphs, Trauma Case 2, Study Condition 1.

The deconvolution graphs of Figure 6.9 show a much more stable process. However, these graphs still show that stress permeated the physician's mental schemas at each moment of the trauma code, as demonstrated by the variations in the graph lines, corresponding to the most critical moments. The improvements are clear at each of the iterations. The graphs show erratic behavior due to stress and environmental noises, but, results always improved as time progressed from DTI-1 to DTI-6. All six graphs of Figure 6.9 show that the physician had a strong sense of his/her ability to position cognitive resources optimally and to remain task oriented in spite of the critical moments that were present in all iterations. These difficulties were the source of the stress encountered during the performance of the trauma procedures. The percentage of correct decisions oscillated from a low of 64% to a high of 86%, finally settling at 80% at the end of the golden hour. The last deconvolution graph, Figure 6.9d, shows the de-blurring that brought decisions from 77% down to 73% at what seemed a critical moment in the trauma. It should be noted that once again physicians de-blurred their decision-making processes and made new decisions and judgments to determine a new course of action, causing the percentage of correct decisions to go up and stabilize at 82%. Intriguingly, understanding the critical moments in trauma cases is probably one of the major considerations for the physician, making his or her mental process at those times the most valuable asset in forming their diagnostic impressions and impelling the actions of the entire trauma team.

6.2.4 Trauma Case 2 – Study Condition 2. The results of the CMs in Figure 6.10 show that at the start of trauma Case 2 decisions had slowed down, having an accuracy at both DTI 1-2 and DTI 1-3 of 76.9%. Results were improved in DTI 1-5, reaching 79.8% accuracy and regressed in DTI 1-6 to 76.9% just as at the beginning of the trauma case. These CMs have been summarized in Figure 6.11, which gives a better visualization of the entire accuracy level of this case. In the CM for DTI-5, in which the percentage dropped to 76.9%, the decrease can be attributed to a critical moment. At this very instant, as observed, the medical team must have received some critical information that blurred the physician's thought processes, causing his decision-making process to slow down or be too noisy. These are the moments where intuition and pattern recognition approaches take first seat in decision-making. However, physicians are careful about the over-use of pattern recognition because, despite the fact that often it provides the correct answer, "it occasionally fails, sometimes catastrophically" (Croskerry, 2009). The characteristics and capacities of the medical team members influence the strategies that should be examined or decisions made by the medical team while at the edge of a critical event.

Confusion Matrix
Decision Time Interval 1-2
Accuracy: 76.9%

	R	P	J	I
R	65	5	1	1
P	5	7	0	0
J	1	0	3	0
I	5	1	1	5

Confusion Matrix
Decision Time Interval 1-3
Accuracy: 76.9%

	R	P	J	I
R	68	4	0	0
P	4	8	0	0
J	0	0	4	0
I	12	0	0	0

Confusion Matrix
Decision Time Interval 1-4
Accuracy: 77.9%

	R	P	J	I
R	69	3	0	0
P	5	6	1	0
J	0	0	4	0
I	9	0	1	2

Confusion Matrix
Decision Time Interval 1-5
Accuracy: 79.8%

	R	P	J	I
R	67	3	0	2
P	5	7	0	0
J	0	0	4	0
I	5	0	2	5

Confusion Matrix
Decision Time Interval 1-6
Accuracy: 76.9%

	R	P	J	I
R	68	1	0	3
P	4	7	0	1
J	3	0	1	0
I	7	0	1	4

Figure 6.10. Confusion matrices, Trauma Case 2, Study Condition 2.

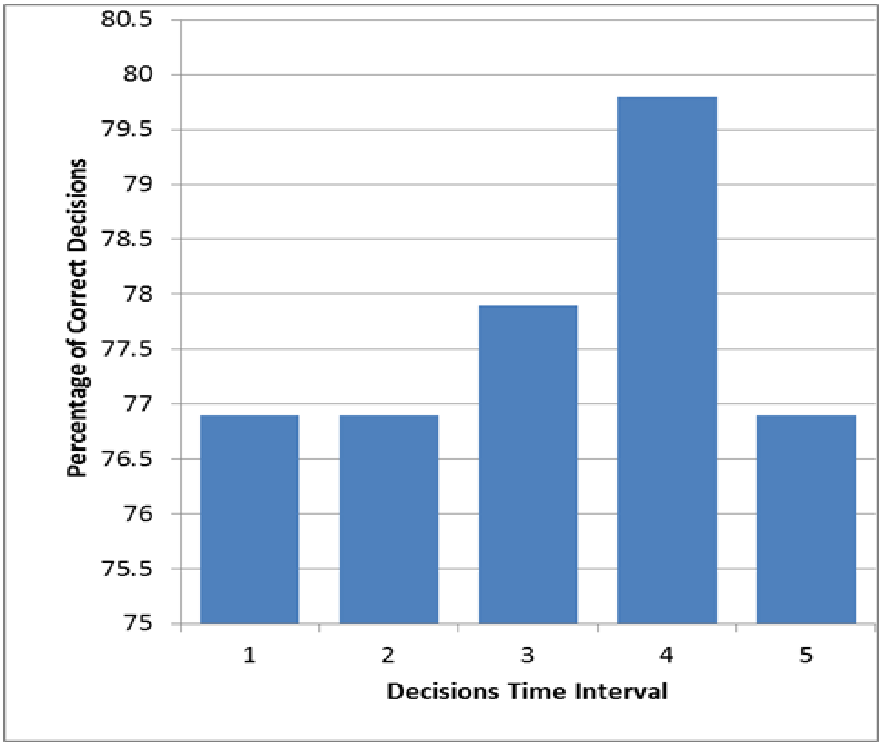

Figure 6.11. Summary confusion matrices, Trauma Case 2, Study Condition 2.

