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A Finite State Automaton Representation And Simulation Of A Data/Frame Model Of Sensemaking

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A FINITE STATE AUTOMATON REPRESENTATION AND SIMULATION OF A DATA/FRAME MODEL OF SENSEMAKING

by

Emma A. Codjoe

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of
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Department: Industrial & Systems Engineering
Major: Industrial & Systems Engineering
Major Professor: Dr. Celestine A. Ntuen

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School of Graduate Studies
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This is to certify that the Master's Thesis of

Emma A. Codjoe

has met the thesis requirements of
North Carolina Agricultural and Technical State University

Greensboro, North Carolina
2011

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Dean of Graduate Studies

DEDICATION

To my dad, Anthony Antredu Atta-Codjoe for believing in me; and my family, for the prayers, support and encouragement.

BIOGRAPHICAL SKETCH

Emma A. Codjoe was born in Accra, Ghana on February 5, 1982 and received her Bachelor of Science degree in Chemical Engineering from the Kwame Nkrumah University of Science and Technology in 2006. Prior to undergraduate studies, she received her computer certification for Microsoft Office from Oxford College International in London, United Kingdom in 2002.

Emma has professional experience as a Risk Assessment and Monitoring Officer and Client Care Coordinator with London Care PLC, United Kingdom from 2003 to 2006. She did her National Service at the Office of Parliament, Ghana as a Technology and Information Research Associate from November 2006 to September 2007. Finally, in November 2007, she secured a job with the Barclays Bank of Ghana Limited as a Contract and Retail Associate at the High Street and Ahodwo-Kumasi Branches until August 2008.

She was inducted into Alpha Pi Mu, Phi Kappa Phi and the Golden Key International Honor Societies in 2010. She is a candidate for the Master's in Science (MS) Industrial and Systems Engineering degree at North Carolina Agricultural and Technical State University. She received recognition from the Graduate School as a 4.0 Kennedy Scholar and superior academic standing from International Students and Scholars Office.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

TABLES **PAGE**

LIST OF NOMENCLATURE

$	Dollars
%	Percent
(C++, C)	Computer programming language
(n)	Current stage
(n+1)	Next stage
(n-1)	Previous stage
$(S, A, \longrightarrow)$	Labeled transition system as a tuple
(s_1, s_2)	States in a FSA
(X, M)	Classes of X-ray peaks
$< X, Q, Y, D, W >$	FSA defined as a five tuple
$< \Sigma, S, s_o, \delta, F >$	FSA defined as a quintuple
°F	Degree Fahrenheit
a.m.	Ante Meridiem (Latin)
AL	Alabama
ANOVA	Analysis Of Variance
CTA	Cognitive Task Analysis
DFM	Data/Frame Model
DMSC	Dynamic Model of Situated Cognition
F	F-test statistic

FEMA	Federal Emergency Management Agency
FL	Florida
FOCUS	Framework Of Comprehending and Understanding Situations
FSA	Finite State Automaton
ft	Feet
G	Graphical programming language in LabVIEW
G(1-5)	Geomagnetic Storm Scale
GLM	General Linear Model
HC	High Complexity
HK	Hurricane Katrina
hr	Hours
HSM	Hurricane Sensemaking Machine
Hz	Hertz
in	Inches
Kp	K-index
LA	Louisiana
LabVIEW	Laboratory Virtual Instrument Engineering Workbench
LC	Low Complexity
LED	Light Emitting Diode
MC	Medium Complexity
min	Minutes

mph	Mileage(s) per hour
MS	Mississippi
NDBC	National Data Buoy Center
NHC	National Hurricane Center
NOAA	National Oceanic and Atmospheric Administration
NTN	Node-to-node
NWS	National Weather Service
OODA	Observe Orient Decide Act
p.m.	Post Meridiem (Latin)
PST	Problem Stage Time
p-value	Probability value
R(1-5)	Radio Blackouts Scale
s	Seconds
S(1-5)	Solar Radiation Storm Scale
SAS	Statistical Analysis Software
Yhat	Predicted value
α	Alphabet from a set of symbols in a FSA

ABSTRACT

Codjoe, Emma A. A FINITE STATE AUTOMATON REPRESENTATION AND SIMULATION OF A DATA/FRAME MODEL OF SENSEMAKING. (**Advisor: Dr. Celestine A. Ntuen**), North Carolina Agricultural and Technical State University.

This thesis presents the application of a finite state automaton (FSA) to analytic modeling of Data/Frame Model (DFM) of sensemaking. A FSA is chosen for the DFM simulation because of its inherent characteristics to mimic changes in system behaviors and transitional states akin to the dynamic information changes in dynamic and unstructured emergencies. It also has the ability to capture feedback and loops, transitions, and spatio-temporal events based on iterative processes of an individual or a group of sensemakers. The thesis has exploited the human-driven DFM constructs for analytical modeling using Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW) software system. Sensemaking times, problem stage time (PST), and node-to-node (NTN) transition times serve as the major performance factors. The results obtained show differences in sensemaking times based on problem complexity and information uncertainty. An analysis of variance (ANOVA) statistical analysis, for three developed fictitious scenarios with different complexities and Hurricane Katrina, was conducted to investigate sensemaking performance. The results show that sensemaking performance was significant with an F (3,177) of 16.78 and probability value less than 0.05, indicating an overall effect of sensemaking information flow on sensemaking. Tukey’s Studentized Range Test shows the significant statistical differences between the

complexities of Hurricane Katrina (HK) and medium complexity scenario (MC), HK and low complexity scenario (LC), high complexity scenario (HC) and LC, and MC and LC.

CHAPTER 1

Introduction

1.1 Background and Definitions of Sensemaking

When one encounters a new situation, she reasons around it; when she finds a shortcut or dead end, she remembers it—what she does in actual fact is learn it. We try to make sense of information and the situation confronting us through many phases of knowledge processing of which the majority is cognitive. These are aspects of sensemaking.

The American Heritage College Dictionary (2002) defines the word “sense” as, (1) understanding, (2) signification, (3) present of meaning, (4) a mechanism of faculty as receiving (forming) mental impression, (5) deducing from observation or unnoted stimuli in respect to a particular field or relation, (6) instructive comprehension, (7) discerning awareness, (8) opinion, view, sentiment, of something felt and held by an individual or a group of people, (9) awareness derived through interpretation of stimuli or sensory information, (10) accustomed steady ability to judge and decide between possible courses with intelligence and soundness. The definitions 1-10 above represent the epistemological aspects of sensemaking. The same dictionary defines “make” to imply, (1) to frame or formulate in the mind; (2) form as a result of calculation of design; (3) enact or establish. These characteristics represent the ontological views of sensemaking. By combining the two words, the same referenced dictionary defines sensemaking as a noun – “sensible, reasonable, and predictable”. Thus, sensemaking implies the ability to design, build, and derive an understanding of situated information.

Sensemaking is simply making sense of situation information. Sensemaking is typically attributed to Weick (1995) who notes that sensemaking is an interplay of action and interpretation rather than the influence of evaluation on choice. Sensemaking is a label for a coherent set of concepts and methods used to study how people construct sense of their worlds—mostly, the world of information. As a human endeavor, it is noted by Huber and Daft (1987, p.154) that active agents construct sensible events through a sensemaking process. And they do so as they “structure the unknown” (Waterman, 1990, p.41).

Sensemaking involves putting stimuli into some kind of framework (Starbuck and Milliken, 1988, p.51).When people put stimuli into frameworks, this enables them to “comprehend, understand, explain, attribute, extrapolate and predict”. Based on this perspective, Seick, Klein, Peluso, Smith and Harris-Thompson (2004) view sensemaking as a process of framing, or fitting data into a frame that assists us to filter and construe the data while examining and improving the frame. As frames form and identify the relevant data, data mandates frames change in nontrivial ways (Klein, et al, 2006). While frames define what counts as data, they themselves actually shape the data.

Sensemaking implies the set of processes involved in the progression of a person’s understanding of a situation. It is noted that sensemaking manifests in situations with unexpected surprises such as natural disasters and emergencies (Weick, Sutcliffe and Obstfeld, 2005). As unexpected events usually trigger the desire for coping mechanisms, Louis (1980, p.241) notes that sensemaking is a thinking process that uses retrospective accounts to explain surprises. Surprises, which are unexpected situations, have to be explicitly explained to attain situation awareness and subsequently an understanding of the situation.

Sensemaking is also a process, design, or a technique of bringing together information, attaining situation awareness (Endsley, 1995) and interpreting the information in perspective so as to gain knowledge and understanding for actions (Ntuen, 2009). Sensemaking as a tool for naturalistic knowledge discovery fits data from a situation of interest into a frame.

Many experts on the subject matter confirm that sensemaking involves deliberately placing stimuli into some kind of framework (Seick et al., 2004; Starbuck and Milliken, 1988). Weick (1995) suggests that a frame can be a story or script, a map or other types of depiction. Ring and Rands (1989, p.342) define sensemaking as a "process in which individuals develop cognitive maps of their environments". For example, experts make use of concept maps during their sensemaking process in an attempt to discover intrinsic knowledge within contextual information. Ntuen (2009) attributes sensemaking be a naturalistic knowledge discovery tool, "as the process through which people use information to construct, maintain and reconstruct interpretations of the world." In this way, sensemaking can be seen as a tool, a process or theory of how people reduce uncertainty or ambiguity; socially negotiating meaning during decision-making events (Ntuen, 2009).

The differences in the ways people make sense of a situation can be ascribed to the depth of how they present an internal representation of a system to the external world; their mental models, the mental depiction of “how things work” (Seick, et al, 2004). As observed by Snowden (2002) and Weick, et al. (2005), sensemaking is more noticeable in a situation of confusion, chaos, pandemonium, and emergency. In each situation, information is known to be characterized by uncertainty, dynamically evolving, and lacks crisp descriptions. Due to these characteristics, sensemaking is primarily a cognitive process.

1.2 Sensemaking as a Cognitive Process

Sensemaking involves the use of the most fundamental aspects of human cognition which include, but are not limited to, the ability to reason, recognize patterns, compare facts, differentiate between “what makes sense” and what does not, and make decisions. All or some of these cognitive tasks can take place simultaneously—sometimes inherently without our notice.

The anecdotal sensemaking definitions above inform us of the multifaceted and equivocal views of sensemaking. Viewed from Polanyi’s association of sensemaking with tacit knowledge (Polanyi, 1967), sensemaking is a cognitive process which allows people to interpret information in context so as to derive knowledge for actions. Polanyi refers to intrinsic and private knowledge as tacit. Polanyi is cited and credited for the definition of tacit knowledge and how it influences the sensemaking process. According to Polanyi, tacit knowledge is what is known but cannot be told. The reasoning behind the statement is that the knowledge has become so personal in the unconscious mind and, therefore, it cannot be expressed because there is no access to it through the conscious mind. Polanyi said "we know more than we can tell."

Weick (1995) states that sensemaking refers to how meaning is constructed at both the individual and the group levels. This means that sensemaking is both an individual as well as a group cognitive process. Sensemaking has been used to identify changes in existing patterns or the emergence of new patterns in information networks (Weick and Sutcliffe, 2001).

As a cognitive process, information is the heart of sensemaking. However, the information required may be missing completely. In this case, the sensemaking process starts by making guesses using retrospective knowledge. The information may be incomplete, in which case, the sensemaker mentally estimates and makes connections to the missing information. Finally, information may be overwhelmingly too much; sensemaking requires data mining techniques to discover relationships and associations in the context. These situations attribute sensemaking to “a sprawling collection of ongoing interpretive action, central to the conduct of everyday organizational life” for the simple fact that it creates and discovers (Smith and Hitt, 2005).

1.3 Sample Sensemaking Applications

Sensemaking is an everyday human endeavor. It occurs naturally when the sensemaker is using tacit knowledge and, collectively, while sharing the tacit knowledge with others through various interaction and communication modalities. There is no single spot for sensemaking application. It is omni present and ubiquitous. For the purpose of this thesis, few contextual uses of sensemaking are presented below (Ntuen, Park, and Gwang-Myung, 2010).

(i). Sensemaking is an aspect of information foraging: Pirolli and Card (1999) define information foraging theory as an approach to understanding how strategies and technologies for information seeking, gathering, and consumption are adapted to the flux of information in the environment. The theory assumes that people, when possible, will modify their strategies or the structure of the environment to maximize their rate of gaining valuable information. Pirolli (2007) notes that foraging tasks consist of information gathering, representation of the information in a schema that aids analysis, the development of insight through the manipulation of this representation, and the creation of some knowledge product or direct action based on the insight.

(ii). Sensemaking is an information fusion tool: As an information fusion tool, sensemaking is viewed as a thinking process that uses retrospective accounts to explain surprises (Louis, 1980, p.241), and uses new information to update prospective predictive states of a situation. Munya and Ntuen (2005) used these axioms to develop an information fusion model using abduction reasoning and Bayesian learning models. Relevant to information fusion, Pirolli (2007) and Pirolli and Rao (1996) use sensemaking to refer to activities in which external representations such as texts, tables, or figures are interpreted into semantic contexts.

(iii). Sensemaking supports situation understanding: One of the purposes of sensemaking is to allow the sensemaker to understand the situation by reducing ambiguities and uncertainties to near crisp quantitative information values. Many studies (Fodor, 2000; Klein, 2003; Weick, 1995) have shown that when complex and chaotic situations are encountered, it is sensemaking that helps the decision-maker to frame the context of the situation in order to develop some clues for situation awareness and understanding. Sensemaking also helps the decision-makers to solve problems that require intuition and retrospective knowledge.

