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Decision making in trauma centers from the standpoint of complex adaptive systems

Policarpo C. deMattos Daniel M. Miller Eui H. Park

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Policarpo C. deMattos
Department of Industrial Systems Engineering, North Carolina A&T State University, Greensboro, North Carolina, USA
Daniel M. Miller
Department of Leadership Studies, North Carolina A&T State University, Greensboro, North Carolina, USA, and
Eui H. Park
Department of Industrial Systems Engineering, North Carolina A&T State University, Greensboro, North Carolina, USA

Abstract

Purpose – This paper aims to examine complex clinical decision-making processes in trauma center units of hospitals in terms of the immediate impact of complexity on the medical team involved in the trauma event.

Design/methodology/approach – It is proposed to develop a model of decision-making processes in trauma events that uses a Bayesian classifier model with convolution and deconvolution operators to study real-time observed trauma data for the decision-making process under tremendous stress. The objective is to explore and explain physicians' decision-making processes under stress and time constraints during actual trauma events from the perspective of complexity.

Findings – Because physicians have blurred information and cues that are tainted by random environmental noise during injury-related events, they must de-blur (de-convolute) the collected data to find a best approximation of the real data for decision-making processes.

Research limitations/implications – The data collection and analysis is innovative and the permission to access raw audio and video data from an active trauma center will differentiate this study from similar studies that rely on simulations, self report and case study approaches.

Practical implications – Clinical decision makers in trauma centers are placed in situations that are increasingly complex, making decision-making and problem-solving processes multifaceted.

Originality/value – The science of complex adaptive systems, together with human judgment theories, provide important concepts and tools for responding to the challenges of healthcare this century and beyond.

Keywords Decision making, Complexity theory, Medical care, Stress, Injuries, Doctors

Paper type Conceptual paper

1. Introduction

The background and significance of the study, the research question, and a brief review of the literature is provided in this paper. Covered also are the main topics of trauma centers within emergency medicine, some aspects of the theories of complex adaptive systems (CAS), and human judgment in decision making (JDM) as applied to clinical decision making in trauma centers. An attempt is made to carve out a narrow but relatively deep slice, trading comprehensiveness for a chance to get at some of the

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more general principles in the areas of JDM and CAS. The paper presents an examination of the complexity that exists in trauma center systems.

2. Complex adaptive system and trauma centers

The view of the physical universe has been for centuries dominated by Newtonian science in fields such as biology, chemistry, computer science, economics, physics, social sciences, and engineering design. This has been referred to as "the machine metaphor" in which "any entity could be understood by reducing it to its smaller and smaller parts" (Hoffman, 2000) and ignoring the relationships between those parts. Once each of its separate parts was understood, the entity's current state outlined, and the rules that made it functional were understood, its future behavior could be predicted without much difficulty. In essence, we have been dealing with a deterministic system because if you know the entity's initial condition, no doubt you will know the outcome. This reductionism conceptual framework worked well during the industrial revolution, promoting "capacity for mass production and dependence upon predictable environments" (Hoffman, 2000). In complexity science, this conceptual framework is no longer sufficient to help us understand the complexity of the living systems with all their smallest parts interacting with each other.

Many social systems are too complex to predict accurately their future and CAS offers a framework for understanding these systems, including the complexities of trauma center activities. CAS is a diverse alignment of connected yet independent agents that focus on systems of many interdependent components with these agents having the ability to interact, adapt, or learn by creating models to anticipate the future, in which reality can be illuminated. These systems systematically exhibit patterns that can help humankind cope with an increasingly complex and unpredictable future and the notion that trauma situations can be strategically engineered such that they may be understood by the CAS theory. The science of CAS provides important concepts and tools for responding to the challenges of healthcare this century and beyond. However, "models of complex adaptive systems are hard to formulate" (Holland, 1992). Some of the most important characteristics of CAS may be summarized as a large collection of diverse parts or individualized agents interconnected in a hierarchical manner; localized interactions among these agents; order, innovation, progress can emerge naturally without the need to be imposed centrally or from outside; capacity for self-organization, and capacity to modify internal models (Levin, 2003; Goldstone and Sakamoto, 2003; Eidelson, 1997; Plsek and Greenhalgh, 2001; Gell-Mann, 1994).

To the extent that the World Health Organization and the American College of Surgeons consider trauma a disease, today's multiple trauma patients have more complex boundaries: "they are the result of the interplay of genetic predisposition, environmental context, and lifestyle choices" (Plsek and Greenhalgh, 2001). With this view of today's environment, trauma physicians are placed in situations that are increasingly complex. This complexity is the results of the inter-relationship, inter-action, and inter-connectivity of elements within a system and between a system and its environment (Chan, 2001; Gell-Mann, 1996). Figure 1 illustrates a conceptual framework for trauma event's diagnostic course of action with all of its complexity, represented by the intertwining helix depiction of the types of decisions the medical team faces.