Referring to the deconvolution graphs (a through e) of Figure 6.12, each offers the possibility of a clinically plausible series of stressful moments which caused many variations. The third deconvolution graph, labeled "(d) Case 2 Study 2 DTI 1-4," shows significant variations with constant de-blurring, but always trending upward improvement, achieving 81% before settling at the level of 79%. The knowledge required to derive an appropriate decision is not quite straightforward in trauma events because sometimes the fast pace and graphical nature of the occurrence affects information retrieval. However, there is an intuitive appeal in thinking that the physician's cognitive processes can significantly affect performance and lead to strategies that result in correct decisions. The final decision for this case was to transfer the patient to trauma surgeons in the operating room.

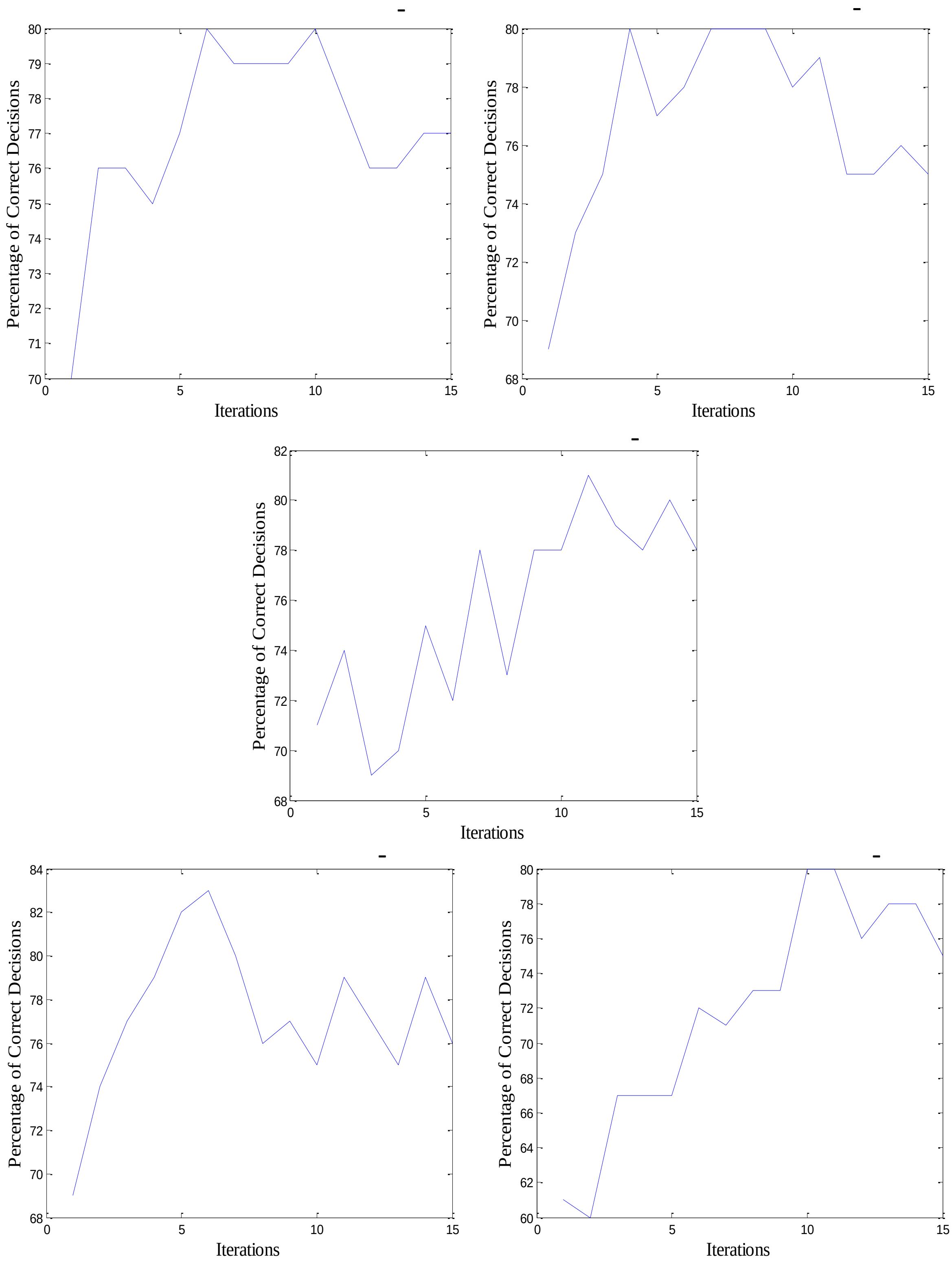

Figure 6.12. Deconvolution graphs, Trauma Case 2, Study Condition 2.

6.3 Discussion

In presenting the philosophy of science while considering the methodological questions that arise in the context of observation, Wartofsky (1968) argued that:

"Any descriptive utterance, any observation statement, is already a hypothesis; and further, that every such hypothesis already carries with it a matrix of relevance which guides us to engage in those tests of experience which we take to support or to fail to support this hypothesis."

The overarching objective of this research was to understand the manner in which physicians make decisions under the stress of trauma situations and to help explain their thought processes. Physicians must rely on more than technical skill or textbook knowledge to get through the golden hour of a trauma event. Most of the situations faced by physicians in trauma cases cannot be decided on an empirical basis alone. Ultimately, they require having an understanding of the complexities of the case, an appreciation of the fact that individual humans react to injuries and sickness in different ways, and an awareness that affective emotions can sometimes run high.