1.4 Research Rationale

Sensemaking process is necessary for understanding the effectiveness of sensemaking outcomes as viewed from different stages and sensemaking lenses. Currently, most of the sensemaking processes (as will be discussed in Chapter 2 of this thesis) are qualitative and lack the formal methods for quantitative evaluations. It is surmised that, by quantifying the sensemaking process, at least four advantages can be derived:

a) Recognizing sensemaking break points: Determining when a sensemaker is right during a contextual sensemaking process is elusive and needs metrics to help pinpoint when breakdown in the sensemaking process occurs, for example, when and where in the process confusion of interpretation occurs.

b) Reducing equivocality: It is known that sensemaking is anchored on information interpretation which may differ from one sensemaker to another. Through a quantitative analysis, it is possible to develop a sensemaking filter or “barometer” that uses a common metric to reduce equivocality in the way different sensemakers give interpretations and meanings to the same situation.

c) Performance Assessment: A quantitative model with robust analytical rigor can be used to assess the performance of sensemakers, either individually or as a team. For instance, given a sensemaking problem situation, one may be interested in comparing the performance of an expert and a novice sensemaker using some determined metrics such as outcome effectiveness, sensemaking time, and the ability to discover significant information from a complex data set.

d) Identifying Best Practices: Quantitative analysis can use simulation techniques to determine significant best practices for a sensemaking process at different problem scales and sizes. For example, a properly constructed analytical model can help in determining the most suitable hypotheses for a problem situation, or a set of recommended courses of action as outcomes of a specific sensemaking process.

1.5 Research Objectives and Approach

The major goal of this thesis was to develop a quantitative model for a sensemaking process. Specifically, there were two objectives:

a) To use a finite state automaton (FSA) as a quantitative model to represent and simulate the behaviors of a sensemaking process defined by Data/Frame Model (DFM) of Seick, et al. (2004).

b) To evaluate the usefulness of the analytical model using the Hurricane Katrina situation. A cognitive task analysis of Hurricane Katrina was used to derive the basic input to the simulation model. Sensemaking performance metrics under a simulated domain was developed to assess the effectiveness of the FSA-DFM simulation.

A FSA was selected because of its ability to model discrete or continuous state changes in a system, including the ability of its representation to capture feedback and loops, transitions, and spatio-temporal events. The features of DFM are yet to be exploited for analytical modeling even though it has robust characteristics for this purpose. The DFM has sensemaking states that are reminiscent of FSA; transitions that represent the progressive processing of data into information, and information to knowledge. These include the human cognitive tasks such as refutations, comparisons, pattern associations, and identifying alternatives, recognizing and isolating violations during the sensemaking process, and the searching for information to confirm certain beliefs. The mapping of these DFM properties into FSA models was the focus of this thesis.

1.6 Chapter Summary

Currently, sensemaking is viewed as a qualitative model of imparting retrospective knowledge to the understanding of complex or chaotic situations. From the situation understanding framework, one must be cognizant that conditions requiring sensemaking involve changing conditions that translate to belief changes and updates of our cognitive understanding of the new contexts relative to the old ones and how states and/or events in the new context deviate from our previous knowledge. Generally, there is no converging point of focus in constructing a sensemaking model in evolving and dynamic /novel systems. However, the DFM has provided a benchmark for developing quantity models for sensemaking processes so as to measure their effectiveness—both at the problem levels and at the sensemaker levels. This thesis has chosen FSA as an analytical representation of DFM because of the procedural characteristics of DFM that fits into the FSA framework.

The thesis is organized into six chapters. Chapter 1 provides the basic introduction of sensemaking, the rational for the study, objectives, and an approach. Chapter 2 includes an anecdotal literature review that complements the thesis and focuses on the sensemaking process. Chapter 3 introduces a theoretical framework for sensemaking simulation and modeling. Problems in simulation and modeling of sensemaking process are recognized. Chapter 4 describes the fundamental theory of DFM and FSA with illustrations using a case study in Hurricane Katrina. Chapter 5 includes the FSA-DFM computer simulation that includes the structure, representation and validation of the quantitative computational model. Chapter 6 discusses experiments and data analysis. Finally, Chapter 7 gives the thesis summary, conclusions and suggestions for future research.

CHAPTER 2

Literature Review

2.1 Sensemaking Making Process

According to Albert and Hayes (2006; pp 63):

> “Sensemaking consists of a set of activities or processes in the cognitive social domain that begins on the edge of the information domain with the perception of available information and ends prior to taking action(s) that is meant to create effects in any or all the domains.”

The sensemaking process is about creating a common meaning, defining semantically and syntactically uniform interpretation across contexts, and creating a taxonomy or lexicon of common understanding that minimizes equivocality as much as possible (Weick, 1995).

The phenomenologist view is that sensemaking starts with the fundamental assumption of phenomenology—that the sensemaker is inherently involved in some state observations, which must be understood from experience perspectives and horizons (Dervin, 2003). Sensemaking then brings certain assumptions together by asserting that, given a situation and an incomplete understanding of that situation, we arrive at an uncompromising position of seeking a model of situation understanding (Ntuen, 2006).

Bergman and Mark (2002), quoting from Weick (1995), note that, “Sensemaking processes are quite different than procedural processes. Sensemaking processes are performed when the process goals are ambiguous and need to be defined or the process goals are clear but there is no known procedural (prescriptive) process that can be performed to satisfy the goals. Sensemaking processes are usually imprecise in description and indefinite in duration, although a specific limit can be specified". A sensemaking process occurs when there is a need to make a judgment about many competing objectives that are time bound (Weick, 1995).

Ntuen (2006) notes that a key to developing a sensemaking process is to appreciate the understanding that humans bring to the information context and the problem situation, and the way in which that understanding is used, shared, tested and evolved during the process. How sensemaking occurs, and how understanding is used, is strongly dependent on how one thinks and how one represents the world. Sensemaking is the process of choosing the right set of perceptions and mental models to be able to understand and act successfully in this type of environment. As noted by Alberts and Hayes (2003), "Sensemaking is much more than sharing information and identifying patterns. It goes beyond what is happening and what may happen to what can be done about it. This involves generating options, predicting adversary actions and reactions, and understanding the effect of particular courses of action (pp. 102)."

Past and recent research on sensemaking has developed several variants of the sensemaking process. The ones that apply to this thesis are: Observe Orient Decide Act (OODA) model developed by Boyd (1987), Dynamic Model of Situated Cognition (Shattuck and Miller, 2004), Situation Handling Model (Wiig, 2002), Data/Frame Model (Seick, et al, 2004), and Sensemaking Process Model (Ntuen, 2006). Brief reviews of these models follow.

2.2 Observe Orient Decide Act (OODA) Model

The OODA model was developed by Boyd (1987) to address the concerns of military decision-making processes that consider uncertainties. In the OODA model, the “Orient” sub-model attempts to capture the cognitive processes involved during sensemaking—although it was never addressed as such. The components describe the human cognitive tasks with feedback and feed-forward loops. Boyd describes the sensemaking process in four stages with the orientation stage being the stage at which most of the sensemaking process takes place. The generic OODA model is shown in Figure 2.1.

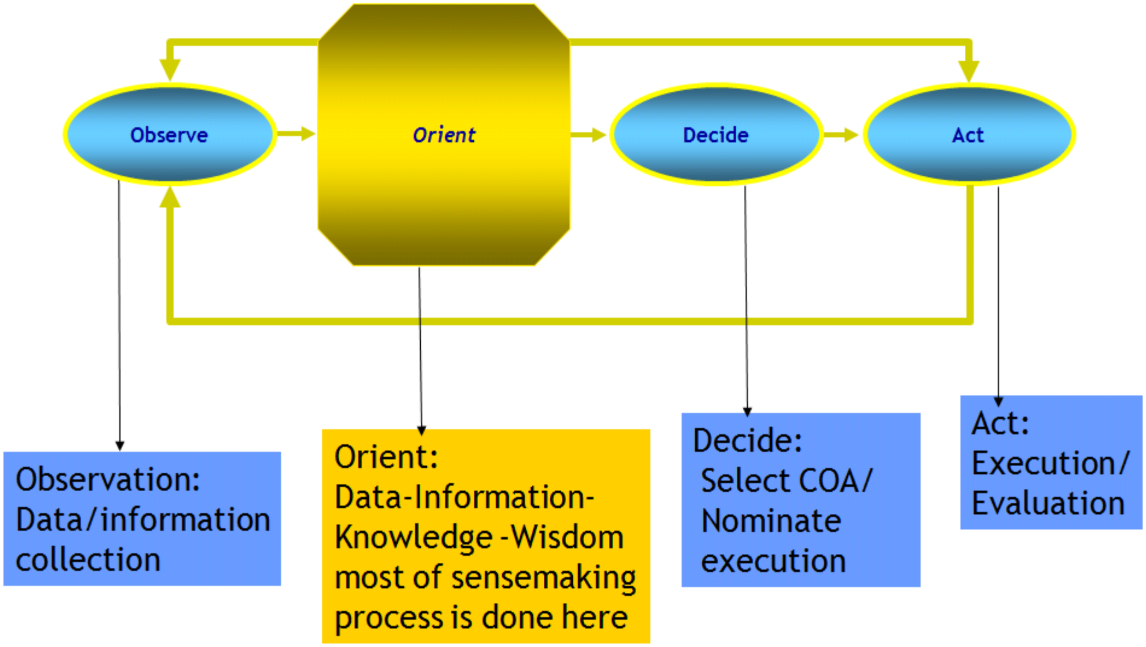


Figure 2.1. Classical Cognitive Structure of the Observe, Orient, Decide and Act Model (Boyd, 1987)

1. Observation: This stage entails the data collection process using human and technology sensors.
2. Orientation: At this stage, the collected information is used to form a mental image of the circumstances. Here, data is converted to information, and information is converted to knowledge. These products are stored into adaptable schema codes which are later used to "deconstruct" old images and then "create" new images. This orientation emphasizes the context in which events occur for use in the understanding of future system states. Sensemaking occurs mostly during the orientation stage (Leedom, 2004).
3. Decision: This task involves analysis and selection of potential courses of actions for execution.
4. Action: This phase addresses the notional requirements for execution and evaluation of the expected consequences of the action. The evaluation loop is responsible for the feedback through "lessons-learned" made possible through data collection from realistic situations.

2.3 Dynamic Model of Situated Cognition (DMSC)

Sensemaking can be viewed as a sequence of situated acts. Situatedness (Clancey, 1997; Suchman, 1987) holds that "where you are, what you do, when you do matters". Thus, "situatedness" is concerned with locating everything in a context so that the decisions that are taken are a function of both the situation and the way the situation in constructed or interpreted. Situations may change over time therefore the cognitive processes required to adapt to such changes must be dynamic. This change is dependent on the constructive memory which holds that memory is not a static imprint of a sensory experience, but is subject to continuous changes due to new information stimuli (Dietrich and Markman, 2000). The sensory experience is stored and the memory of it is constructed in response to any demand on that experience. A graphical representation of this model is illustrated by Figure 2.2.

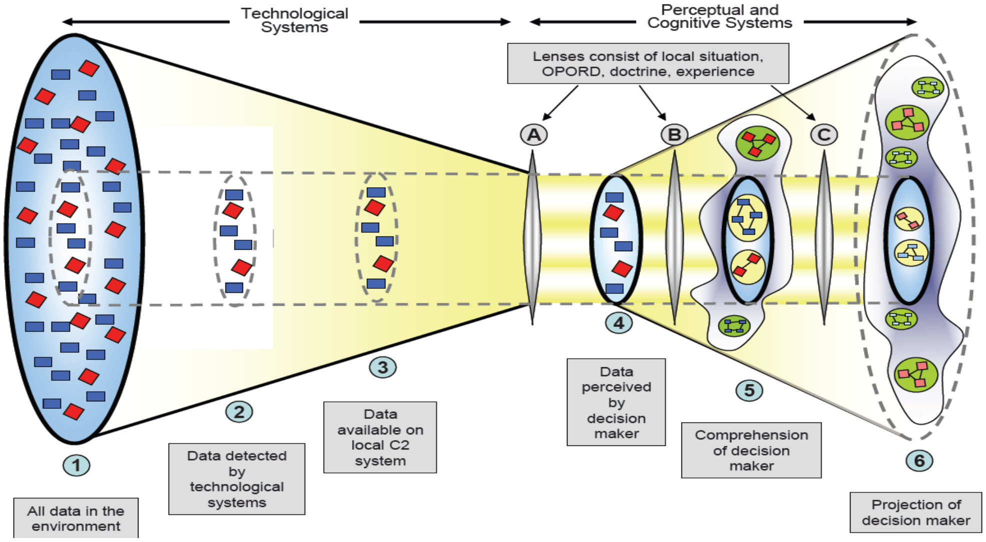


Figure 2.2. Dynamic Model of Situated Cognition (Shattuck and Miller, 2004)

Shattuck and Miller (2004) describe a DMSC as a system in which data flows from the environment, through sensors and other machine agents to the human agents in the system. This approach overcomes the biases which are inherent in analytical methods focusing almost exclusively either on machine agents or on human agents. The DMSC posits that there are various stages of technological and cognitive system performance. On the technological side, all the data in the environment, data detected by technological systems (e.g., sensors), and data available on local command and control systems (e.g., workstations) are included. Each of these stages includes a subset of what was included in the preceding stage. Building upon this technology are the perceptual and cognitive systems offered by the human operator.