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

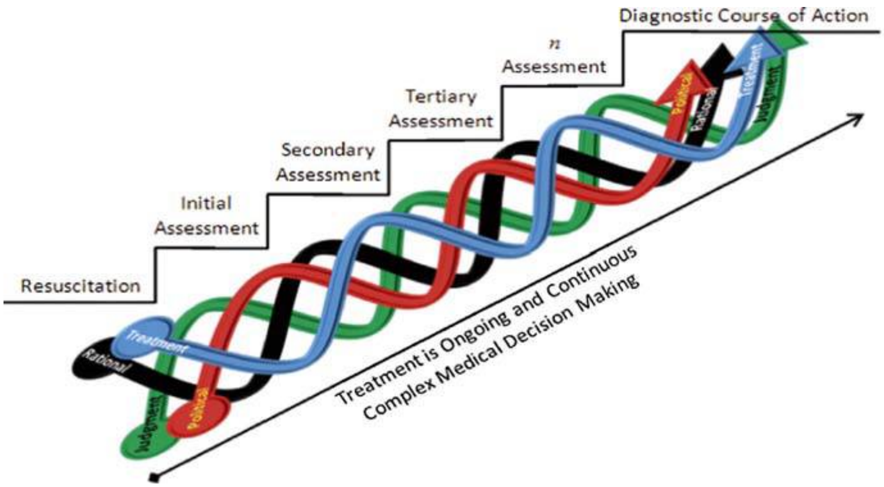

Figure 1.
Conceptual framework for diagnostic course of action

decision makers understand non-linear relationships within and impacting complex systems. The increasing complexity of the trauma center systems makes clinical decision-making and problem-solving processes complex, requiring vital solutions during critical periods. In the context of agent-based modeling, decision makers (agents) scan their environments and develop schema representing interpretive and action rules to engage members in distinguishing what is essential before decisive action takes place. Trauma centers' events are driven by whomever is in charge with a "holistic thinking" methodology, which are "a natural fit with environments of high complexity and uncertainty" (Coffey, 2010). Because trauma centers are highly variable medical domains, it is necessary to have a good protocol in place and a superior leader who prioritizes with a genuine and sustained interest in organization performance and who is capable of integrating, over time, all events faced by the medical team.

To understand a trauma center's increasing turbulent and rapidly changing context requires appreciating its inherent holistic nature, an understanding of each of its components, and a visualization of how each part is integrated into the whole framework. The fundamental characteristics of CAS, which are discussed in the following sections, may therefore provide trauma team members (i.e. physicians, nurses, 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, affecting the success or failure of the team as measured by the outcome of life or death of the injured patient. The current state of a trauma patient (living system) is no predictor of what that patient will be in any given time because small disturbances in complex systems can produce exponentially significant different behaviors – the "Butterfly Effect" (Lorenz, 1972). The intricate interrelationships of elements within a trauma center (complex adaptive system) give rise to multiple chains of dependencies among clinicians (agents). Changes happen in the context of this intricate intertwining of inter-relationships and inter-actions at all levels within trauma centers. The application of JDM in the clinical decision making process helps recognize the interactions between all agents. Finally, the paper assesses the system's behavior using Bayesian techniques, Convolution and Deconvolution models, and utilizes space-time compression concept to clinical judgment in decision-making for a focused integrative analysis.

Trauma physicians' are well trained in diagnostic reasoning and rely heavily on research of other scientists to create structures for learning or to adapt to severe, stressful conditions of a trauma center. When physicians are confronted by multiple trauma patients, the diagnostic reasoning and linear rationality relationships can become less reliable as the situation may cause lack of situation awareness and poor sense-making in response to unpredictable and stressful environments. Additionally, the rapid expansion of medical knowledge leads to the daunting but crucial task for the physician to distill which information is valid and applicable to their particular individual trauma patients, and how it is to be best applied as means to avoid active failures.

Medical knowledge is expanding rapidly. To 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 of ever and fast expanding worldwide library of biotechnology and medicine. Medical decision making techniques help deciding whether and how the results of a study apply to a physician's patients. Evaluating the validity of medical information becomes crucial at arriving to a proper diagnosis or a diagnostic course of action during trauma events. From the implications of complexity, and the way physicians' adaptation to stress are viewed emerge the question 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 the various components of the clinical decision making task while in the golden hour's critical moments?

3. Content analysis and trauma literature

The application of the theories of complex adaptive systems, intuition, and human judgment in trauma centers of hospitals, which receive large range of trauma injuries. These injuries may be categorized as penetration trauma (e.g. gunshot, knife wound) and multi-system trauma, such as car crashes, falls, and other events. Trauma is the leading cause of death in patients aged 15 to 44 years in Western countries (Spijkers *et al.*, 2010). 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 *et al.*, 2010). Complications are at least inconvenient for the patient or can lead to more severe negative consequences such as, prolonged hospital stays, increased costs of medical care, and mortality.

Trauma patients are those who have sustained a physical injury. Surgeons in particular used the term "trauma" to refer to the physical injury, whereas other medical providers prefer the term "injury." Patients arriving at trauma centers are placed in the hands of highly specialized teams comprising of 15 to 20 people, including physicians surgeons, physicians residents, registered nurses, medical students, and technicians. Most hospital providers of trauma centers have three separate teams to ensure 24-hour coverage. Trauma injury is serious, and injury deaths worldwide place a significant burden in the world's work force as it impacts mostly the youngest and potentially most economically productive members of the global workforce. The World Health Organization estimates trauma injury as 12 percent of the world's burden of disease.

Injuries have a substantial impact on the lives of all American residents, their families, communities, and society. According to the Center for Disease Control (CDC), during the year of 2005 a total of 173,753 injuries related deaths occurred and in 2006 and estimated 29,821,159 persons with nonfatal injuries were treated in the US hospital emergency departments (Besser, 2009). The consequences of these injuries can be extensive and wide ranging. They can be physical, emotional, and financial crippling, and in the case of disabling injuries, the consequences are enduring. In the US alone, more than 1.7 million individuals incurred intentional and unintentional traumatic brain injury and almost 90 percent 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 damages, fire loss, and employer costs, among others (Fildes, 2008). By 2020, it is estimated that more than one in ten people will die from injuries (Fildes, 2008). However, almost 50 percent of the worlds' trauma related mortality occurs in young people aged 15 to 44-years-old, the most economical and productive members of the global population.

The importance of research in efficiently generating medical evidence and diminishing the problem of injuries has been described before. 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 organizations and groups involved in the care of trauma need to become more united and develop common messages with which they could collectively advocate. WHO's report emphasized a preliminary set of key messages (Shiffman, 2009) that included that every injured person should have:

- basic life saving care in the field and rapid transport to a site of definitive care;
- access to adequate, timely, essential care that is life or limb saving at hospitals and clinics; and
- access to adequate, essential rehabilitation services for those with disabilities resulting from their injuries.