Emotional reactions often have the potential to interfere in the trauma team's abilities to function at full capacity. As was observed and perceived during the observation period, there were children, young adults, older adults and elderly patients with serious injuries and sickness that included a broken cranium, heart failure and even gunshot wounds, all of which caused the emergency department to be locked up. All these events not only affected the trauma team's ability to function, because these medical professionals are feeling human beings, themselves, but also threatened the trauma team's safety. The various systems physicians use to go about caring for the severely injured or sick are generally not the basis upon which they make decisions. Instead, good decisions are made when a good balance has been achieved between the information acquired during the trauma case and an appropriate methodology used to assess it.

Looking at the statistics arising from the deconvolution graphs gives some insight as to why, in trauma codes, no one can expect decision-making to follow any given known parameter. This combination of CM and deconvolution graph is a clear way to visually represent the decision-making process. It allows for rapid comparison of the physician's cognitive process, the reality of the case and the utilization of a number of information processing strategies in order to decide on a course of action. This type of decision-making in such environments is by its very nature complex, in spite of physicians' knowledge of the human organism's life-growth-self reproduction-self regulation-death cycle. The knowledge of this cycle tends to somewhat reduce the complexity. However, each member of the trauma team's physical experiences of the case, such as sight, touch, hearing and smell, generate a phenomenal range of decision-making assumptions that might be radically different from those of the other members. Therefore, evolvement and adaptation are truly fundamental processes within some theoretical framework in a decision-making process. As the deconvolution graph line variations illustrate, physicians are acting spontaneously and trusting each other's intuition, knowledge and judgment in making decisions under stress.

Rational decision-making in environments such as trauma centers is far from being perfectly deductively rational, and physicians admit that there is some level of uncertainty. Pattern recognition, among many other important tools, was discussed in Chapter 5 as one of the models that emergency physicians have relied upon to deal with uncertainty and make decisions about situations encountered in trauma. These emergency physicians throughout their careers increase their capacity to recognize unfamiliar situations as familiar ones, as well as increase their abilities to decide on courses of actions for present situations by recognizing patterns that fit the present emergency. It is that ability of expert physicians to see things using their vast library of knowledge that inexperienced decision-makers cannot see which makes these decision makers exceptional. But, in trauma codes, these physicians are working in teams, and as the case unfolds, the pattern recognition may change for each member of the team. Each member sees the picture from a different angle, and one "must distinguish between the continuous seeing and the dawning of an aspect" (Wittgenstein, 1953 p. 193-194). Ultimately, each team member reports their perception of what they believe to be the actual problem at hand, and this sharing contributes to changing their perceptions and de-blurring their mental models. Wittgenstein points out that different concepts touch at a single point and coincide over a stretch and "seeing-as" is altogether a process of seeing and thinking, in which ambiguity escapes the agent altogether (Wittgenstein, 1953 p. 194-195).

Croskerry (2000) recognized that an emergency physician's thinking while making clinical decisions is of the inductive type, and its nature and limitations need to be understood. It is possible for a patient to arrive at an ED with certain symptoms and be diagnosed with an ailment, and the next arriving patient with the same symptoms may be similarly diagnosed while a more serious condition may be missed. The results of the model suggest that physicians in EDs were more likely, in the face of novelty during trauma events, to incrementally revise and modify their thinking strategies in order to optimize performance and avoid the kind of situation just described. Therefore, it shows the natural adaptability and evolution of the system in creating opportunities for physicians to de-blur their thinking processes and produce a more seamless transition in structuring their decisions.

On the other hand, physicians often have only fragmentary data or information cues about trauma patients upon their arrival at a trauma center. Still they try, for the most part successfully, to arrive at an internal schema, a mental model of the problem and its solutions. It was referred to above and in the previous section as “optimizing performance” and as decisions that have “reached an optimum.” Most trauma cases are blurred with fragmented data. In this real environment of trauma medicine blurred with fragmented data, the options are almost unlimited in a given instance in which all events occur and small errors can be proved catastrophic. There is no way a physician can find an optimum or even recognize it in the face of incomplete data and such a chaotic and fast-changing environment. In such environments, measurement can never be as perfect as in textbooks. However, it can be seen from the deconvolution graphs that physicians’ mental models reach an optimum equilibrium after arising, sometimes overshooting variations on a straight line, upward or downward in a zigzag manner before either stabilizing at a certain percentage of accurate decisions or reaching the border of chaos. The paradox here is that just because one physician knows, understands or is quite well-versed in some procedure, no one can expect that it will go well when a similar situation presents itself.

Emergency physicians get into these situations often, insofar as they see a lot of patients in a given period of time, but during the following period of time, in spite of the fact that the new patient arrivals have similar conditions, they may have very different reactions to those conditions as compared to the previous patients. The deconvolution graph line variations show decision makers during trauma events incrementally and persistently revising and modifying their strategies to optimize results. This constant revision causes physicians to select and use the cognitive strategy of asking questions of knowledgeable other people, and their answers trigger metacognitive experiences about how the endeavor is faring, activating as result a deliberate, conscious memory search for an effective decision-making strategy (Flavel, 1979).

CHAPTER 7

Contributions and Future Work

7.1 Research Summary

It has been argued that *"From the standpoint of clinical reasoning, it is disconcerting that clinicians often are unaware of, or have little insight into, their thinking processes"* (Croskerry & Norman, 2008, p. s24-s29).

Emergency physicians are trained to integrate medical knowledge acquired through years of experience with everyday novel situations. The novel situations that present in a trauma center (TC) are especially likely to occur in situations that require and stimulate a lot of careful, highly conscious thinking and cognitive input together with a strong medical knowledge base for clinical decision-making. These situations help us to develop a richer understanding of trauma medical teams during the actual performance of their functions in a trauma center. The medical team itself might end up having to be characterized not only by a narrow time frame (the golden hour period) but also by the manner in which these teams respond to each event, because from one night to the next, the team might look very different in terms of who is working, how they all work together and what leadership styles exist.