2.4 Situation Handling Model

According to Wiig (2002), sensemaking is a continuous integration of evolving situation handling activities. This requires, for example, mental reference models, concepts formed around situations of interest, the volition act of trying to understand the situation relevant to the available information, the thirst to make useful and flexible judgment of events and activities based on principles, facts, and theories of the universal constructs. Figure 2.3 illustrates Wiig's sensemaking process. In Figure 2.3, it is assumed that people possess most situation handling knowledge in the form of mental models. The four types of mental models are:

1. Situation Recognition Models: These are used for sensemaking and provide characterizations of memorized events and are recalled when comparable situations are perceived. People possess large libraries in the form of schemas with tens of thousands of situation recognition models that incorporate encoded information of situations they have encountered in their life.

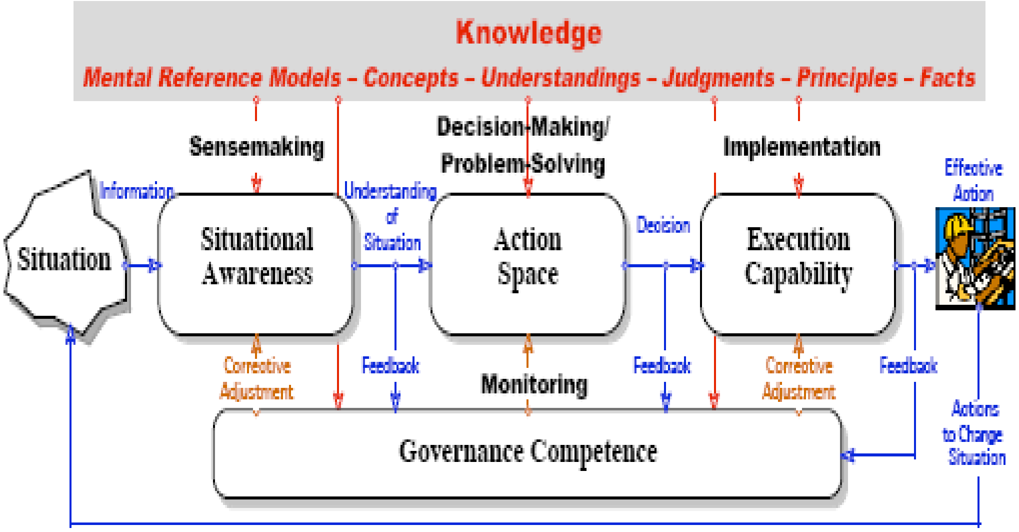


Figure 2.3. Personal Situation-Handling (Wiig, 2002)

2. Decision-Making and Problem-Solving Models: Consist of a mental library of reference models that cover a large domain and guide the decision-making /problem-solving process. These mental reference models range from quite concrete action models to abstract and meta-knowledge models. They provide simple rules for the handling of routine and well-known situations by rote, to procedures for more complex situations which may need creation of innovative actions, to methodologies for problem-solving in novel situations. Selections of mental models that are called into action depend on the level of situation familiarity and understanding that result from sensemaking activities.
3. Execution Method Models: These are used to provide guides to implement the desired action generated by courses of action planning exercise. Many Execution

Method Models are complicated and take into account trade-offs between available resources and decision objectives. Some also include aspects for how to deal with constraints of different kinds. All seem to provide dynamic perspectives on the evolving implementation process.

4. Governance Approach Models: These are used for monitoring and provide both principles and guides for evaluating the situation-handling process. These models contain goals and objectives for the particular situation that is handled.

2.5 Data/Frame Model (DFM)

Framing indicates how we structure problems into a particular set of beliefs and perspectives that constrain data collection and analysis. The framing usually narrows the information search around local outcomes as opposed to issues further distant in effect. For example, an analyst may frame a solution for short term gains, disregarding long term consequences of the decision.

Data and cues can be thought of as vocabularies from which hypotheses are developed into frames to guide in a sensemaking process. As postulated by Sieck, et al. (2004), military data will go through the military frame of reasoning, economic data will go through economic models, and political data will go through political frame, and so on. The frame paradigm is therefore sensitive to context, which makes it possible to capture the dynamics and continuity of information changes in the domain context. DFM consists of six sensemaking functions, along with temporal path relations that link the functions as illustrated by Figure 2.4.

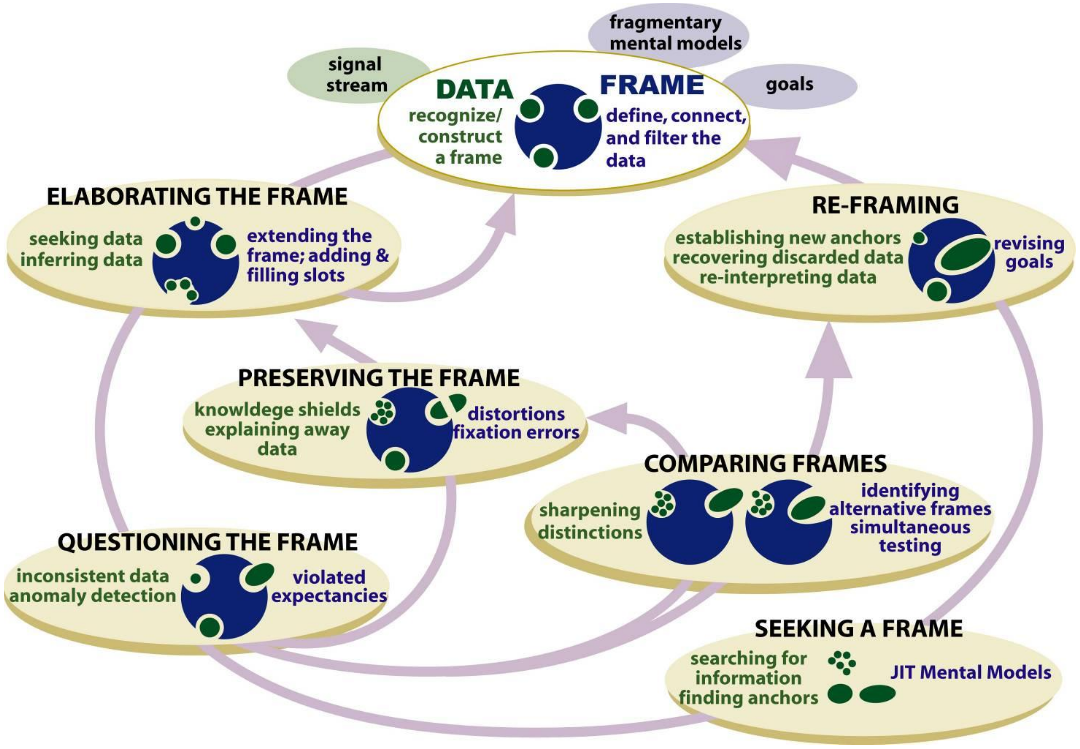


Figure 2.4. Data/Frame Model (Sieck, et al., 2004)

1. Elaborating the frame: Information from a particular situation is gathered and it is analyzed with the data to see if it is adequate. It is in this stage that data is sought and inferred directly from a particular situation. The frame is extended and elaborated further as more is known about the situation.
2. Questioning the frame: It is realized that data possessed is not adequate, anomalies may be detected and the expectancies of the frame are violated. This leads people to question the accuracy of the frame.
3. Preserving the frame: In this stage, the inadequate/contradictory data is justified and its importance is minimized. Reasons why the inconsistent data does not

match the frame are explored and presented. The preservation of the frames depends on the expertise of the person trying to make sense of the situation.

4. Comparing the frame: Information is gathered in support of the main frame and alternative frames are elaborated on so as to compare them with the primary frame. Once the frames have been elaborated and there is distinguishing information for each of them, the decision maker can be more effective.
5. Seeking a frame: This is the process of selecting the most appropriate frame according to the key information that have been obtained. The keys driving the selection of a frame are called anchors and they will help the decision maker to construct better frames based on the previous ones.
6. Reframing: Finally, the decision maker has the task of finding new anchors in order to discard unnecessary data and possibly recover previously discarded data. The data is interpreted again, the goals are revised, and a redirection of the sensemaking is performed whenever the expectations of the current situation are not met.

The DFM is a follow-up to an existing model called the Framework of Comprehending and Understanding Situations (FOCUS). DFM was developed by scientists in the third year of research at Klein Associates and is a qualitative model to interpreting situations that do not seem to have any definite pattern or make sense after all. This model was contextualized through cognitive task analysis and empirical studies of experts versus novices. Development of DFM was preceded by several studies of expert sensemakers to tap into their intuitive means of breaking down complex situations.

2.6 Sensemaking Process Model

Ntuen (2006) recognized eight interacting stages in a sensemaking process. The descriptions of these stages follow. This model is represented by Figure 2.5.

1. Situation Framing: At this stage, sensemaking involves putting stimuli into some kind of framework (Starbuck and Milliken, 1988, p.51). Framing can begin with beliefs and take the form of arguing and expecting or, it can begin with actions and take the form of committing or manipulating. In both cases, sensemaking is an effort to tie beliefs and actions more closely together as when arguments lead to consensus action during team problem solving.

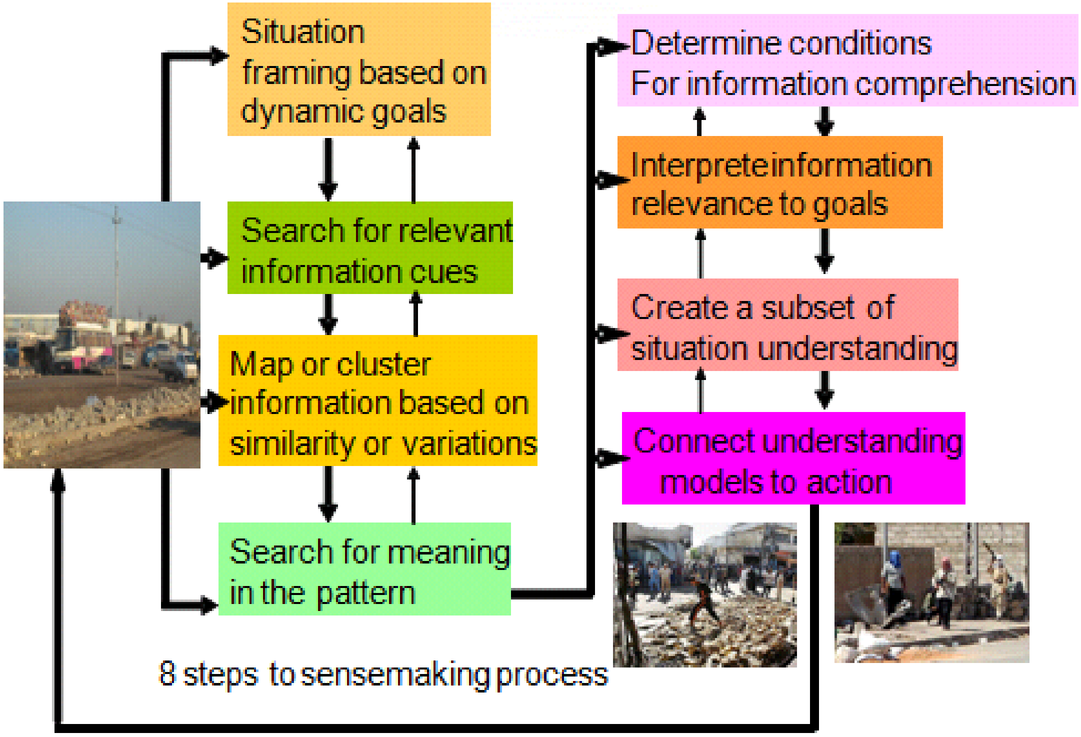


Figure 2.5. Stages in the Sensemaking Process (Ntuen, 2006)

2. Searching for Cues: A clue can start as a signal guided mapping where the sensemaker basically starts with a hypothesis and looks for data to confirm an assumption. On the other hand, a cue-guided search may be used; a bottom-up search that uses information cues as an initial data frame. From here, the sensemaker seeks linkages and patterns in the available information or data and makes classifications according to saliency of the cues in order to develop some sense of patterns and correlation likely to lead to a first level nominal awareness. It also requires recalling information relevant to a context in which these cues are applicable. It requires an extensive memory resource. The extent to which the process uses cognitive resources depends on how much adjustment the sensemaker decides to make in response to evolving contexts and information changes.
3. Information Mapping: The next step in the sensemaking process is information mapping. Here, the available information cues are used by the sensemakers to develop a map or a relation topology where clusters of similar information stimuli are arranged in the form of patterns or taxonomy trees. The mapping process can include link maps, conceptual maps, free body diagrams, decision trees, and semantic diagrams.
4. Search for Meaning in Information Pattern: Sackman (1991) views sensemaking as the mechanisms that organizational members use to attribute meaning to events. Such mechanisms include the standards and rules for perceiving, interpreting, believing and acting that are typically used in a given cultural setting

(p.33). Meaning is therefore tied to a specific context and search of how one concept relates to, influences or allows sensemakers to gain a first level interpretation of the big picture. As an epistemological construct, meaning is a subtle, loose, and diverse assignment of definition to a knowledge token, object, or artifact. In this respect, “we know more than we can tell” (Polanyi, 1967). Polanyi describes the semantic aspect of tacit knowing, how meaning tends to be displaced away from ourselves, and toward the external. Meaning is also realized through the process of how we describe things, objects, events, and so forth hence, meanings are embedded in language through description (Macdonald, 1995), implying that meaning cannot be absolute or objective in the positivist sense (Ambrosini, 1998).