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.

To be effective, trauma center teams should discover their members' unarticulated needs, innovate, and develop frequently, timely, accurate, and problem solving communication skills effectively to translate and disseminate information. This research shows that, as the focus of clinical decision-making research changes, it positively influences the quality of decisions and outcomes of the trauma center medical teams. The ultimate goal remains to speed novel ideas and improved clinical decision-making schemata to trauma centers throughout the world. Injuries similar to other disease processes involve interactions among hosts, agent, and environment with lasting physical and psychological impact. Because of the diverse health effects associated with injuries, positive outcomes are often dependent on the availability of a continuum of multidisciplinary research to provide patients with quality care, better life expectancy, functional status, and greater satisfaction. Moreover, until government and the community come up with plausible solutions for the trauma disease, patients are receiving optimal care at the many trauma centers throughout the world. 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, 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 establishing a trauma center criteria for the care of the injured (Fildes, 2008).

4. Perceptual richness in complex adaptive systems

There are a number of contemporary trends that seem to be contributing to the growth of interest in complex systems theories trends, and have been attracting so much attention. One researcher of complexity theory, Cohen (1999), has provided at least three instances of this interest. 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 to the fact that prices for sensing, processing, transmission, storage, and retrieval of information is 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 to the integration of the European countries and the mergers of mega-size corporations to the micro-level events such as 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 a 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."

5. Trauma centers as complex adaptive systems

We have seen that complexity results from the inter-relationship, inter-action, and inter-connectivity of elements within a system and between a system and its environment. Gell-Mann explains: "complexity 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). Complexity has to do with interactions in the system, through which something new emerges. Complex systems are systems that comprise many interacting parts with 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, 2008). However, it is the collective actions of vast numbers of elements that give rise to the complex, hard-to-predict, and changing patterns of behavior that has fascinated researchers (Mitchell, 2009). In a way, complexity science can be seen as a form for investigating the properties and behavior of the dynamics of non-linear systems. Indeed, complexity may be understood as a stage in the evolutionary process of any dynamic system (Miller, 1999). The changes occurring in many processes can be explicated in terms of how complex adaptive systems organize, develop, and evolve.

The study of complex adaptive systems (CAS) these last few years have fascinated scientist from every corner of the world and across many disciplines in the physical and natural sciences: evolutionary biology, genetics, artificial intelligence, psychology, and mathematics are but a few. Murray Gell-Mann, the Nobel laureate in physics in 1969, is among those scientists who has these last few years become fascinated with CAS and one who sees the potential for a much broader impact of complexity theory in all aspects of humankind 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). The researcher, (Levin, S.) stated in his article that it is easy to find books that discuss with varying degrees the specifics of certain systems as CAS. However, it is another matter 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). In a later study, however, Levin attempted a fairly general and flexible definition by using three properties (Levin, 2003):

(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.

As another researcher put it, complex adaptive system actively searches for regularities, by acquiring information about its environment and its own interaction with that environment, identifying regularities in that information, then compresses the acquired information into an organized collection of schemata or models, then takes 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. Complex implies diversity – the Santa Fe Institute researchers identified several definitions, from entropy, mutual information, and fractal dimension, to effective complexity, thermodynamic depth, spatial computational complexity, etc. – a wide variety of elements.

Adaptive suggests the capacity to alter or change the ability to learn from experience. Another study also attempted a fairly general definition by stating "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). A more complete definition of CAS can be stated as a "collection of individual agents with the 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 and Greenhalgh, 2001). However, it is obvious by now that the form of a complex adaptive system reflects the ways in which its elements interact with one another.

Some researchers of CAS (Chan, 2001; Mitchell, 2009; Gell-Mann, 1994; Holland, 1992; Nugus, 2010) just to name a few have begun to extract common kernel from all these systems, that is, each of these systems involve a similar "evolving structure" and, furthermore, in seeking to adapt to changing circumstances, these systems have demonstrated that their parts can be thought of as developing rules that anticipate the consequences of certain responses.

J.H. Holland, a Professor of Psychology and Computer Science at the Santa Fe Institute for Complexity Science, and also the creator of Genetic Algorithm, stated that the ability of the elements in CAS to adapt or learn is the pivotal characteristic of complex adaptive systems. They are adaptive, not only because they respond to changes in their surroundings, but also because they influence their environments to conform to their current organizational state (Holland, 1992). This is the evolution aspect of complex systems. There are systems of crucial interest to human kind that have so far defied accurate simulation by computer. Economies, ecologies, immune systems, healthcare system, and the brain all exhibit complexities that block broadly based attempts at comprehension. "Models of this complex adaptive system are hard to formulate" (Holland, 1992). Besides evolution, these complex systems seem to share two other characteristics: aggregate behavior and anticipation. It is the aggregate behavior that researchers seek to understand and modify. Therefore, it is imperative to understand how the aggregate behavior emerges from the interactions of the parts of the system (Holland, 1992).

The assertion is made here that a trauma center should be dealt with as complex adaptive systems because it comprises 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 entire trauma center system exhibits behaviors that are different from those of the parts, but just how complex is a complex system? How do we measure complexity? "These are key questions, but they have not yet been answered to anyone's satisfaction and remained the source of many scientific arguments in the field" (Mitchell, 2009).

A review of the literature shows that the clinical decision making process for most specific medical procedures is 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 moments of multi-trauma-injury patients. The medical team's protocols and algorithm do not factor in the human judgment of the clinical decision making processes. Complex situations bring massive amounts of difficult information that decision-makers come across and even stumble upon to help them make their decisions, requiring "decisions typically made though gut feeling or intuition" (Yolles, 2006).