The trauma medical team is in a real struggle to save someone's life, and there are medical procedure skills acquired through years of training, in addition to algorithms provided by the healthcare system, that teams have learned to apply to each trauma situation. With high levels of experience, these skills become almost automatic. But the fact remains that in this struggle for life or death, formal procedures are in most cases not sufficient or adequate to solving ambiguous and uncertain problems. It is the difference between formal structure and informal structure. Trauma centers may be considered informal as they are composed of specialists (i.e., physicians) who, for the most part, are autonomous agents of the hospital who are trying to make sense of what is going on around them. There are continuously decisions being made that feed into this trauma system. The key is to understand that these decisions are driven by intrinsic rational, intuitive, clinical judgment and sometimes political decision-making processes, and then there is the unknown and the complex that factor into the event—the uncertainty piece. Additionally, there is that crucial need to understand that in every way, in every case, real-world problems, such as living systems in trauma codes, place heavy cognitive demands on decision-makers for rapid and reflexive orienting, allowing his or her adaptive processes to take over to deal with the situation effectively.

Emergency physicians assertively demonstrate the ability to make wide-ranging and far-reaching decisions regarding sick or multiply injured human beings in short periods of time. This ability is only possible because emergency physicians know what they want to achieve and have been trained in how to focus their knowledge and experience on the event at hand to reduce the uncontrolled environment that exists at the beginning of trauma codes. Furthermore, emergency physicians have clear goals about the roles they play in acute injury care, in spite of the fact that the events to be faced will typically be unpredictable. It was observed in the TC that there is no lack of clarity about the role of an emergency physician.

These decision-makers apply the knowledge of pattern recognition frameworks that must be adapted in solving difficult problems wherein all that is available are data that cannot be easily modeled to fit the reality of the trauma. By virtue of the great number of trauma codes that show up at their door steps, emergency physicians tend to build large mental libraries of these patterns that become important to planning their actions. Thus, experience helps physicians to sharpen their thinking processes in this complex environment to avoid chaotic situations and to focus their energies on increasing the quality of patient care.

This dissertation showed that for the most part trauma physicians are dealing with voluminous and difficult-to-handle information. Thus, it is in part experience that plays an important role in trauma decision-making by facilitating the gathering of information and the development of alternative paths to problem-solving action during trauma events. Because the study was conducted at an academic environment, the role of each of these emergency physicians also included building up the cognitive style of resident physicians and ascertaining that they did not get so little information that they became bored nor so much information that it risked leading to overload and burn-out as repeated situations reached the edges of chaos. It is a complex environment in which performance criteria change with each case at hand. Therefore, this study also discussed the fact that trauma centers provide unique environments not only for interns but for more experienced physicians, as well, for learning processes in complex skill acquisition. Physicians talk about not being able to know how sick patients are when they arrive at the hospital. Because of the inherent complexity of the human body, which is compounded by serious injuries or sickness, there is not enough science currently available for physicians to determine the prognosis of patients in detail when they present at the hospital. Initially, physicians' ways of speaking do not describe the facts as they really are. However, physicians tend to see the situation as comparable to making an experiment in which only time will tell whether the decisions they have made were correct and will result in optimal outcomes for their patients.

7.2 Contributions

The model DMPUS presented here to explain the physicians' decision-making thought processes offers a way of understanding how decision-makers approach stressful problems. The most immediate result of the model was to be able to capture physicians' cognitive tasks as they play an important role in trauma events. The model was aimed at providing physicians trauma events with the capability to learn more about their own behaviors and those of the environment.

The combination of Bayesian classifier and deconvolution operators in a model was designed to mimic the information processing of decision-makers under stress. Deconvolution is widely used in many branches of science. Communication engineers, for example, use (in real time) convolution and deconvolution models extensively in communication systems such as the telephone to un-do distorted messages that have become garbled by the telephone system. This kind of study is important for high-pressure environments in which human decision-makers and high technologies coexist. This study attempted to understand the process of metacognition experiences, the understanding of physicians' cognitive processes through which strategies are developed to decide under pressure the course of action for a trauma code situation.

The resulting benefits of this study are important information about how physicians think during decision-making processes in emergency situations, which carries potential benefit to society. Aspects of complexity concepts were emphasized to provide a better understanding of critical situations often encountered by decision-makers in difficult task environments. A key contribution is that it traces the major determinants and pervasive effects of decision-making occurrences for a deeper understanding as to why expert decision-makers tend to make judgments without assigning numerical values. Physicians as decision-makers play an important role in adapting to flows of knowledge based upon fragmentary data about the system presented in trauma centers. Humans generally have the predisposition to selectively perceive information that is consistent with their existing views. A better understanding of how physicians think will most likely generate an increase in new sets of tools to assist in strategic decision-making.

One significant fact observed during this study was the explosion of information that accompanies all the technologies that trauma centers utilize in the care of trauma patients. A good portion of a physician's training has to be allocated to learning each technology apparatus, and this learning must be updated with each new apparatus that is acquired. But emergency physicians also rely heavily upon their own experience, attitudes and efficacy in trying to affect trauma outcomes. All of these factors play important roles in complex relationship with one another, leading emergency physicians to be able to predict events and trigger actions. It seems reasonable to suggest that much is known about the performance of the different medical specialties which compose a trauma center medical team. Invariably, the factors that limit the performance of each of the members of the team is not the abundance of new technologies; it is the scarcity of research that explores how physicians think in ways that will give them an edge while caring for a complex system such as a human being in trauma.