5. Information Comprehension: In a sensemaking task, comprehending a situation is synonymous to “being aware” of the situation. It involves developing rules to fit or map information from one source or new situation to another source or situation. Information mapping rules are based on repetitive behaviors in which a set of production rules (in the form of “If X then Y”) are used to associate specific meanings and interpretations to system goals. When we comprehend a situation, in a nominal sense, the abstract frame of reference is concretized through associations with specific rules of behavior or schema. During a comprehension task, “changes in the environment will often be met by an updating of the current schema by a subconscious reaction to cues or a consciously expressed intention” (Rasmussen, 1986; pp.151).

6. Interpreting Information Relevance to Goals: Feldman (1989) views sensemaking as an interpretive process that is necessary for “organizational members to understand and share understandings about such features of the organization as what it is about, what it does well and poorly, what the problems it faces are and how it should resolve them.” The act of interpretation may take the form of explicit sensemaking through communication; it may also take place through the transformation and integration of representation of selected information within the defined context (Suthers, 2005). The key challenge, however, is minimizing the variance in a diversity of meanings assigned to the object of interest with its different interpretative viewpoints (Malhotra, 2001).
7. Creating a Subset of Situation Understanding: Understanding a situation means that we have a grasp of the relevant knowledge spectra about the situation. In addition to being situation aware, we also possess meta-cognitive structures that allow us to solve problems that are not familiar that is those problems that evolve according to system changes, relatively unfamiliar and with novel characteristics. Accordingly, Polanyi’s (1967) definition of focal knowledge can be used to infer how individuals assign meanings to what they see and feel. As echoed by Malhotra (2001, 120), by understanding a situation, we can form the conceptual link between information available and the expected result or anticipation of task outcomes. It could also help us to understand the gap between performance expectations based on information in context.

8. The Stage of Actionable Knowledge: The purpose of sensemaking is to connect situation understanding to action or to derive some actionable knowledge. Crotty (1998) observes that, “all knowledge and therefore all meaningful reality as such, are contingent upon human practices, being constructed in account of interaction between the human being and their world (pp.42).” The focal knowledge posited by Polanyi (1958) forms the theoretical basis for describing the enactment of the sensemaking process into an actionable knowledge. According to Polanyi, focal knowledge is a form of articulated knowledge or a situation understanding model that can be used in selecting and executing courses of actions.

2.7 Gaps in Existing Sensemaking Models

Sensemaking models in existence set the premise for improvement on their inherent gaps. The existing sensemaking models are qualitative and lack formal methods for quantitative assessment. While existing models mainly focus on either the human or the machine, this research bridges the gap between the sensemaker and the machine aiding with the sensemaking process.

The OODA model (Boyd, 1987) has a majority of the sensemaking process undertaken at the orientation stage and does not show the processes through which meaning and satisficing understanding are attained. Feedback is not totally covered from the various stages in the OODA model. The DMSC model (Shattuck and Miller, 2004) has neither feed-forward nor feedback measures in place. The model does not account for evolving situational data at any point in technological and cognitive systems.

Wiig’s situation handling model (2002) is centered on mental models and does not take into consideration other avenues through which complete frames of the evolving situations under investigation may be drawn. The existing DFM (Seick, et al., 2004) does not offer any comprehensible conduit to a computational theory of how “frame-able” things are made or influenced. The sensemaking models in existence are not presented in a way that allow for exploration and analytical analysis. This makes it almost impossible to manipulate and study expert sensemakers for the training and education of novices.

2.8 Chapter Summary

Sensemaking is a cognitive process that is utilized to add meaning, understanding and clarity to minimize equivocality and aid in decisions and their executions. This chapter focused on five existing sensemaking models that are applicable to this thesis. The advantages and disadvantages of these models are discussed as well as their gaps. Majority of the sensemaking process is undertaken in the orientation stage of the OODA model. The dynamics and continuity of information changes for the sensemaking process are undertaken in six states in the DFM, the DMSC brings together technological and cognitive aspects for its sensemaking process. Due to continuous integration of evolving situations, the situation handling model is pivoted on four classes of mental models. The reviewed models provide more information on sensemaking and its cognitive characteristics useful to simulation.

CHAPTER 3

Sensemaking Simulation and Modeling

3.1 Cognitive Aspect of Sensemaking Simulation

Sensemaking commonly relies on muddling through an information space to discover patterns of useful information. Weick (1995; pp.127) observed that "if we are concerned with what keeps (human) actions going, we must pay attention to the sense people make of what they have done. Cognitively, there is a bond between what people do, the thinking process involved, and the sense they make of it. The sense people make of their actions draws upon a significant part of cognitive resources in trying to establish useful means to the end states". Thus, sensemaking knowledge is situated as a result of integrating and analyzing isolated chunks of knowledge blocks as events manifest (Ntuen, 2006). Constructively, these isolated chunks of knowledge are linked by some associations to form a cognitive network. Such a network is for information processing that seeks to discover information patterns through the use of mental models, cause-effect relations, et cetera.

In terms of representing the sensemaking process as a network of tasks, it is assumed that sensemaking can be viewed as a sequence of situated acts. Suchman (1987) holds that "where you are, when you do, what you do matters". In the simulation modeling lexicon, these three attributes translate into "event", "time", and "process". These are the basic knowledge ingredients required to describe and represent sensemaking as a simulation model. The construction of the entire process of a sensemaking model requires our intuitive modeling of “what if” and “what next” scenarios—a process that has its origin in simulation of inquiring systems (Conklin, 1997), question-answering systems (Grosz and Davis, 1994), or systems of dialectical discourse (Rittel and Webber, 1973).

Essentially, a cognitive network model of sensemaking is a simplified and approximate representation of reality. As noted by Busby and Hibberd (2004), “cognition is not the individual, but the whole system of information processing that is involved in some task (pp.6198).” By this assumption, a constructive simulation is related to cognition by way of how people construct meaning out of information and information processing tasks. For example, people can recreate a sensemaking story out of a history of personal encounters with different situations. This reflexive knowledge creation is one aspect of building a sensemaking simulation model.

3.2 Problems in Designing Simulation Models for the Sensemaking Process

In the theory of sensemaking, it is difficult to distinguish between knowing and doing, since knowledge is an integral, self-sufficient substance, theoretically independent of the situations in which it is learned and used (diSessa, 1983). Knowledge elicitation is then a major requirement in the modeling exercise. In order to construct a sensemaking model of a situation understanding, Louis and Sutton (1991) suggest nominating a discrepancy among observations, expectancies and novelty as disruptions to our pre-coded cognitive bias. Kelly’s (1955) construct theory advocates that people make sense of the world based on a set of self-reflexive constructs that consist of beliefs, values, mental models (cognitive maps), biases and prejudices. A collection of these constructs helps to define the dimensions and the boundary conditions which one uses to interpret the world and selectively assign meaning to it. This assertion affects how a sensemaking process is defined and represented for computer simulation modeling.

Another problem in modeling sensemaking is related to expertise and experience. In decision making models, simulation algorithms are often developed around data availability, which is illusively less dependent on the data source. Within the discourse in sensemaking, many studies have attributed sensemaking knowledge to the theory of expertise, which is a function of training, skill acquisition, and experience on the job (Ericsson and Lehmann, 1996). It is recognized that expertise gravitates around the domain or situational factors and not the features of the problem to be solved (Chi, Feltovich, and Glaser, 1981; Adelson, 1984). These situational factors are what control how mental models of a system are derived (“sense”) and built (“make”) as cognitive codes in the mind and how it helps the expert to deal with novel situations. For example, proficient sensemakers utilize knowledge structures that extend beyond those of less proficient ones (Ntuen, 2006). The ability to capture and represent the individual and/or team expertise constitutes a major challenge to building simulation models for a sensemaking process. There are at least seven problems responsible for this. These are discussed next.

3.2.1 Information Space

Information is an important commodity for sensemaking. Two opportunities are available, that is there is either too much information (information glut) or too little or no information (paucity). In the former case, information has to be filtered and parsed through the cognitive processes to link statistical similarities or existing knowledge patterns. In the latter, data or information estimates of the situation are developed statistically. In each case, the “ghost” inside the black box of the data is equivocality, related to how individuals or groups interpret and give meaning to a situation.

3.2.2 Operational Elements

Operationally, sensemaking is a dynamic process in which the sensemaker attempts to construct intentional objects of knowledge against the reality of system goals. This is a problem since sensemaking is mapped against the reality of changing situations and changing goals over time and space. This makes time an important component since the current goals might not be the goals at the end of the process.

3.2.3 Contextualization

Knowledge is useful only if it can be understood in terms of the implications for action. Sensemaking involves combining multifaceted information from disparate sources to determine their relevance to actions. Through sensemaking, courses of actions are developed for a problem context. The context and situations are subject to changes and the courses of actions may not apply to these changes. Thus, a specific context in time and place requires a new sensemaking process.

3.2.4 Interpretation and Equivocality

Interpretation reflects an approximation of individual awareness of the situation in a collective sensemaking setting while ignoring some elements and only partially ascribing meaning to the subset of external knowledge (Leedom, 2005). Interpretation leads the sensemakers to more focused knowledge required for the formalisms needed for intended actions. Leedom (2005) observed, “Given the difficulty in externalizing tacit knowledge, these articulations, by nature, reflect only an approximation of each individual’s activated knowledge, ignoring some elements and only partially describing the remainder.” “Each of us lives in what is ultimately a unique world, because it is uniquely interpreted and thereby uniquely experienced.” (Bannister and Fransella, 1986; pp. 10).

The process of interpretation is not in isolation. It is affected by individual and group psycho-sociological characteristics such as bias, emotion, affection, thoughts, and actions (Duval and Wicklund, 1972). The act of interpretation may take the form of explicit sensemaking through communication; it may also take place through the transformation and integration of representation of selected information based within the defined context (Suthers, 2005). The key challenge is minimizing the variance in a diversity of meanings assigned to the object of interest with its different interpretative viewpoints (Malhotra, 2001). Nosek (2001) suggests that members of groups have to “face the existence of multiple and conflicting interpretations. which requires that individuals: scan for and filter relevant information to create and maintain a sufficiently shared mental model to act effectively as possible.”

3.2.5 Cognitive Task Analysis

Cognitive task analysis (CTA) is the analysis of types of cognitive tasks and cognitive resources required to perform a task. Gott (1994) suggests that CTA only be used in situations where the task is complex, dynamic, unstable, ill structured, and difficult to learn because the action occurs in the mind of the performer. This fits the sensemaking process. The following are suggested CTA procedures (Randel, Pugh, and Wyman, 1996):

- Development of a cognitive task process model, which is accomplished by interviewing the sensemaker in a specific domain or context;
- Development of an information flow model using task diagrams and information processing flow diagrams to capture the sensemaker's process;
- Performance of a misconceptions analysis by reconciling convoluted terminologies and stratification of intelligence products according to the stakeholders; and,
- Performance of a structural knowledge analysis by developing conceptual maps or cognitive network representations of the sensemaking process.

As shown above, there are basic challenges in developing CTA for a sensemaking domain due to situation changes in time and space. However, some general CTA can be achieved. For instance, Polanyi's (1958) definition of focal knowledge can be used to infer how individuals in an organization assign meaning to what they see and feel. As echoed by Malhotra (2001), by understanding a situation, we can form the conceptual link between information available and the expected result or anticipation of task outcomes. It could also help us to understand the gap between performance expectations based on information in context (Malhotra, 2001; pp. 120), skillful knowledge (Hodgkins, 1992; Reber, 1993), formalized team knowledge (Nonaka, 1991), and knowing in action (Schon, 1994). Knowing in action is embedded in a socially and institutionally structured context; it goes beyond available rules, facts, theories, and operations.

A CTA for sensemaking will also have to recognize how to externalize the tacit knowing of the sensemakers. Explicit knowledge has sometimes been expressed in terms of knowing-how and knowing-that, which is essentially the application of what we know in order to solve problems (Ryle 1984, pp. 25-61). Knowing-how, or embodied knowledge, is characteristic of the expert, who acts, makes judgments, and so forth, without explicitly reflecting on the principles or rules involved. As Dretske has pointed out (Dretske 1988, p. 116), knowing-how involves more than just a certain technical or physical "know-how"; it also involves knowing how to obtain desired end-states, knowing what to do in order to obtain them, and knowing when to do it.

A CTA has many other challenges during a sensemaking process. Some of these are: identifying the “primitive” or tacit knowledge of the sensemaker in different situations; understanding how a team of sensemakers achieve compromise solutions; determining how sensemakers translate complex information into actionable knowledge; and, preserving and transferring a specific knowing to different situations (this is a tacit knowledge generalization problem).