6. Intuition and medical judgment in clinical decision making

The literature of intuition and judgment in decision making has immensely grown these last few years, encompassing a great deal of both theoretical issues and interdisciplinary applications. As discussed by Connolly *et al.* (2000), although intuition and judgment disciplines are as old as civilization, they have been studied in a scientific, empirical way these last few decades. And, the fact that we are now studying these disciplines with decision-making in a scientific manner is an exciting discovery in and of itself (Connolly *et al.*, 2000). 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 we are visiting is shrouded in a mist of dim uncertainty" (Gigerenzer, 2007). However, intuitive judgment is bounded by "gut feelings" during attempts to avoid misses and false alarms, which undisputedly is "the intelligence of the unconscious" on practical issues of real-time decision-making.

At the arrival of an injured patient in a trauma center, protocols to obey and algorithms to be followed take precedence in the process of caring and even resuscitating the injured patient. Whist in the midst of the trauma situation, the logic of mathematical models, evolutionary biology, and even a myriad of engineered technology help find a plausible solution for saving the patient's life. On the other hand, repeatedly, the things rarely observed are the judgment, the intuition, and the gut feelings of the leading medical team that bring about the successful outcome of the event. The logical scientific reasoning helps to bring the event to fruition; but not always because of the logic of scientific knowledge and technology, which is applied in the case. However, it is the medical team's unconscious choices and decisions in contradiction to one's deliberate reasoning that makes it all possible. Sometimes we are not even aware of making these choices or decisions. "The unconscious parts of the 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, seems to go beyond the technicality as if good expert clinical judgment is an intuitive nature. It is irrefutable that science makes up a substantial part of medical decision-making processes, but as the famous physician Atul Gawande pointed out in his book, it is "also habit, intuition, and sometimes plain old guessing" (Gawande, 2002).

7. Knowledge gathering in challenging work environments

Researchers of intuition and human judgment, such as Gary Klein, might say that, during a serious multiple trauma, the physician "had stumbled onto the phenomena of intuition" as he made the right human judgment decision (Klein, 2004). "Intuition is holistic and can reveal a remarkable degree of accuracy if the learning context has provided representative and valid feedback" (Plessner *et al.*, 2008). Atul Gwande, a medical doctor, tells us in his book true medical cases, one of which is "The Case of the Red Leg", in which he saved the life of a young woman with "an extremely rare and horrendously lethal type of infection known as necrotizing fasciitis (fa-she-EYE-tiss)." As the case is unfolded in the pages of the book, it immediately comes to mind the powerful forces of intuitive judgment in that environment of a trauma center characterized by substantial unpredictability and always constrained by time and little information. Experiments demonstrate the amazing fact that less time, and less information can improve decision making (Gigerenzer, 2007). "The output of intuition is a feeling, for instance, the feeling of liking the entity or a feeling of risk" (Betsch, 2009) because feelings are powerful means of communication. Trauma systems, amalgams of medical personnel from different specialties, rely on the combination of this sort for human judgments, which can be buttressed by solid information forthcoming from the medical team as represented by Figure 2, which depicts the

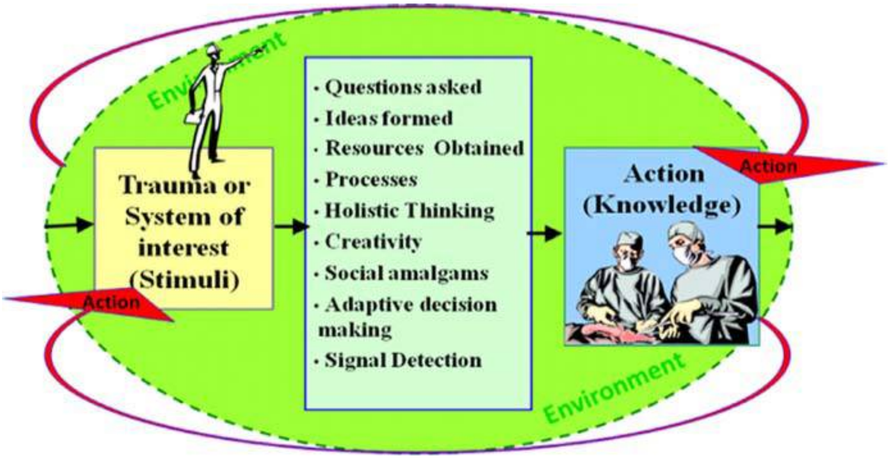

Figure 2.
Knowledge-in-action

complex spatial arrangement of "knowledge-in-action." If the initial intuition is proven correct, the physician expectancies should match the events with the solid knowledge-base of the assembled multidisciplinary team.

Conversely, if intuition fails the physician, he/she can quickly use the team's vast stored knowledge to notice the existent problem, take corrective action, and provide representative and valid feedback on the event. The intuition feeling is a risk that is worth taking.

Expert medical personnel are capable of attending and extracting the most relevant cues in the trauma environment and can avoid attending to distracting or irrelevant cues that the learning context provided as feedback. In "The Case of the Red Leg," the physician's perceptual skills included many of the intuitive decision making processes of pattern recognition, the use of extraction of cues, visual search strategies, and signal detection.

For many complex clinical decisions, all the data in the world cannot surpass the lifetime's worth of experience that informs one's gut feeling, instinct, or intuition (Matzler *et al.*, 2007). Researchers have struggled to understand human judgment and intuition by building mathematical models of how each item of information influenced the clinical decision maker's overall judgments. The consistent and amazing finding of these researchers was that ridiculously simple mathematical models did as well as in study after study as sophisticated, experienced clinicians; and the explanation for, and implications of, these results are still hotly debated (Connolly *et al.*, 2000). "Intuition is an essential, powerful, and practical tool," that has been defined as "the way we translate our experience into action" (Klein, 2004).