By exploiting the Bayesian classifier and the deconvolution model, and understanding the existing convolution at the onset of each trauma code, it is possible to extract the much-needed knowledge that helps physicians to focus on a potential diagnosis. The study suggests that all the medical specialties composing a trauma team are more than capable of contributing strong observations and interpretations as to how they see the situation and how to proceed to find a solution or solutions. Whether those observations are right or wrong matters not, because they are hypothesizing about the diagnosis, which, when followed by actions, returns feedback. Here physicians are engaging in cognitive strategies at work that are harder to describe or measure.

7.3 Research Limitations

As with most research, this study had some natural limitations. One of the limitations of this research is mostly related to the collection of data and the difficulties of translating physicians' thoughts into a mathematical exercise to be solved by analytical reasoning. The data collected was from a very limited number of trauma case scenarios; though the scenarios were observed in real-time, suggesting a small body of evidence. While this difficulty is common in the healthcare sciences due to the sensitive nature of patients' information and the complexity of securing IRB approval for these kinds of real-time research, its potential limitations warrant reflection. The researcher, as non-medical personnel, was limited in his knowledge of the areas of medical terminology, physiology, human anatomy and medical procedures during the observation of an ongoing-under-stress trauma code. The observation of a physician in action is always limited by the difficulty of understanding what physicians are actually doing, thinking and saying.

Physicians in trauma centers' domains have the pressures of dealing with a wide range of emotions originating from the environment, patients, patients' families and medical personnel surrounding the trauma case, which causes a highly charged emotional situation. The leading physician of a Level 1 trauma resuscitation unit knows the team he/she is working with, and, as such, communication among the team members was observed to be at times silent, with only exchanged eyes contact and suggestive glances. Because the researcher's observations could raise concerns, given that they were intended to measure and explain physicians' thinking processes in their decision-making actions, EMAP-1 was asked to review the collected data to mitigate this concern by verifying that information acquired was correct. This limitation, the difficulty of obtaining sufficient patients' medical records, precluded the ability to give more validity to the decision-making model. It only considered a few trauma cases. The narrow range of trauma cases limits the generalization and scalability of the research findings to complex adaptive systems in general. It will be useful to replicate the findings in other trauma center domains and in larger scale, to include the medical records of trauma cases that have occurred during the full period of a year. At the site of this research, more than 3,200 trauma cases are seen yearly, which provides good opportunity to further validate the model. Admittedly, this study suggests that more research needs to be carried out pertaining to decision-making processes in trauma centers using a sufficient number of cases. The healthcare industry has distinguished itself by the importance and support it gives to research in the areas of patient care and training of its medical personnel.

The second limitation pertains to the fact that the study was conducted at an academic setting. It is known that the medical profession is based upon an apprentice-like model of medical training, which is more closely observed in the academic setting. Attending physicians, while still watching over their apprentices like a hawk for the entire procedure, take a step back to allow for medical residents to take over the event in order to learn, placing an onus on the attending physician. Physicians' residents, because of their highly inquisitive minds, suffer significant pressure as well to acquire competence in many areas within a short time. Because of this academic setting, the decision-making process was sometimes distributed amongst team members in order to maximize the acquisition of clinical acumen, wisdom and good medical judgment.

7.4 Conclusions

This study begins to clarify whether a specific understanding of physicians' decision-making processes can be gained in a trauma center setting, where they are confronted with complex, stressful and rapidly changing situations. The main goal of this study was to explain physicians' decision-making processes while under the stress of treating a traumatized (injured or very sick) human being. It has explored the processes by which physicians make decisions during a trauma occurrence. Emergency and trauma physicians are performing rapid resuscitation and damage control while in the golden hour of a trauma event. The survival of a Level 1 trauma patient is given the highest priority in trauma physicians' mental processes. The study shows that the setting of trauma medicine and emergency medicine requires a different way of approaching problem solving.

More than three decades ago researchers expressed concerns that no attention had been given to the principles that underlie clinical decision making, researches in the cognitive aspects of medical decision-making had diminished, and a comprehensive theory of diagnostic thinking and problem solving was not yet available (Croskerry, 2000; Kassirer, 1976; Kassirer, 1995). Trauma and emergency medicine are not the usual models of organizations with which scholars tend to be familiar. Trauma centers' models of decision making are a mixture of formal and informal actions and the spontaneity of its participant agents who are facing novel problems and developing new ideas. Many times this study mentioned the complexity involved in each and every trauma case presented due to the human body being a complex system. Besides dealing with decisions pertaining to the immediate problem of caring for the patient injuries or sickness, physicians are also overloaded with the problem of resource allocation management. Resource allocation management is a complex problem in and of itself (Ntuen, & Park, 1995). The attending emergency physician is always aware of the case requirements and is attentive to the behavior of the system. While planning in time and space, physicians' capacities for decision-making and judgment become the dominant traits that allow them to take in the necessary information about the system and decide upon problem-solving actions.

7.5 Implications for Future Research Studies

Since 2009, the Centers for Disease Control (CDC) in the United States have been pushing strongly towards assessment, evaluation and dissolution of barriers and obstacles to conducting acute injury care research. The opportunities for research in emergency medicine abound, as the numbers of research studies conducted to date in this area have been modest. The CDC is aware that human performance measurement in complex environments such as those in trauma centers is a multifaceted problem that will require interdisciplinary research efforts. Future studies in this marginally explored field of how physicians think during decision-making processes are needed in trauma medicine.