3.2.6 Search for Representation

Russell, Stefik, Pirolli and Card (1993) note that the sensemaker creates representations to capture important regularities; in a way that supports the use of instantiated representations. This means that every situation requires that the sensemaker use some knowledge codification structure to cope with the emerging situation. The representation can be cause-effect mapping, rules of behavior, and so on.

Pirolli and Card (1999) studied an expert intelligence business analyst and observed that a schema structure was developed for each dimension associated with the type of information required to make decisions; for example, a schema for market survey and analysis, report types, and market penetrations. Through interviews and protocols with intelligence analysts, they found the evidence of schemata used to organize information to support the cognitive tasks of planning, reasoning and evaluation about alternative courses of action. Smallwood (1967) has used schema slots to describe the internal models held by pilots during instrument monitoring. Downs and Stea (1973) and Scholl (1987) have used schema organization of information to develop computational models of cognitive maps. Geiselman and Samet (1980) and Noble (1989) have applied schema theories to summarize military information and to elicit situation awareness information from the memory.

Due to the background, the challenges in sensemaking knowledge representations can be as equally multi-facetted as the sensemaking constructs itself. These include, but are not limited to, developing representation architectures that are robust and resilient to changing information and situations; recognizing common practices in problem situations; recognizing individual differences in the way humans process information and react to different situations; and, the ability to develop a common representation ontology and general formalisms that describe a sensemaking process.

3.2.7 Retrospective Case-based Memory

Based on a problem typology, a sensemaker is likely to encounter three broad events along a continuum of familiar to complex as noted by Vincente and Rasmussen (1992; pp. 589). These are:

a. Familiar events are routine in that sensemakers experience them frequently. As a result of a considerable amount of experience and training, sensemakers have acquired the skills required to deal with these events.
b. Unfamiliar but anticipated, events occur infrequently and, thus, the sensemakers do not have a great deal of experience to rely on.
c. Unfamiliar and unanticipated events rarely occur. These may pose a surprise and an unexpected call for novel ideas on the part of the sensemaker.

In each of the problem instances above, the sensemaker depends significantly on retrospective knowledge which would instantiate past cases from the long-term memory. During an occasion of panic and unpreparedness, the sensemaker is challenged on many fronts. These include:

- The ease with which previous cases can be retrieved and analyzed in order to compare them with the current situation;
- The availability of robust, cased-based rules to guide in the reasoning process;
- The availability of analytic rigor for cause-effect relations based on retrospective memory information; and,
- When confronted with a new novel situation, the ease of automatically matching similar features of the problem to those that have been encountered in the past.

In general, case-based sensemakers may tend to behave as if they know certain rules for the problem.

3.3 Chapter Summary

The ability to effectively model sensemaking has a correlation with the expertise level of the sensemaker. Experience makes it possible to use retrospective data to aid in mental simulation to make sense of novel circumstances. This thesis chapter centers on the challenges associated with sensemaking simulation. Our personal constructs tend to influence the definition and representation of the sensemaking process computationally during simulation. It is realized that situations are dynamic and constantly changing and, as the contexts change, so will the decisions and actions. Decisions for one situation might change as the situation develops. This indicates that sensemaking is context specific; therefore, what works for one situation may not work for another. Since, according to Polanyi (1967) we know more than we can tell, only a fraction of knowledge from an expert may be available to support data for simulation.

CHAPTER 4

Data/Frame Modeling and Simulation

4.1 Analytical Data/Frame Model

As DFM is discussed, the Hurricane Katrina disaster (Ubilla, Abdoun, Sasanakul, Sharp, Steedman, Vanadit-Ellis and Zimmie, 2008) shall be used as a case study in this thesis to demonstrate the applications of DFM as a sensemaking process. The brevity of events of Hurricane Katrina that occurred in the United States during the hurricane season 2005 follows.

Hurricane Katrina, dangerous Gulf hurricane that passed through New Orleans and many parts of Mississippi (MS) on August 29, 2010 (Bond-Graham, 2010) rained down destruction on humans and civil infrastructures. The devastation exceeded any level of preparation by the available emergency task forces, which included the Federal Emergency Management Agency (FEMA). Every potential situation seemed to be a priority: rescue operations for citizens trapped in the water; temporal shelter for survivors without home, food and water; tracking and recovering the dead to minimize health hazards; medical help; looting and so on. There was the potential for outbreaks of epidemiological diseases such as dysentery and influenza. There were mixed and confusing strategies that are mixed military and civilian relief task forces, hurried plans, and uncertain information. FEMA had to quickly assemble experts to help determine how the established national emergency policies made sense under the Katrina catastrophes.

The situation in New Orleans was that of panic, fear, confusion, and surprise to even the best planners. Information had to be managed from disparate sources.

In this particular case, many issues remain relevant: emergency deployment problems, lack of incident command structure, interoperability problems with responding mutual aid and lack of notifications to the public such as those without television, internet, and other important public information media. One can also consider plan assessment of worst case scenario versus what actually occurred; evacuation as a function of time; demographic characteristics of the people who stayed versus those who left and, information on vandals who looted properties. Detailed chronology of response steps and their effects such as when were food/drugs/tents deployed to readiness, when were they delivered to the city of New Orleans, when were they distributed on the ground, and how quickly did it make a difference may also be considered.

One of the models suited for sensemaking is the DFM, discussed earlier in Chapter 2. DFM is a subjective approach to information discovery. However, a discovery of its potential for quantitative modeling and simulation has been made during this research. We shall show its saliency in addressing complex problems such as Hurricane Katrina.

DFM consists of six sensemaking functions along with temporal path relations connecting the functions. These six functions are: elaborating the frame; questioning the frame; preserving the frame; comparing the frame; seeking the frame and reframing (Figure 2.4). These DFM components are discussed with application to the Hurricane Katrina case.

4.1.1 Data

- Sporadic data about storm, heavy rains and winds come in from the meteorological agencies and from satellite and radars. Media buzz about the situation in the Bahamas is publicized; various experts give opinions about the degree of possible damage and destruction to the projected hit or affected areas. An initial frame of the chaotic situation is outlined and drafted to from an initial picture of what is going on.

4.1.2 Elaborating the Frame

- Seeking/Inferring Data: Weather forecasts, reports and facts indicating hurricane and strong winds are bound for the northern Gulf Coast states are gathered and compared to previous weather information inferred by meteorologists and experts. Forecasted numbers of people to be displaced then becomes the source to indicate eminent danger.
- Extending the Frame: As more reports and satellite and radar images are received, additional information and aspects about the circumstances such as the growth of the tropical depression into a category 1 hurricane are added.
- Adding and Filling Slots: The extent of hurricane damage is amended as satellite and radar images of the hurricane are received. More information is sought, analyzed and structured to fit what was known from the Bahamas. The extent of damage caused by the tropical depression (turned storm) in the Bahamas is received.

- Internal Knowledge: Experiences from previous hurricanes, storms and floods aid to elaborate the frame and draw a clearer picture.

4.1.3 Questioning the Frame

- Inconsistent Data: Data being communicated does not match the frame, as residents and experts have received information about hurricanes of this magnitude in the past, which have turned out to be false alarms. Satellite and radar images of Hurricane Katrina are comparable to some previous hurricanes, but this is a storm of considerably greater magnitude.
- Anomaly Detection: Detection of unique circumstances initiates the use of proxy strategies. The hurricane strengthens very quickly and a hurricane watch followed by a hurricane warning is issued for Southeast Florida (FL). Even though winds are not very high, considerable damage is done and 14 people are reported dead.
- Violated Expectancies: Frames provide expectancies but when violated, people begin to question the precision of the frame. Previous false alarms violate people's expectancies and this causes them to disregard the hurricane alerts and warnings despite the reports of the hurricane strengthening very rapidly. Hurricane progresses from a category 1 into a category 5.

4.1.4 Preserving the Frame

- Knowledge Shields/Explaining Away Data: Minimize the importance of conflicting data and rationalize why inconsistent data does not match frame. Preparing for the hurricane with its floods and winds is pertinent, but it is at the expense of human lives. A hurricane watch is issued for Louisiana (LA) and a hurricane alert for Alabama (AL) and FL. A warning is issued from the National Hurricane Center (NHC) of coastal storm surge flooding and the possibility of some levee failure. New Orleans is issued a mandatory evacuation.

- Distortions/ Fixation Errors: continuing in the flawed situation account despite the anomalous data. People ignore seriousness of warnings despite hits in other cities and refuse to evacuate. Nonchalance of some residents and refusal to evacuate poses a major issue. Authorities fail to enforce mandatory evacuation.

4.1.5 Comparing Frames

- Sharpening Distinctions: Congregating evidence in support of the original frame; satellite and radar images confirm that the hurricane is fast approaching with gusty winds and heavy rainfall in its trail. Reports emerge from other cities of gusty winds. Hurricane Katrina hits LA and later the LA-MS border leaving significant damage, death and many missing people.
- Identifying Alternative Frames: Try to save engineering systems in place since levees will fail and cause dangerous floods (e.g. New Orleans). Hurricane Katrina weakens into a tropical storm in MS then later into a tropical depression in Tennessee. There is inadequate preparation such as allocating resources and training citizens to cope with degrading infrastructure and services as an aftermath of the hurricane.
- Simultaneous Testing: Assessing a frame as a way of contrasting incoming media reports, expert opinions, meteorological information and eyewitness calls to

analyze situation. Sensemakers deliberate which emergency to focus on immediately.

4.1.6 Seeking a Frame

- Searching for Information and Finding Anchors: Choose a relevant frame to produce justification. Mandatory evacuation is effected since hurricane hits main land as a category 3 and levee system fails flooding New Orleans. Destruction occurs in Bahamas even as a category 1 hurricane and navy satellite images of a fast growing hurricane over a very short time period serve as anchors to draw initial frame. Government's emergency response after the hurricane is long overdue. There are reports of violence and lawlessness in New Orleans.
- Cause-Effect Analysis: Local cause-and-effect analysis is made to produce just-in-time mental models of situation. Mental models abet the visualization of effects of failure to evacuate in the event of a terrible hurricane and flooding.
- Constructing a New Frame: Hurricane does not cause as much damage as anticipated. Nonetheless, major complications may be due to the lack of appropriate emergency response and the failure of human systems in place, such as levee failure, media coverage of chaos, and inadequate education of the people on safety procedures resulting in their poor judgment.

4.1.7 Reframing

- Establishing New Anchors and Re-interpreting Data: Defines association versus noise so as to allow for the dispose of irrelevant data whilst giving importance to new data. Reports of chaos, violence and lawlessness, indicating security unrest and a stalling relief process, must be resolved. Failure of levee system indicates need to research and implement an engineering system that works immediately to curb subsequent hurricanes and flooding.

- Recovering Discarded Data: Data hitherto discarded but is of pertinence to the frame such as projected financial and economic cost of Hurricane Katrina to the affected states and the federal government is used.
- Revising Goals: The goal to evacuate projected hit areas to include, provision of; adequate emergency response, security, support for physically and financially challenged victims and employing intelligible action is modified.

4.1.8 Frame

- Sieve out and concentrate on salient data so as to define goals and connect information. Set-up makeshift clinics and emergency centers to treat the injured and contain infections. Maintain a federally funded free transportation, temporary accommodation and feeding to relocate residents and people from the hurricane hit areas. Provide joint police and army presence for safety and security enforcement.

4.2 DFM Representation with Finite State Automata

4.2.1 Concepts of Finite State Automata

A FSA also referred to as a finite state machine is useful for modeling state changes in a system including effects of interaction with the environment (Oommen, Ng, and Hansen, 1991). FSA consists of a set of states and transitions between states, which may be labeled with labels chosen from a set; the same label, however, may appear on more than one transition. The finite states are joined by a set of edges that represent transitions, with an edge as a pair of vertices, while a sequence of edges is referred to as a walk (Linz, 2006).

There are many variations of automaton, but those that provide thematic knowledge for this project are Moore and Mealy automata. Moore machine is a FSA in which its outputs are determined by the current state alone (and do not depend directly on the input). The state diagram for a Moore machine will include an output signal for each state. The advantage of the Moore model is a simplification of the behavior. Consider Hurricane Katrina and DFM data/frame stage. The state machine recognizes two commands: "data available" and "data not available", “information clear”, or “information not clear” which trigger state changes. The entry action in state “data available” will trigger the sensemaker to start data analysis, leading to the decision “familiar” or “not familiar”. At the state of “data not available”, the action may lead to “search for more data” or “abort data search”.

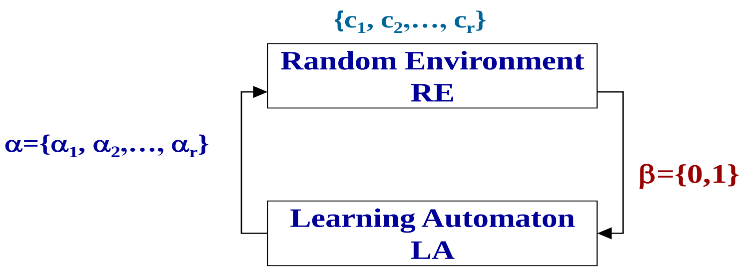
The Mealy FSA uses only input actions and output depends on both input and state. In the same example above, under Mealy FSA, there are two input actions: "analyze data if there is a command to determine correlation" and “search for more information if the there is no familiarity with the available data.” The Mealy FSA is known for its reduction of states (Wagner, 2005).