8. Capturing the environment

The basic premise of this paper lies in understanding the complexity trauma physicians' decision-making processes under stress. One way of exploring this is through theories of complex adaptive systems together with intuitive human judgment theories, which shall provide important concepts and tools for explicating decisions that are ill-defined, fuzzy, and uncertain. Clinical decision makers in trauma centers are placed in situations that are increasingly complex, making decision-making and problem-solving processes multifaceted. In complex situations the information that decision makers have to deal with and make sense of in order to help them make their decisions is often massive and difficult to handle, "resulting in decisions which are typically made through gut feeling or intuition" (Yolles, 2006). But, as Weick succinctly summarizes, it is impossible to make sense of a situation without an identity and "identities are constituted out of the process of interaction" (Weick, 1995), which is one of the characteristics of complex adaptive systems.

The intended model of decision-making processes in trauma events uses Bayesian Classifier with Convolution and Deconvolution operations to study real-time observed trauma data for decision-making process under tremendous stress. "Convolution is by far the most important operation that describes the behavior of a dynamical system" (Mendel, 1990) and 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, they must de-blur (de-convolute) the observed data to find the best approximation of the real data. Convolution is used to add some stress on the physicians' rational decision-making processes to simulate the conditions of the environment. Deconvolution is used to clear out the extraneous noises to allow physicians to have a clearer picture of the diagnosis or diagnostic course of action.

9. 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 framework for almost all conceived 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. 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.

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 in Figure 3, the region within the boundaries Judgment (J), 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.

From Figure 4 below entitled "Framework for Clinical Decision Making in Trauma Centers," one might observe that the Diagnostic Course of Action may be the end of the mapping, but diagnosis and treatment is throughout the process. This is throughout these interventions or these constants in the framework, which maybe imagined as a helix. This helix has been drawn as a quadruple helix of medical judgment, political, rational, and treatment, leading to the diagnostic course of action. One could imagine that there is this ongoing helix, and as one moves from the initial and secondary assessments to the diagnostic course of action, it creates a double helix the same way the model of DNA is represented, by curving around in a helix format. Hence, it is three-dimensional at this conjecture, and it sort of represents that there's an ongoing-ness of the process in a constant direction that is being infused. There is also

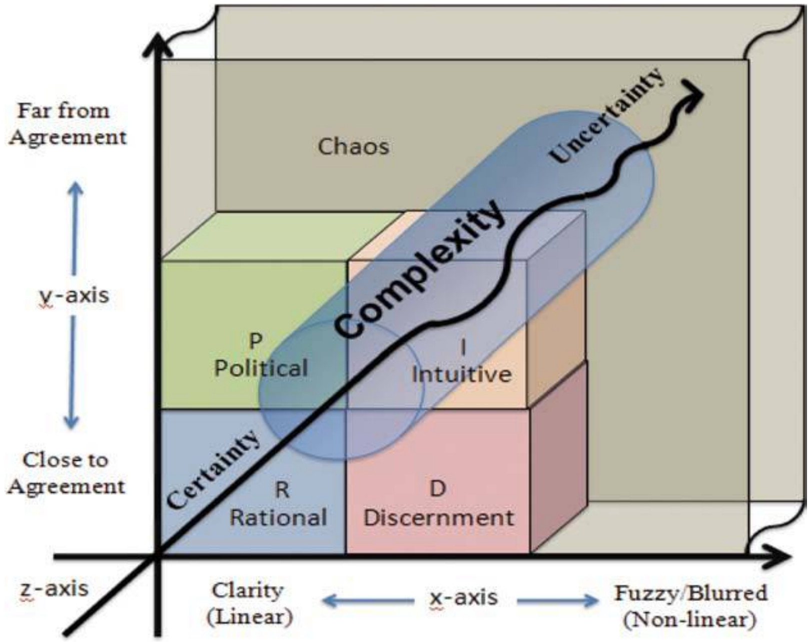

Figure 3.
Concepts and fields of complexity

Source: Stacey (2000)

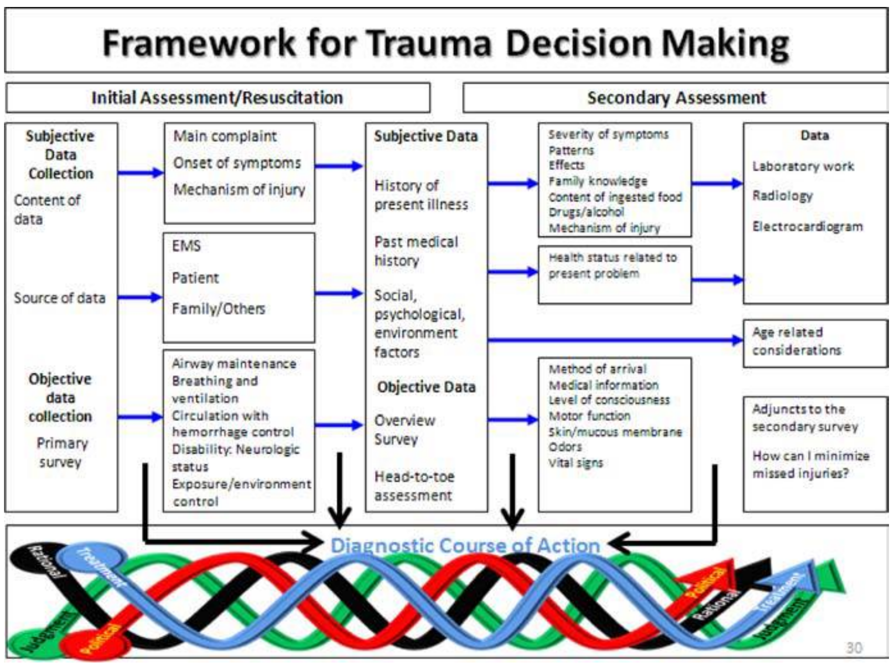

Figure 4.
Framework for decision-making in trauma centers

the conceptualizing of the treatments or behaviors, meaning intervening behaviors, which the medical team is doing.