The following suggestions are proposed for further research that will have meaningful implications and direct consequences towards understanding the decision-making processes in trauma centers. These include (a) voice recognition for gathering physicians' performance data, (b) developing a greater understanding of the role metacognition plays in physicians' communication, comprehension and problem-solving skills that helps physicians monitor their decision-making processes, (c) developing principles to help understand physicians' thinking processes to make them more visible processes, (d) the development of a conceptual framework for the minimization of cognitive errors in trauma centers and (e) replication of the study by looking at all or most trauma cases recorded for a particular trauma center for an entire year, with the collaboration of emergency physicians who have an interest in decision-making processes and in how physicians think during actual trauma codes.

It seems that by large, there is far too little rather than more-than-enough information available about physicians' thinking processes while making decisions in trauma-related events. It is difficult to discern what physicians are thinking, because it is part of their culture. Researchers studying medical doctors have brought to light the critical importance of decision-making in all disciplines of medicine and the need for collaborative efforts of multidisciplinary research teams involving physicians, engineers, medical decision-making researchers and many others (Croskerry, 2005).

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Appendix A

Level 1 and Level 2 Trauma Code Criteria

Level 1

Traumatic cardiac arrest

- Hypotension or Shock (includes systolic blood pressure < 90 mmHg)

  (It includes field intubation, inability to incubate, or assisted ventilations)

  - Glasgow Coma Scale < 8
  - Gun Shot Wound of neck or torso (chest, back, abdomen, or groin)
  - Receiving blood transfusion to maintain vital signs

Level 2

- Heart rate < 50 or > 125
- Respiratory rate < 10 or > 29
- History of hypotension but normal blood pressure at present
- Glasgow Coma Scale 8 – 10
- Stab to torso
- Gun Shot Wound to the head
- Gun Shot Wound proximal to knee or elbow
- Paralysis/suspect spinal cord injury
- Amputation proximal to wrist or ankle
- Neurovascular compromise in an extremity
- Intubation at an outside hospital
- Multisystem trauma on outside imaging
- Significant neurologic injury (Glasgow Coma Scale < 10)

- Flail chest
- Crush injury to pelvis
- Auto versus pedestrian
- Ejection from vehicle
- Two or more long bone fractures

Burn Criteria Level 1

- Any burn with Hypotension or Shock (systolic Blood Pressure < 90mmHG)
- Any burn with threatened airway patency

Burn Criteria Level 2

- 15% total body surface area
- 10% total body surface area, age < 10 or >60
- Burn patient incubated prior to arrival
- Burn patient with obvious non-thermal injuries

Appendix B

Physicians Specialties

1. Allergy
2. Anesthesiology
3. Cardiology
4. Critical care
5. Dermatology
6. Emergency Pediatrics
7. Emergency Toxicology
8. Emergency Medicine
9. Endocrinology
10. Family Medicine
11. Gastroenterology
12. Geriatrics
13. Hematology
14. Hospice Palliative Care
15. Hospitalist
16. Infectious Diseases
17. Internal Medicine
18. Neurology
19. Neurosurgery
20. OBGYN
21. OBGYN Gynecologic Oncology
22. OBGYN Maternal and Fetus Medicine
23. OBGYN Reproductive Medicine
24. Oncology Hematology
25. Oncology Radiation
26. Ophthalmology
27. Orthopedics
28. Orthopedics Hand Medicine
29. Orthopedics Sports Medicine
30. Otolaryngology
31. Otolaryngology Pediatrics
32. Pain Medicine
33. Pathology
34. Pediatrics Adolescent
35. Pediatric Cardiology
36. Pediatrics Critical Care
37. Pediatrics endocrinology
38. Pediatrics Gastroenterology
39. Pediatric Hematology
40. Pediatric Oncology
41. Pediatric Infectious Disease
42. Pediatrics Nephrology
43. Pediatrics Pulmonologist
44. Physical Medicine and Rehab
45. Psychiatry
46. Pulmonologist
47. Radiology
48. Radiology Interventional
49. Radiology Nuclear Medicine
50. Radiology Pediatric
51. Rheumatology
52. Surgery colon Recta;
53. Surgery General
54. Surgery Plastic
55. Surgery Oncological
56. Surgery Thoracic
57. Surgery Transplant
58. Surgery Vascular
59. Urology
60. Urology Pediatric
61. Women's Health

Appendix C

Details of Trauma Cases

Table C.1

Trauma Case 1 – Motorcycle Crash

Time	**Blood Pressure**	**Heart Rate**	**Respiratory Rate**	**Mechanism of Injury**	**Oxygen Level Sa O_2%**	**Pupils L/R**	**Glasgow Coma Scale**	**Physician Decision**	**Observations**
15:06	Patient arrives at ED transported by EMS - CPR in progress						3	1	Patient arrived at ED transported by EMS - CPR in progress. Trauma team places collection of vital signs on hold in order to revive patient without success. CPR continued until patient expired. Patient sent to morgue.
15:10	CPR still in progress						3	1	
15:12	Patient dies - Patient sent to morgue						0	1	
18:30	Family and Police arrived								
	Mechanism of injury was a Mopped Bike Wreck								

Table C.2

Trauma Case 2 – Gunshot Wound to Lower Extremity

Time	Blood Pressure	Heart Rate	Respiratory Rate	Mechanism of Injury	Oxygen Level Sa O_2%	Pupils L/R	Glasgow Coma Scale	Physician Decision	Observations
4:39	110/80	84	18	2	96	3/3	15	1	Gunshot wound to the lower extremity.
4:44	135/72	78	18	2	98	3/3	15	4	
5:01	131/70	89	15	2	93	3/3	15	4	
5:06	125/70	83	18	2	96	3/3	15	3	
5:37	126/89	90	20	2	93	3/3	15	2	