In practice, both Moore and Mealy automata can be used in a mixed model. Both methods can be deterministic. In deterministic automata, every state has exactly one transition for each possible input. In non-deterministic automata, an input can lead to one, more than one or no transition for a given state. A non-deterministic automaton has a number of probable moves and may predict a set of possible actions. Instead of stipulating the exact action, the automaton is given a choice of possible moves. For this to be feasible, the transition function is described so that its range is the set of plausible states. The vertices represent the states. If a walk has no duplicated edge it is said to be a path and, if no vertex is replicated, the path then is termed simple. A walk from a vertex to itself without repetitive edges is a cycle and, if there is no replicate other than the cycle's base, then it is simple. Conclusively, a loop is an edge from a vertex to itself. To aid in the visualization and representation of FSA, transition graphs are used. Figure 4.1 shows simple FSA components and their interaction with the environment.

A FSA is a device that can be in one of its finite number of states. In certain conditions, it can switch to another state. This is called a transition. When the automaton starts working (when it is switched on) it can be in one of its initial states. There is also another important subset of states of the automaton: the final states. If the automaton is in a final state when it stops working, it is said to accept its input. The input is a sequence of symbols. The interpretation of the symbols depends on the application; they usually represent events or can be interpreted as "the event that particular data became available." The symbols must come from a finite set of symbols called the alphabet. If a particular symbol in a particular state triggers a transition from that state to another one that transition is labeled with that symbol. The labels of transitions can contain one particular symbol that is not in the alphabet (Daciuk, 1998).

Here is a list of terminology used throughout the remainder of the thesis:

1. FSA: A collection of states and transitions that outline a path of actions that may occur.
2. State: A state is a position in time. For example, when you are at the bus stop, you are currently in a waiting state.
3. Event: An event is something that happens in time. For example, the bus has arrived.
4. Action: A task performed given a certain event that occurred. For example, you enter the bus.
5. Transition: A link between two states. May be unidirectional or bidirectional.



- **A:** $\alpha=\{\alpha_1, \alpha_2, \ldots, \alpha_r\}$ - *r* actions
- $\{c_1, c_2, \ldots, c_r\}$ - action *penalty probabilities*
- $\beta=\{0,1\}$ - response from the *Environment*: *reward* and *penalty of sensemaking behaviors*

Figure 4.1. Simplified Finite State Automaton Diagram

Formally, a labeled transition system is a tuple (S, A, →) where S is a set of states, A is a set of labels or actions and $\rightarrow \subseteq S \times A \times S$ is a ternary relation of labeled transitions. If $s_1, s_2 \in S$ and $\alpha \in A$, then $(s_1, \alpha, s_2) \in \rightarrow$ is written as $s_1 \overset{\alpha}{\rightarrow} s_2$. This represents the transition from state s_1 to state s_2 with label α as the trigger or action enabling transition. Labels may represent different things depending on the language of interest. Typical uses of labels include expected input (conditions) that must be true to trigger the transition, or actions performed during the transition. Finite automata are defined as algebraic structures connecting internal states to input and output sequences proffering a common model of the agent (Kopecek and Skarvada, 2003).

FSA studies of Wagner (2005) construe it as a quintuple; constituents of which are as indicated below.

$$\mathbf{FSA} = < \boldsymbol{\Sigma}, \boldsymbol{S}, \mathbf{s_0}, \boldsymbol{\delta}, \mathbf{F} >$$

where;

i. Σ is the input alphabet; a finite non empty set of symbols,

ii. S is a finite non empty set of states,

iii. s_0 is an initial state; an element of S: $s_0 \in S$,

iv. δ is the state transition function: $\delta: S \times \Sigma \rightarrow S$,

v. F is the set of final states, a (possibly empty) subset of S.

The pedagogical works of Booth (1967) on FSA also define it as a five tuple represented in the equation below;

$$\mathbf{F} = < \boldsymbol{X}, \boldsymbol{Q}, \boldsymbol{Y}, \boldsymbol{D}, \boldsymbol{W} >$$

where;

i. X represents a finite set of input symbols
ii. Q represents a set of possible internal states of the automaton
iii. Y represents a finite set of output symbols
iv. D represents a mapping of X × Q onto Q and is referred to as the next-state function
v. W represents a mapping of X × Q onto Y and is called the output function

The prime goal of an automaton is to study and engage the environment in its decision process. Therefore, a characteristic of the conventional FSA is the ability of its system to adapt and interact with an environment to identify the best suited environmental action (Oommen, et al., 1991). Inferring from Figure 4.1 the FSA algorithm is a simple four-stage process namely:

a) The automaton chooses one of the possible actions (α) offered.
b) The chosen action at time t is given as input to the environment.
c) The random environment determines the rewards or penalties of the chosen action.
d) The environment response to the input: the automaton chooses the next action.

4.3 Theoretical Data/Frame Modeling

The analytical model for DFM is shown in Figure 4.2 with some example inputs for each state. The DFM was modeled with FSA methods to illustrate the behavior transitions of a hurricane over time. A decision flow encompassing sensemaking for the purpose of this thesis is also represented below by Figure 4.3. The decision flow below was developed from the DFM. It engulfs the states from the original DFM and sensemaking questioning and answering. The cognitive processes of the sensemaker which is illustrative of the thinking path during a sensemaking process of a complex situation is illustrated by this figure

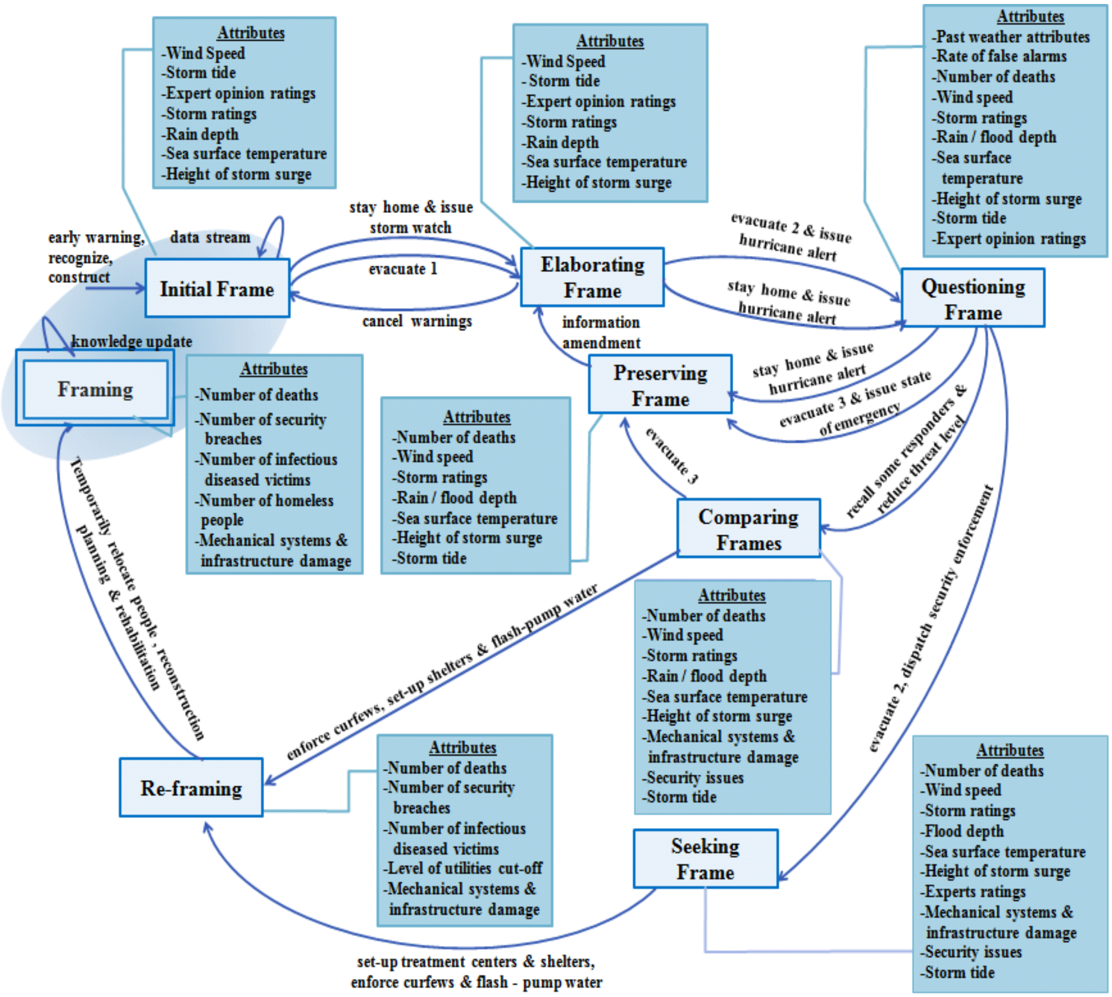


Figure 4.2. Finite State Automaton of Information Flow for Hurricanes

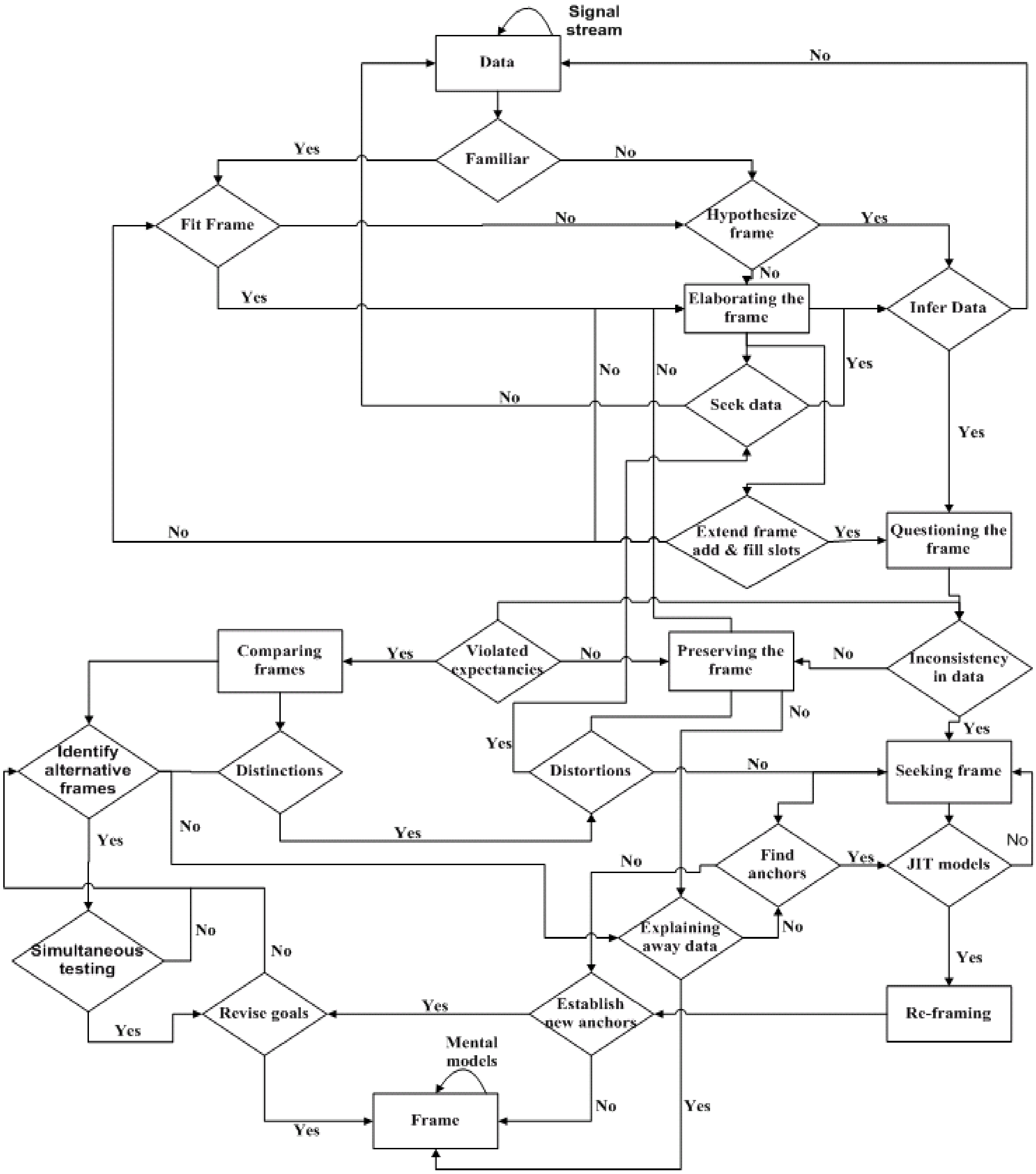


Figure 4.3. Decision Flow of Sensemaking Process using Data/Frame Model

4.3.1 Sample Production Rules in FSA for Hurricanes

The life cycle of a hurricane can be understood with Figure 4.4, which gives the path to formation from a tropical disturbance into a full-blown hurricane. Characteristics of the elements in this life cycle such as speed of accompanying winds, height of accompanying storm surge and depth of accompanying rainfall aided in the formulation of the production rules for the automaton aforementioned.