This is all about perception. This is about perception and data collection, and how people perceive the ongoing event and collecting information and, simultaneously, information processing. It can be considered the ultimate treatment; but then there are behaviors. This can be conceptualized as a part of the information data-processing scheme, as a plot from left to right. It is the initial contact with data, in which it finds that there's political, rational, and judgment decision-making. Moreover, as Figure 4 shows, there are people perceiving data as well as handling data. Therefore, the data are treated and handled in three ways. This is certainly an interesting form of uncertainty, which 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 the rational, intuitional, and political decision making as the event unfolds. Somehow, that is literally what goes on at all of these different stages of employing data and analytically observing the whole process throughout the trauma event. The trauma physician with 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 next move, and so on.

In a sense, the trauma force one to have 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, mentally, to read all cues and clues and make reasonable assumptions. When physicians make judgments about some environmental state, transformations must occur. A very basic example is where one tries to navigate from one side of a dark room to the other, that an individual is going to adjust in order to get bearings. Throughout the process, the individual gets tactile and auditory cues, which are being fed into the system and "simultaneously try to shape and react to the environments he/she faces" (Weick, 1995). The study is to attempt to operationalize, conceptually, these concepts (variables) taking place at once, maybe, together with the flow of the process of the en-gated work. Intrinsically, there are different points; there is the initial assessment and there is the secondary assessment working like gates. They act as gates of decision processes that are going on from the time of the trauma admission. In other words, these are complex decision processes that feed to a gate. However, referring to Figure 4, if one thinks of these transitions as gateways or benchmarks, so to speak, in the decision process, despite being vertical, they get their initial input, and get their initial vigorous push and get a rapid increase in the stimulus as they go through these gates represented by each of the assessments to the diagnostic course of action.

Proceeding with the discussions of the preceding paragraph, the intersections of the three steps in Figure 4 (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. This is because a patent feedback loop creates the system that is out in the environment, and the environment gives it some sort of feedback, which then the system corrects. The trauma center operating as a system, and constantly getting information, it then reaches these points, these markers, these gates, and it changes. It can correct, and then there's over-correction that can be used as metaphor of steering.

The physician and the medical team are always treating, never stopping, such that the conceptualized gates or markers that get the system in motion. This treatment motion is symbolized by the arrows. The treatment motion is important in this model and every decision cues along the way are then 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 characterizes the unknown. Because there's always the stuff that is chance, variation will occur regardless of the approaches taken by the medical team. If one thinks of these four (political, rational, medical judgment, and chaos of Figure 3), dynamic ways of decision making, that are inexplicably tied, the complexity shows out. The argument here is that there's no such thing as purely rational decision making. One can always aspire to it, but there's no such thing as purely rational because no decision can be free of subjectivity or bias. Even if one attends to it (when I say attend, I mean attention from a cognitive point-of-view), the questions asked as a researcher are inherently biased because they are formed by interest. For example, the things one sees walking down the street versus what I see or what somebody else sees might have something to do with what catches our eyes. Therefore, there's this construct called "bounded rationality," which is literally used to designate rational choice that takes into account the cognitive limitations of the decision maker (Simon, 1972) that makes that argument that has been around for a long time. There's no such thing as total or complete rational decision making. There's a limit to rational decision making. Decision makers, in any specialty or profession, try to do it, but as often it is the case, it does not happen.

Consequently, the next step maybe 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 existent definition. This operationalized definition is important because as it can be visualized from Figure 3 that the edge of chaos encroaching on the three decision types (political, rational, and judgment) gives rise to the decision-making process under stress, which makes up the idea of the complexity. A search of the literature on this aspect of the trauma decision-making under stress has not yet produced any work from other researchers. This is an interesting study because it shows social, political, and even economic pressure that forms the power play from interested stakeholders. These factors combined in to the mix make rational straight forward, but then judgment and political decision-making variables need to be also 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, rational, judgment, and chaos. 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 the adaptability, the complex systems that are of interest are often described as complex adaptive systems" (Goldstein *et al.*, 2010).

The research is a search for a way to develop a theory such that the framework can be thoroughly analyzed, and ways are found to moderate dysfunction and forestall the emergence of chaos. In order to pull it off, the goal is to define a construct of interest that will allow the development of ways to measure and observe in real time trauma physicians in action. As discussed earlier, the strands 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, human judgment, and treatment decisions are each represented by one strand. The unpredictable is then added. Referring to Figure 1, it is when the three or four of these ongoing actions (the helix) hit the edges of chaos they become complex. There is then this threshold of uncertainty where these edges come in and become complex and generates disagreement.

Figure 5 shows the process map to trauma centers DMPUS that originates with the Emergency Medical Service (EMS) getting at the trauma scene and transporting patients to the hospital and the constant communication between EMS and trauma center, until the moment the trauma center medical team takes over the patients. The map clearly depicts the convolution moment in time and the decision-making model of Deconvolution to the RDMP, resulting in the diagnosis.

10. Research design and procedures

The proposed methodology, including the research design and the procedures by which data is to be collected and analyzed for this study, is presented in the next paragraphs. The model has been designed on an *X*, and *Y*-axis to allow for mapping the decision making process and for looking at the processes as medical team members reach what has been described in the preceding sections as gates, benchmarks, or simply markers. Therefore, assess the proportions of the four factors (political, rational, medical judgment, and treatment) that are applied to the gates and then actually make observations. It is necessary that these gates are looked upon as a sort of markers or decisions in the big picture. Every gate is somewhat alike in that the decision maker has gone through a stage, which is a decision-making marker that records the passing through a threshold (i.e. initial assessment, secondary assessment, tertiary, and so on).

11. Data collection

The data are to be collected from a major healthcare system that has a Level 1 Trauma Center with leadership of a medical doctor. The plan is to go into the trauma center as the event is occurring and get the data first hand, real-time data collection of actual events.