Table C.3

Trauma Case 3 – Multiple Gunshot Wounds

Time	Blood Pressure	Heart Rate	Respiratory Rate	Mechanism of Injury	Oxygen Level Sa O_2%	Pupils L/R	Glasgow Coma Scale	Physician Decision	Observations
15:09	122/82	68	16	2	100	2/2	15	4	Multiple gunshot wounds.
15:11	111/72	71	16	2	100	2/2	15	4	
15:25	130/64	72	16	2	100	2/2	15	1	
15:30	111/83	65	16	2	100	2/2	15	1	
15:40	111/94	67	14	2	100	2/2	15	1	
15:45	132/88	70	14	2	99	2/2	15	3	
16:00	142/69	82	20	2	99	2/2	15	2	
16:20	138/74	88	18	2	100	2/2	15	1	

Table C.4

Trauma Case 4 – Vehicle Crash

Time	Blood Pressure	Heart Rate	Respiratory Rate	Mechanism of Injury	Oxygen Level Sa O_2%	Pupils L/R	Glasgow Coma Scale	Physician Decision	Observations
21:28	132/100	106	14	1	97	3/3	15	3	Vehicle crash. Patient badly hurt. Patient was very alert but very uncooperative and screaming at medical staff.
21:33	151/89	113	24	1	98	3/3	15	3	
21:48	154/89	109	21	1	98	3/3	15	1	
21:55	144/86	104	20	1	98	3/3	15	1	
22:10	155/106	123	21	1	95	3/3	15	1	
22:20	147/110	112	21	1	98	3/3	15	4	
22:33	152/83	103	16	1	99	3/3	15	4	
22:45	149/70	111	24	1	100	3/3	15	1	
23:18	146/84	106	26	1	98	3/3	15	1	
23:01	133/60	101	20	1	98	3/3	15	2	
0:06	164/77	106	23	1	99	3/3	15	2	
0:50	135/73	91	22	1	97	3/3	15	2	
1:15	142/73	92	20	1	99	3/3	15	1	

Table C.5

Trauma Case 5 – Severe Knife Stab

Time	Blood Pressure	Heart Rate	Respiratory Rate	Mechanism of Injury	Oxygen Level Sa O_2%	Pupils L/R	Glasgow Coma Scale	Physician Decision	Observations
18:49	190/78	106	20	3	99	4/4	15	1	Patient transferred to WFU from another hospital for a higher level trauma center facility. Severe knife stab to the chest. Primary and secondary assessments conducted. Bleeding was controlled. Patient sent to the operating room for surgery after being stabilized.
18:55	160/78	110	20	3	99	4/4	15	4	
19:10	132/78	118	19	3	99	4/4	15	3	
19:14	110/81	120	16	3	99	4/4	15	3	
19:18	100/67	110	16	3	100	4/4	15	1	

Table C.6

Trauma Case 6 – Blunt Knife Stabs to Chest

Time	Blood Pressure	Heart Rate	Respiratory Rate	Mechanism of Injury	Oxygen Level Sa O_2%	Pupils L/R	Glasgow Coma Scale	Physician Decision	Observations
3:10	160/98	108	15	3	98	3/3	15	3	Chest wounds due to multiple knife stabs.
3:14	161/99	106	15	3	94	3/3	15	4	
3:18	171/109	90	16	3	98	3/3	15	4	
3:20	144/109	92	18	3	98	3/3	15	1	
3:24	139/102	107	18	3	98	3/3	15	1	
3:28	140/100	98	20	3	94	3/3	15	3	

Table C.7

Trauma Case 7 – Vehicle Crash

Time	Blood Pressure	Heart Rate	Respiratory Rate	Mechanism of Injury	Oxygen Level Sa O_2%	Pupils L/R	Glasgow Coma Scale	Physician Decision	Observations
3:09	103/85	91	20	1	99	4/4	8	3	Patient involved in a vehicle crash. After arrival at ED, patient was stabilized, X-rays, and sent to CT-scan laboratory on the stretcher in which the patient arrived. Patient mildly agitated.
3:15	103/85	94	16	1	98	4/4	8	3	
3:20	123/87	91	20	1	98	4/4	8	4	
3:25	126/65	94	16	1	94	4/4	9	4	
3:40	126/62	94	16	1	99	4/4	9	4	
3:50	135/63	98	16	1	108	4/4	10	1	
3:58	145/70	101	20	1	100	4/4	10	1	
4:01	98/93	82	20	1	100	4/4	10	1	
4:03	98/93	69	17	1	100	4/4	9	2	
4:07	107/42	74	15	1	95	4/4	15	2	
4:12	101/43	64	16	1	95	4/4	15	1	
4:17	95/46	80	15	1	85	4/4	15	1	

Table C.8

Trauma Case 8 – Vehicle Crash

Time	Blood Pressure	Heart Rate	Respiratory Rate	Mechanism of Injury	Oxygen Level Sa O_2%	Pupils L/R	Glasgow Coma Scale	Physician Decision	Observations
16:00	142/68	124	24	1	96	2/2	9	1	Patient brought in by EMS due to vehicle crash. Possible spine problems. Primary and secondary assessments at bedside conducted. X-ray and CT-scan were ordered by the trauma team. Patient arrived intubated. Patient was extubated and tolerated procedure well.
16:12	130/76	101	19	1	100	2/2	9	1	
16:20	133/102	112	13	1	98	2/2	9	1	
16:27	133/74	101	13	1	100	2/2	9	3	
16:29	145/70	101	15	1	98	2/2	9	3	
16:33	121/72	105	13	1	99	2/2	9	4	
16:36	139/88	100	13	1	99	2/2	8	4	
16:40	111/72	93	16	1	100	2/2	8	3	
16:44	115/70	79	16	1	99	2/2	15	3	
16:49	114/71	80	18	1	100	2/2	15	2	
17:00	100/61	78	18	1	100	2/2	15	3	
17:23	111/62	80	20	1	98	2/2	15	3	
17:31	108/71	91	20	1	99	2/2	15	4	