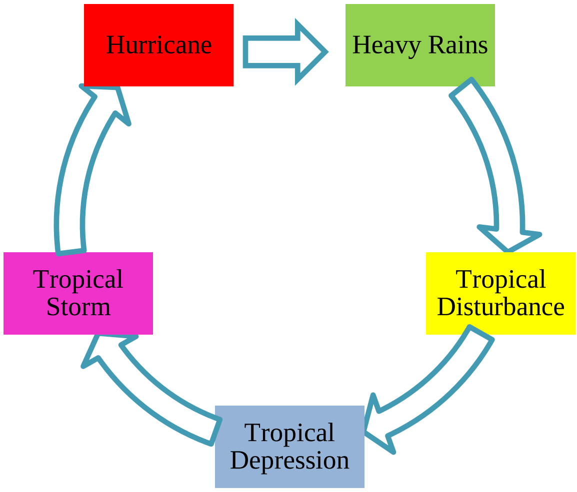


Figure 4.4. Life Cycle of a Hurricane

The FSA for the Hurricane Katrina was designed with conditions based on the theory of classifications and categorizations. The National Oceanic and Atmospheric Administration (NOAA) rank storms with a Space Weather Scale according to the type of storm. The K-index for geomagnetic storms is derived in real-time from the Boulder

NOAA magnetometer. Table 4.1 below indicates three storm types and their corresponding attributes. Storms in this table are categorized from five to one in decreasing order of severity. The scale was introduced by the NOAA to communicate to the public and technical operators space weather conditions and their likely effects on technological systems in the form of a Richter scale. See (www.NOAA.gov).

Table 4.1. National Oceanic and Atmospheric Administration Space Weather Scale

Geomagnetic Storms		
Category		**Physical Measure**
Scale	**Descriptor**	**K-index (Kp) values 3-hour intervals**
G5	Extreme	9
G4	Severe	-9, 8
G3	Strong	7
G2	Moderate	6
G1	Minor	5
Solar Radiation Storms		
Scale	**Descriptor**	**Flux level of ≥ 10MeV particles (ions)**
S5	Extreme	10^5
S4	Severe	10^4
S3	Strong	10^3
S2	Moderate	10^2
S1	Minor	10^1
Radio Blackouts		
Scale	**Descriptor**	**X-ray peak brightness (class, flux)**
R5	Extreme	X20, (2×10^{-3})
R4	Severe	X10, (10^{-3})
R3	Strong	X1, (10^{-4})
R3	Moderate	M5, (5×10^{-5})
R1	Minor	M1, (10^{-5})

Another categorization scale for the FSA conditions is that of hurricanes as illustrated below in Table 4.2. The Saffir-Simpson Scale and storm surge classifications of hurricane intensity (Graumann, Houston, Lawrimore, Levinson, Lott, McCown, Stephens and Wuertz, 2005) are in use. This table shows the categorization of hurricanes with their corresponding storm surge.

Table 4.2. Hurricane Intensity using Saffir-Simpson Scale and Storm Surge

Category	Effects	Speed (knots)	Speed (mph)	Storm Surge (ft)
5	Catastrophic damage	≥ 136	≥ 156	≥ 18
4	Catastrophic damage	114-135	131-155	13-18
3	Devastating damage	96-113	111-130	09-12
2	Extremely dangerous, extensive damage	83-095	96-110	06-08
1	Very dangerous, some damage	64-082	74-095	04-05

Production rules that govern the transition of the FSA are detailed below.

1. Initial Frame

If (38mph > wind speed) or

(2ft >storm surge) or

(1 >expert ratings) or

(1 > NOAA storm rating) or

(rainfall < 8in) and

(sea surface temperature < 82^{0}F) and

```
            (storm tide < 2ft)
Then, data stream update
ElseIf,
If          ($38mph \le$ wind speed $\le$  73mph) or
            ($2ft \le$ storm surge $\le 4ft$) or
            ($1 \le$ expert ratings $\le 2$) or
            ($1 \le$ NOAA storm rating $\le$  2) or
            ($8in \le$ rainfall $\le 14in$) and
            ($82^{0}F \le$ sea surface temperature $\le 90^{0}F$) and
            ($2ft \le$ storm tide $\le 4ft$)
Then, stay home & issue storm watch
Else,
If          ($73mph <$ wind speed $\le 156mph$) or
            ($4ft <$ storm surge $\le 18ft$) or
            ($2 <$ expert ratings $\le 5$) or
            ($3 \le$ NOAA storm rating $\le$  5) and
            (rainfall $> 14in$) and
            (sea surface temperature $> 90^{0}F$) and
            (storm tide $> 4ft$)
Then, evacuate 1
```

The initial frame marks the start of the FSA. As data streams of ongoing satellite and radar images from National Data Buoy Center (NDBC) and NHC, phone calls, eyewitness news et cetera, is received, an early warning is issued by the National Weather Service (NWS). An initial frame of the incoming data is constructed once the data is recognized. The state of initial frame transits to the elaborating frame state. Residents are advised to stay home while a storm watch is issued for the next 36 hours. This action is undertaken if the weather attributes fall below that of a category 1 hurricane together with other constraining factors such as expert ratings on potential danger and damage and depth of rainfall. If on the other hand, weather attributes fall above that of a tropical storm, with increased rainfall depth and very high storm and danger ratings; an evacuation 1 action is issued. Evacuation 1 encompasses the issue of an order to evacuate the affected or projected hit areas with no coercion on the part of the issuing authorities such as FEMA, Governor, et cetera. Finally, if the weather attributes fall below that of a tropical depression then the data stream coming in updates the existing data while further observation is of the situation is done.

2. Elaborating Frame

If (111mph $\leq$ wind speed) or
(9ft $\leq$ storm surge) or
(3 < expert ratings $\leq$ 5) or
(3 $\leq$ NOAA storm rating $\leq$ 5) and
(rainfall > 14in) and
(sea surface temperature > 90^oF) and

```
            (storm tide  > 4ft)
Then, evacuate 2 & issue hurricane alert
ElseIf,
If          (38mph < wind speed < 111mph) or
            (2ft ≤ storm surge ≤ 8ft) or
            (2 ≤ expert ratings < 4) or
            (2 ≤ NOAA storm rating < 4) and
            (8in ≤ rainfall ≤ 14in) and
            ($82^0$F ≤ sea surface temperature ≤ $90^0$F) and
            (2ft ≤ storm tide ≤ 4ft)
Then, stay home & issue hurricane alert
Else,
If          (wind speed < 38mph) or
            (storm surge < 2ft) or
            (expert ratings < 2) or
            (NOAA storm rating < 2) and
            (rainfall < 8in)  and
            (sea surface temperature < $82^0$F) and
            (storm tide < 2ft)
Then, cancel warnings
```

The next stage of the sensemaking process is the elaboration of the initial frame of a damaging storm, that could possible become a hurricane formed at the commencement of the automaton. More data is sought and inferred for information and the existing frame is extended with added slots. In order to progress to the next state, questioning frame; if the hurricane attributes are greater than that of a category 2 with high depths of rainfall, expert damage and disaster ratings then, a hurricane alert must be issued and an evacuate 2 order given. Evacuate 2 entails announcement in print, radio, television, et cetera for residents, tourists, workers and people in the vicinity to evacuate. Aid workers (police, fire personnel, coast guards, national guards, volunteers, et cetera) are sent to the area to encourage, assist and advice people to leave. On the other hand, if the attributes are less than that of a tropical depression with rainfall depth below the threshold of 8 inches then, warnings will be cancelled until there are new changes. Residents are advised to stay home while a hurricane alert is issued if the attributes are between that of a tropical depression and a tropical storm.

3. Questioning Frame

If (wind speed ≤ 73mph) and
(storm surge < 3ft) and
(expert ratings < 2) or
(NOAA storm rating < 2) and
((past wind speed, storm surge, rainfall, sea surface temperature, storm tide, storm ratings, deaths > current wind speed, storm surge, rainfall, sea surface temperature, storm tide, storm ratings, deaths)) and
(rainfall < 8in) and
(sea surface temperature < 83^0F) and

```
        (storm tide < 3ft) and
        (false alarms rate < 1%) and
        (number dead$_{(n)}$ <  number dead$_{(n-1)}$)
Then, recall some responders & reduce threat level
ElseIf,
If      (73mph < wind speed < 85mph) and
        (8in ≤ rainfall < 14in) and
        ($83^0$F ≤ sea surface temperature ≤ $86^0$F) and
        (3ft ≤storm tide < 5ft) and
        (3ft ≤ storm surge < 5ft) or
        (false alarms rate > 1%) or
        (number dead$_{(n)}$ ≥  number dead$_{(n-1)}$)  or
        (2 ≤ expert ratings < 3) or
        (2 ≤ NOAA storm rating < 3) or
        ((past wind speed, storm surge, rainfall, sea surface temperature, storm tide, storm ratings, deaths ≥ current wind speed, storm surge, rainfall, sea surface temperature,  storm tide, storm ratings, deaths))
  Then, stay home & issue hurricane alert
ElseIf,
If      (100mph ≤ wind speed) or
        (8ft < storm surge) or
        (4 < expert ratings ≤ 5) or
```

```
          ($4 <$ NOAA storm rating $\leq 5$) or
          (rainfall $> 24$in)  or
          ((past wind speed, storm surge, rainfall, sea surface temperature , storm tide,
          storm ratings, deaths  < current wind speed, storm surge, rainfall, sea surface
          temperature, storm tide, storm ratings, deaths)) or
          (false alarm rate $> 1\%$) or
          ($\text{number dead}_{(n)} \geq \text{number dead}_{(n-1)}$) and
          (sea surface temperature $> 92^{0}$F)  and
          (storm tide  $> 8$ft)
Then, evacuate 3 & issue state of emergency
Else,
If        ($85\text{mph} \leq$ wind speed $< 100$mph) and
          ($5\text{ft} \leq$ storm surge $\leq 8$ft) and
          ($14\text{in} \leq$ rainfall $\leq 24$in) and
          ($87^{0}\text{F} \leq$ sea surface temperature $\leq 92^{0}$F) and
          ($5\text{ft} \leq$ storm tide $\leq 8$ft) or
          ($3 \leq$ expert ratings $< 5$) or
          ($3 <$ NOAA storm rating $< 5$) or
          (false alarms rate $\geq 1\%$) or
          ($\text{number dead}_{(n)} \geq \text{number dead}_{(n-1)}$) or
          ((past wind speed, storm surge, rainfall, sea surface temperature , storm tide,
          storm ratings, deaths  < current wind speed, storm surge, rainfall, sea surface
```

temperature, storm tide, storm ratings, deaths))

Then, evacuate 2 & dispatch security enforcement

At this state, the sensemaker questions the existing frame for inconsistent data detection and explanations to violated expectancies making use of tacit knowledge, hindsight and retrospective data of memorized past similar situations amongst others. The comparison of past weather attributes with current weather attributes are converted to numerical values from 0 to 4 with zero serving as the default value. The conversion is interpreted as follows: past weather attributes greater than current attributes, one; past weather attributes greater than or equal to current attributes, two; past weather attributes less than or equal to current attributes, three and past weather attributes less than current attributes, four.

Transition from this state to the state of comparing frames is on condition that all attributes of this state but storm ratings occur simultaneously. The current attributes must be less than that of a category 1 hurricane and past storm attributes (that caused low to no damage) must be greater than current storm attributes. Also, if rate of past false alarms (warning of storms, hurricanes or weather dangers that did not occur) is less than 1% and the number of dead people associated with the evolving weather occurrences reduces with time, then the threat levels should be reduced and some responders may be relieved of their duty. These occurrences should prompt the sensemaker to consider an alternate frame as the focus. The existing frame and alternate frames must be compared for the best frame. When the false alarm rates are high (greater than 1% significance level), there is the tendency for people to ignore eminent danger and assume it to be another false alarm. High false alarm rates also introduce doubt for sensemakers. Lower rates nevertheless, alert everyone involved to take threats and diagnosis seriously.

However, if the current attributes are greater than or equal to a category 2 hurricane, past storm attributes (that caused damages) are less than the current storm attributes, false alarm rate is greater than 1%, the number of dead people associated with the evolving weather occurrences increases with time or experts rating of danger and damage is high then, issue a state of emergency and evacuate 3 order to transit to the state preserving frame. This move confirms that the current frame of a devastating hurricane and its complications is confirmed. Evacuate 3 engrosses an enforcement of mandatory evacuation of the vicinity. Rescue crews and responders are sent to the locality to aid in evacuation. People are escorted out of the area either willingly or unwillingly for the sake of their safety by joint police and army.

Furthermore, an order to stay home and an issue of a hurricane alert are the plausible causes of action that may be passed on to decision makers if the attributes are that of a category 1 hurricane. People in the projected hit areas or affected areas are advised to stay indoors in a comfortable place to wait out the hurricane while further observation is underway. The “dos and don’ts” during a hurricane are streamed to educate the people. Finally, if the occurring hurricane’s attributes are between that of a category 1 and 2 but other attributes such as expert ratings or past weather attributes suggest increased threats then, dispatch security enforcement and issue an evacuate 2 action to transit to seeking frame. The weather occurrences poses a threat but the increase in deaths unrelated to the direct impact of the hurricane making landfall coupled with the evolving violent behaviors of the people in the affected areas such as rapes, suicide, lootings, burglary, vandalism, gang activities, drug and alcohol peddling, violent assaults, et cetera, present more eminent danger and must be curbed.

4. Preserving Frame

If (Update information = (wind speed, storm surge, rainfall, sea surface temperature, storm tide, storm ratings, deaths)$_n$ = (wind speed, storm surge, rainfall, sea surface temperature, storm tide, storm ratings, deaths)$_{n+1}$)

Then, amend information.