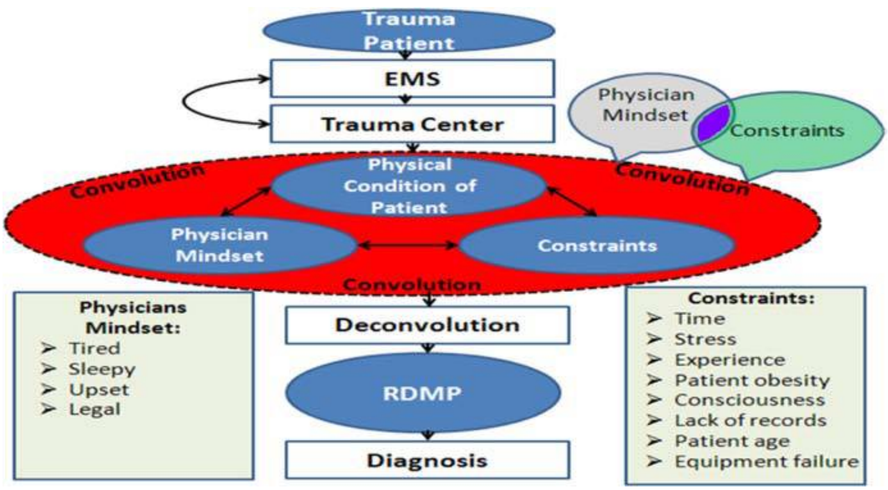

Figure 5.
Process map of trauma center decision-making

However, there may be problems along the way, with being inside a clinic collecting such information for the research purposes. If this situation is encountered because of the hospital's policies, the researcher is prepared to act with a survey being prepared with the help of experts in the medical field to survey emergency and trauma physicians. The survey will be mailed to physicians of hospital in the southern region of the US.

The process of getting the observations is to be accomplished by audio recording the trauma event cases admitted for trauma care. Each trauma (patient) event is to be considered an observation, one cycle, and each cycle represent one person as being input (arrival) and output. Each observation is to be audio recorded, from the moment the trauma patient arrives at the trauma center until the time the patient leaves the care of the trauma medical team, or to a maximum of 60 minutes of audio-recording, whichever comes first. This 60-minute mark, where a decision is made whereas the run is over and through. And data are to be gathered on all these different runs, look at those different gates of the framework, or those points of decision making, whether is the triage, the initial assessment, the secondary assessment, diagnosis course of action, and so on. Those gates or markers constitute decision-making thresholds. The data coded for each cycle (patient) helps find out where the input is, and where the start and finish points.

Subsequent to these audio recordings, the appropriate next step is to code the spoken words as being one of those four aspects of decisions outlined in the model. For example, if a member of the team says: "I do not know," that is an uncertainty phrase and the researcher would code it as chaos. The physician would say to a nurse "Do this procedure my way," this would be coded as political decision making. Additionally, while the researcher observes the event unfolding, the entire scenario can be mapped out from the verbal standpoint. Hence, the data are transcribed, encoded, and analyzed to observe how it unfolds in different scenarios, in real time as those scenarios are played out. It is real data that get transcribed. Throughout the trauma event, audio record the conversations that go on through the intake from the moment that patients hit the trauma center and take down and code all that verbal data from the stakeholders (i.e. nurses, EMSs, physicians).

The coding of those recordings may be accomplished by assigning 1 (one) for chaos, 2 (two) for political, 3 (three) for rational, 4 (four) for human judgment, and any phrase that hints at those four parameters is coded for analysis. This process outline provides a theoretical framework, provides a way to operationalize complex decision-making, and a means of measuring the process by means of data collection. With a higher area of complexity, it is expected to see more of each of the three parameters going on because people are using their influence, their medical judgment, or their intuition in the decision-making process, as to whether to deal with the problem rationally, politically, or simply by making a medical judgment. Or, the medical team might conceivably use and lean on any one of those three main decision-making types to mitigate for the uncertainty.

12. Power influence

The medical team itself might end up having to be characterized, not only by this time frame (60 minutes), but these medical teams may respond differently to each event because, from one night to the next it (the team) might look very differently in terms of who is working, how people work together, and what leadership styles exist. For that reason, ideally the person who is "in charge" is leading or making decisions and conducting; but what's ideal and what's real are two different things. The physician with the medical team is in a real struggle for saving someone's life. And, there are protocols and algorithms provided by the healthcare system that these medical teams have to adhere to in every trauma situation. However, the fact remains that in this struggle for life or death formal organizational procedures might not be sufficient or adequate to solving ambiguous and uncertain problems. It is the difference between formal organizational structure and informal structure. Trauma centers may be considered informal as it is composed of specialists (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 is going to be a decision made constantly that feeds into this trauma system. The key is to understand that these decisions are driven by intuitive judgment, rational, and power. Power is the broad term; power is about influence. Sometimes power is because he is your superior; sometimes it is because of gender, or many other reasons. Hence, there's the power, which is the political, the rational, the intuition and then there is the unknown that factors in to that, the uncertainty piece.

The framework presented in Figure 4 demonstrates that complex factors can help find a way to create a bounded context for observation. The time frame is unambiguous: the initial contact with the patient to referral or transfer of the patient to a hospital room. More precisely, the patient gets transferred out of the trauma center. The term "bounded context" is specific because it is an area with explicitly defined borders, and it has its own model, and maintains its own rules and regulations. By splitting the large emergency medicine department into diverse small areas, of which the trauma center is one, it has gained all the advantages of modularity and separation of concerns, but still keeping its integrity intact.

The development of a bounded context helps resolve issues around conflicting positions encountered amongst all of emergency medicine areas that might get involved in the trauma event. It allows the study to focus on problems, and to provide better use of all resources. While conducting the study within the trauma center, researchers can more specifically define the boundaries of the research for the establishment of the bounded context. A trauma center of a major hospital system has committed to helping in the study and has become a key link to forming the logistic of the bounded context for gathering data to capture verbal communications, transcribe it, code it, and feed it back into the theoretical model.