Table C.9

Trauma Case 9- Gunshot Wound

Time	**Blood Pressure**	**Heart Rate**	**Respiratory Rate**	**Mechanism of Injury**	**Oxygen Level Sa O_2%**	**Pupils L/R**	**Glasgow Coma Scale**	**Physician Decision**	**Observations**
2:05	148/98	88	20	2	93		11	3	Gun Shot Wound
2:09	160/56	85	20	2	95		11	1	
2:12	139/62	86	16	2	90		12	1	
2:18	132/87	88	16	2	95		11	1	
2:20	140/73	87	20	2	96		11	3	
2:50	124/82	70	18	2	94		12	4	
3:00	154/78	70	17	2	95		13	4	
3:05	152/98	89	18	2	95		15	3	
3:09	124/71	88	18	2	94		15	3	
3:15	142/91	86	17	2	94		15	4	
3:28	135/77	88	18	2	95		15	2	

Table C.10

Trauma Case 10 –Severely Burned

Time	**Blood Pressure**	**Heart Rate**	**Respiratory Rate**	**Mechanism of Injury**	**Oxygen Level Sa O_2%**	**Pupils L/R**	**Glasgow Coma Scale**	**Physician Decision**	**Observations**
19:10	130/70	97	18	4	96	3/3	15	3	Burned Patient. Patient was working on equipment that caught fire, severely burned patient. Patient was first seen by another hospital and then transferred to a higher level trauma center at WFU. Primary and secondary assessments performed again on patient.
19:15	123/75	101	13	4	96	3/3	15	4	
19:20	125/73	101	15	4	96	3/3	15	4	
19:23	116/73	99	18	4	96	3/3	15	3	
19:28	120/79	98	18	4	97	3/3	15	1	
19:38	126/79	98	17	4	97	3/3	15	3	

Table C.11

Trauma Case 11 – Blunt Chest Wounds

Time	Blood Pressure	Heart Rate	Respiratory Rate	Mechanism of Injury	Oxygen Level Sa O_2%	Pupils L/R	Glasgow Coma Scale	Physician Decision	Observations
3:35	150/95	102	20	4	96	3/3	15	3	Patient transferred from a lower level trauma center for higher care. Trauma team suturing wounds. Chest wounds.
3:45	126/100	93	16	4	96	3/3	15	1	
4:00	156/80	96	16	4	100	3/3	15	1	
4:06	147/82	93	16	4	98	3/3	15	1	
4:10	129/66	82	16	4	98	3/3	15	4	
4:16	130/87	85	16	4	99	3/3	15	3	

Table C.12

Trauma Case 12 – Vehicle Crash

Time	Blood Pressure	Heart Rate	Respiratory Rate	Mechanism of Injury	Oxygen Level Sa O_2%	Pupils L/R	Glasgow Coma Scale	Physician Decision	Observations
21:51	122/48	106	16	1	96	3/3	15	1	Trauma team at bedside conducted primary and secondary assessments. The mechanism of injury was a vehicle crash.
21:52	109/90	104	17	1	96	3/3	15	1	
21:58	121/70	101	18	1	96	3/3	15	3	
22:05	124/54	107	19	1	97	3/3	15	3	
22:09	124/79	106	20	1	97	3/3	15	3	
22:10	130/74	98	16	1	100	3/3	15	4	
22:19	133/73	105	20	1	98	3/3	15	3	

Table C.13

Trauma Case 13 – Vehicle Crash

Time	Blood Pressure	Heart Rate	Respiratory Rate	Mechanism of Injury	Oxygen Level Sa O_2%	Pupils L/R	Glasgow Coma Scale	Physician Decision	Observations
22:32	134/102	102	19	1	94	3/3	8	1	Patient arrived by EMS. Trauma team in place at bedside. Primary and secondary assessments conducted. Patient was stabilized.
22:37	140/83	103	16	1	96	3/3	8	4	
22:43	140/90	102	14	1	96	3/3	9	3	
22:48	138/87	92	13	1	98	3/3	9	3	
22:53	140/83	98	19	1	97	3/3	10	3	
22:56	132/84	95	20	1	98	3/3	12	4	
22:59	142/92	106	16	1	98	3/3	12	3	
23:01	130/100	98	18	1	95	3/3	12	2	
23:10	124/79	94	15	1	95	3/3	12	2	
23:20	133/76	89	13	1	96	3/3	12	1	
23:25	135/89	93	20	1	95	3/3	13	1	
23:30	111/89	93	22	1	94	3/3	15	1	
23:40	122/81	93	18	1	95	3/3	15	3	
23:46	130/77	80	22	1	97	3/3	15	3	

Table C.14

Trauma Case 14 – Vehicle Crash

Time	Blood Pressure	Heart Rate	Respiratory Rate	Mechanism of Injury	Oxygen Level $Sa\ O_2\%$	Pupils L/R	Glasgow Coma Scale	Physician Decision	Observations
7:44								1	Patient arrived at ED via EMS with CPR in progress. All Vital Signs collection was placed on hold in order to revive patient. Trauma team had no success in reviving patient. Patient expired at 07:54 AM, ten minutes after arrival in trauma center.
7:45								1	
7:46								1	
7:47								1	
7:48								1	
7:49								1	
7:50								1	
7:51								1	
7:52								1	
7:53								1	
7:54	0	0	0	1	0	5	0	1	