13. The decision making model

The model designed for this study uses Bayesian Classifier model (BC) and Convolution and Deconvolution operators. Bayesian Classifier is a probabilistic classifier model based on Bayes' Theorem. The Bayesian Classifier model will analyze the "rational decision making process" (RDMP) data that will provide the general framework to describe decisions that are made in the uncertain environment of trauma centers. BC operate by simply considering all of the characteristics of the variables being classified, using information that is entirely insufficient to determine the correct answer (Figure 6).

Regardless, whether characteristics of the variable considered depend on each other or upon the existence of any other properties, BC considers all these attributes to contribute independently to the probability that a variable belongs to a classification. BC assumes that the effect of a variable value on a given class is independent of the values of the other variables. The theory is quite simple. Let $\boldsymbol{X}$ be the collected data whose class labels are unknown and let $\boldsymbol{W}$ be some hypothesis, such as "collected data $\boldsymbol{X}$ belongs to class $\boldsymbol{Y1}$. Then, the object is to determine $\boldsymbol{P(W|X)}$, which means the probability of the hypothesis $\boldsymbol{W}$, given the collected data $\boldsymbol{X}$. The $\boldsymbol{P(W|X)}$ is referred to as the "posterior" probability" of $\boldsymbol{W}$ conditioned on $\boldsymbol{X}$; that is, the probability of having a correct classification of $\boldsymbol{W}$ given the values of $\boldsymbol{X}$ have been observed. BC has been used for problems in medical diagnosis. In spite of its simple design and apparently over-simplified assumptions, BC has worked well in many complex real world situations (Charniak, 1991).

Robinson in "Complexity for Clinicians" explained that the academic study of decision making process considers three characteristics (Robinson, 2004):

(1) descriptive, how people actually make decisions;

(2) normative, the process that would constitute rational decision making; and

(3) prescriptive, tools that will encourage rational action in real life; in other words, moving the descriptive towards the normative.

There is a strong desire to base decisions on rational grounds, which is corroborated by Robinson "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 same conclusions. Mathematically, the rational decision making process can be represented by $\boldsymbol{Y = f(x)}$, where $\boldsymbol{x}$ is the set of parameters physicians will obtain.

Under the stress of a trauma event, physicians have the challenge of time constraint, environmental noise, and other disturbances, causing their rational mental models to be blurred by all these noises. In the model, convolution is used to blur the rational thinking to represent physicians' Decision-Making Process Under Stress (DMUS), in which the function $\boldsymbol{f}$ is stressed. Stressing the function $\boldsymbol{f}$ is the convolution operation. For example, it is like adding lines to an image. It blurs the image through convolution function. However, physicians do not make decisions on blurred models, why then do we have to blur the rational decision-making process? It has to be blurred because physicians under stress have to make swift judgments because of time constraint to create a quick model to identify what has been observed while the cognitive processes are blurred. The mental models must be somehow "cleansed" from impurities materializing from the nosy environment. Therefore, convolution is to add some stress on the rational decision making process to simulate the conditions of the environment. Deconvolution is used to clear out the extraneous noises to allow physicians to have a clearer picture of the diagnosis or diagnostic course of action.

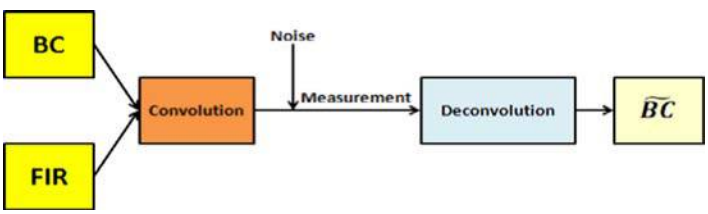

Figure 6.
Decision making model

14. Conclusion

Decision making in trauma events is a daunting but crucial task for trauma physicians. This paper tried to provide the background of the theory on which complexity principles are based and how these principles could be applied to the environment of trauma medicine for the understanding of how physicians make decisions under extreme stress. The expansion of biotechnology also brings more constraints into the environment in which physicians' function. A model of decision making process under stress using Bayesian classifier with Convolution and Deconvolution operators was outlined that can recreate observed phenomena in the complex environments of trauma physicians. The model should shore-up the framework for trauma decision making that was presented, and expand our understanding of complex decision-making processes. As the real-time data collection for the research is conducted that is needed to test the framework, and to permit more scientific conclusions about the nature of the trauma environments, it will provide a meaningful understanding of uncertainty and unpredictability of trauma events.

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About the authors

Policarpo C. deMattos is a Doctoral Candidate in Industrial Systems Engineering at North Carolina A&T State University. His research interests are in complex adaptive systems, decision-making and system engineering. He teaches statistics and is a certified Six Sigma and lean systems trainer. He has a BBA in Finance (Pace University of New York, 1979) and a MS (Industrial & Systems Engineering, North Carolina A&T State University). Mr deMattos has over two decades of corporate finance experience.

Daniel M. Miller is an Associate Professor of Leadership Studies at North Carolina A&T State University. Dr Miller earned his MS and PhD at Cornell University and his BS in Psychology from the University of Nebraska-Omaha. His research interests and professional activities draw upon his foundations in education, leadership, organizational behavior and policy in the areas of social entrepreneurship, health systems, and renewable and alternative energy. Daniel M. Miller is the corresponding author and can be contacted at: DanMMiller@aol.com

Eui H. Park is a Professor of Industrial Systems Engineering at North Carolina A&T State University. Dr Park earned his MS and PhD from Mississippi State. He worked for Boeing for four years before joining North Carolina A&T State University in 1983. His research interests are industrial systems engineering and optimization. He teaches in his areas of research and is also a certified Six Sigma and lean systems trainer.

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