This state of the sensemaking machine preserves the existing frame and keeps the knowledge gained on the hurricane situation current. This state completes the loop that connects elaborating and questioning frame states. This state transits to elaborating frame state if information is updated. Update information includes current storm attributes replacing and keeping information current as time progresses. The monitoring and measurement of hurricane attributes will be on a continuous basis and existing information will be amended with information changes.

5. Comparing Frames

If (111mph ≤ wind speed) or
(storm surge > 8ft) or
(rainfall > 8in) or
(3 ≤ NOAA storm rating ≤ S5) and
(sea surface temperature ≥ 88^{o}F) and
(storm tide > 8ft) and

(number $\text{dead}_{(n)} \geq$ number $\text{dead}_{(n-1)}$) and

(security breach areas ≤ 1) and

(mechanical systems and infrastructure $\text{damage}_{(n)} <$ mechanical systems and infrastructure $\text{damage}_{(n-1)}$)

Then, evacuate 3

Else,

If (wind speed < 110mph) and

(storm surge $\leq$ 8ft) and

(sea surface temperature < 88^{0}F) and

(storm tide $\leq$ 8ft) and

(security breach areas > 1) and

(mechanical systems and infrastructure $\text{damage}_{(n)} \geq$ mechanical systems and infrastructure $\text{damage}_{(n-1)}$) or

(rainfall < 8inches) or

(NOAA storm rating ≤ 2) or

(number $\text{dead}_{(n)} \geq$ number $\text{dead}_{(n-1)}$)

Then, enforce curfews, set-up shelters & flash- pump water

In this state of the automaton, the original frame of a hurricane and an alternate frame of mechanical systems and infrastructure damage are simultaneously contrasted. For this state to progress to the subsequent state, if the existing hurricane frame is the best frame, then the frame must be preserved. On the other hand, if the alternate frame is best then turn to revising the goals through re-framing. Mechanical systems and infrastructure damage that can be experienced during or after a hurricane makes landfall include flooded houses, unsteady houses, collapsed levees, collapsed or unsteady bridges, buildings and dams, et cetera. A category 3 hurricane or greater coupled with increased threats of danger and damage such as an increase in the number of dead people from the evolving weather occurrences warrant an evacuate 3.

Alternatively if the hurricane attributes are those of a category 2 or lower with increases in rates and count of mechanical systems and infrastructure damage, focus must be on salvaging what is left of the infrastructure; providing medical assistance; maintaining order and accommodating victims by providing temporary shelter, food, clothing, warmth, and basic needs. The possible causes of action from the sensemaker to the decision maker are to enforce curfews, set-up shelters and flash-pump water. This transits comparing frames to the re-framing state. Curfews will enable security enforcement keep people in check and properly monitored in the shelters. Collapsed levees and water breaks causing flash flooding of streets, vehicles and building need to be flash-pumped in an effort to restore the affected areas and make it habitable.

6. Seeking Frame

If (wind speed < 110mph) and
(storm surge < 8ft) and
(flood depth < 8ft) and
(sea surface temperature < 88^{0}F) and
(storm tide < 8ft) or
(NOAA storm rating ≤ 2) or

(number $\text{dead}_{(n)} \geq$ number $\text{dead}_{(n-1)}$) or

(security breach areas > 1) or

(mechanical systems and infrastructure $\text{damage}_{(n)} \geq$ mechanical systems or infrastructure $\text{damage}_{(n-1)}$) or

(mechanical systems and infrastructure damage rate ≥ 50%) or

Then, set-up treatment centers & shelters, flash-pump water & enforce curfews

In this state succeeding questioning frame, a realization of a new eminent danger leads a sensemaker to seek and construct a new frame. Increase in post hurricane dangers and a reduction of weather threats propel the construction of a new frame. This state transits to the re-framing state for goals revision when the number and rate of mechanical systems and infrastructure damage increases. An increase in the number of deaths caused by non-weather related problems lead to the construction of a new frame and the plausible causes of action; to set-up treatment centers (to treat the sick and injured) and shelters, flash-pump water, enforce curfews and security presence to prevent breaches. Possible security threats include rape, suicide, looting, burglary, vandalism, gang activities, drug and alcohol peddling, violent assaults and illegal possession of arms.

7. Re-framing

If (mechanical systems and infrastructure damage rate ≥ 50%) and

(number $\text{dead}_{(n)} \geq$ number $\text{dead}_{(n-1)}$) and

(security breaches > 1) and

(number of infectious disease $\text{victims}_{(n)} \geq$ number of infectious disease $\text{victims}_{(n-1)}$) and

(percentage of utility cut-off $\geq$ 25%)

Then, temporarily relocate people, start reconstruction planning & rehabilitation

In this latter state of the automaton, new goals are set and new data re-interpreted making use of retrospective data, more information and foresight. An increase in security violations, rates and number of mechanical systems and infrastructural damage, number of deaths associated with violence and ill health, number of people affected by infectious diseases and percentage of utility (water, electricity, telephone, et cetera) cut-off instigates the temporary relocation of people, commencement of a plan for reconstruction of the affected areas and the rehabilitation of victims. Victims of the disaster, their families and friends have to undergo a form of rehabilitation for the physical, financial, economic, emotional and psychological scars received as a result of injuries, angst and loss from the disaster. Evacuees have to be vaccinated to prevent the further spread of contagious illnesses such as hepatitis A and B, rubella, measles, mumps, tuberculosis, typhoid, influenza and other infectious diseases.

8. Framing

If (number of deaths, number of security breaches, number of infectious disease victims, number of homeless people and mechanical systems and infrastructure damage rate)$_n$ = (number of deaths, number of security breaches, number of infectious disease victims, number of homeless people and mechanical systems and infrastructure damage rate)$_{n+1}$)

Then, knowledge update

This is the last of the states in the sensemaking automaton where goals are defined and data is filtered. It is also the final state in the automaton. In this state, the knowledge gained throughout the sensemaking process is updated and a clear picture of the evolved situation is formed. New information on number of deaths, security breaches, infectious disease victims, number of homeless victims, mechanical systems and infrastructure damage rate replace existing information and become the current information.

4.3.2 Illustrative Example of FSA Simulation of Hurricane Katrina

This model is a subset of the generic model in Figure 4.2 and is to serve as an illustrative example. The sequence of state changes as Hurricane Katrina evolved from August 23, 2005 to August 31, 2005 is represented numerically from stages 1 to 15 to aid in comprehension. The defining conditions governing the transition of the automaton from one state to the other are represented below.

August 23, 2005

5am: Tropical depression in Bahamas; 175 miles Southeast of Nassau

Wind speed = 34.5mph

Storm surge = 2ft

Sea surface temperature = 82°F

Storm tide = 2ft

Recognize, early warning and construct frame of situation

1. Initial Frame to Elaborating Frame

August 24, 2005

11am: Tropical storm, 230 miles east of Miami, FL is named Katrina

Wind speed = 40mph

Storm surge = 2ft

Sea surface temperature = 82°F

Storm tide = 2ft

Expert rating = 1

Action: Stay home & issue storm watch for next 36hours over FL

2. Elaborating Frame to Questioning Frame

August 25, 2005

5pm: Tropical storm becomes category 1 hurricane, 15 miles east of Fort Lauderdale, FL

Wind speed = 75mph

Storm surge = 4ft

Sea surface temperature = 83°F

Storm tide = 4ft

Expert rating = 2

Action: Stay home & issue hurricane alert over FL

3. Questioning Frame to Preserving Frame

August 25, 2005

7pm: North Miami and Hallandale Beaches, Southeast FL hit

Wind speed = 80mph

Storm surge = 4ft

Sea surface temperature = 85°F

Storm tide = 4ft

Rain depth = 12in

Expert rating = 3

Number of deaths = 11

Action: Stay home & issue hurricane alert over FL and surrounding States

4. Preserving Frame to Elaborating Frame

August 26, 2005

1am: Hurricane Katrina weakens into a tropical storm in FL

Wind speed = 45mph

Storm surge = 3ft

Sea surface temperature = 80°F

Storm tide = 2ft

Rain depth = 5in

Number of deaths = 11

Action: Amend information of hurricane for FL

5. Elaborating Frame to Questioning Frame

August 26, 2005

5am: Hurricane Katrina strengthens over Gulf of Mexico around Key Largo, FL

Wind speed = 70mph

Storm surge = 4ft

Sea surface temperature = 83°F

Storm tide = 3ft

Rain depth = 8inches

Expert rating = 3

Number of deaths = 11

Action: Stay home & issue hurricane alert over FL, AL, LA and MS.

6. Questioning Frame to Preserving Frame

August 26, 2005

11:30am: NHC reports hurricane grows into category 2 and proceeds towards LA and MS; they predict a major hurricane

Wind speed = 100mph

Storm surge = 10ft

Sea surface temperature = 93°F

Storm tide = 9ft

Rain depth = 10in

Expert rating = 5

Number of deaths = 11

Action: Evacuate 3 & issue state of emergency in LA and MS.

7. Preserving Frame to Elaborating Frame

August 27, 2005

5am: Hurricane grows into category 3; NOAA forecast hurricane might strengthen into a category 5

Wind speed = 115mph

Storm surge = 12ft

Sea surface temperature = 95°F

Storm tide = 10ft

Rain depth = 14in

Number of deaths = 11

Action: Amend information of hurricane for LA.

8. Elaborating Frame to Questioning Frame

August 28, 2005

2am: Hurricane strengthens into category 4 with warm air over Gulf of Mexico

Wind speed = 145mph

Storm surge = 20ft

Sea surface temperature = 105°F

Storm tide = 16ft

Rain depth = 15in

Expert rating = 5

Number of deaths = 11

Action: Evacuate 2 & issue hurricane alert over LA

9. Questioning Frame to Preserving Frame

August 28, 2005

11am: Hurricane strengthens into category 5 with warm air over Gulf of Mexico

Wind speed = 175mph

Storm surge = 30ft

Sea surface temperature = 125°F

Storm tide = 20ft

Rain depth = 20in

Expert rating = 5

Number of deaths = 11

Action: Evacuate 3 & issue state of emergency in LA and MS.

10. Preserving Frame to Elaborating Frame

August 29, 2005

2am: Hurricane weakens to category 4 but with high tide around New Orleans, LA

Wind speed = 155mph

Storm surge = 24ft

Sea surface temperature = 107°F

Storm tide = 40ft

Rain depth = 15in

Number of deaths = 11

Action: Amend information of hurricane for LA

11. Elaborating Frame to Questioning Frame

August 29, 2005

5am: Hurricane weakens prior to landfall

Wind speed = 150mph

Storm surge = 16ft

Sea surface temperature = 104°F

Storm tide = 30ft

Rain depth = 15in

Number of deaths = 11

Expert rating = 5

Action: Evacuate 2 & issue hurricane alert in LA

12. Questioning Frame to Seeking Frame

August 29, 2005

6pm: Hurricane weakens into category 3 from 6am to 11am and hits New Orleans, MS-LA border, Biloxi and Gulfport, MS. Hurricane continues to weaken throughout the day and becomes category 1 at 6pm and finally a tropical storm later in the evening.

Wind speed = 90mph

Storm surge = 5ft

Sea surface temperature = 92°F

Storm tide = 5ft

Rain depth = 14in

Number of deaths = 1220

Expert rating = 4

Action: Evacuate 2 & dispatch security enforcement to LA

13. Seeking Frame to Re-Framing

August 30, 2005

Day: NHC reports tropical storm weakens into a tropical depression from LA to Tennessee and Kentucky

Wind speed = 35mph

Storm surge = 2ft

Sea surface temperature = 78°F

Flood depth = 5ft

Storm tide = 2ft

Number of deaths = 1220

Extent of mechanical and infrastructure damage = 85%

Number of levee breaches = 53

Security issues = 9

Action: Set-up treatment centers and shelters, flash-pump water and enforce curfews

14. Re-Framing to Framing

August 31, 2005

Day: Flooding of New Orleans, LA and Health and Human Hazard reports public health emergency in LA, MS, AL and FL

Number of deaths = 1450

Security issues = 10

Number of infectious victims = 1100

Level of utility cut-off = 95%

Extent of mechanical and infrastructure damage = 88%

Action: Temporarily relocate residents, reconstruct planning and rehabilitate victims.

15. Framing

September 1, 2005 – Present

Number of people who became homeless = 1 million

Total number of deaths = 1833

Total number of people who contracted infectious diseases = 1249

Number of security issues = 9

Extent of mechanical and infrastructure damage = 90%

Total land affected by hurricane = 90,000 square miles

Gallons of oil spilled = 8 million

Debris created by hurricane = 118 million cubic yards

Estimated cost of Katrina = $125 billion

Action: Knowledge update.

4.4 Illustrative Simulation Results of Hurricane Katrina

Hurricane Katrina based on a theoretical simulation yielded behaviors of state changes with respect to new information and the sensemaking process. Based on the transitions of the FSA in Figure 4.5 below, the movement of states from one to another is numbered in order of progression from 1 to 15. The operation of the automaton seen previously by a sensemaker during the Hurricane Katrina would have provided the thinking path and plausible causes of action discussed below in 15 stages.

Stage 1. Initial Frame Outcome**:** Since the attributes of the storm at present are below that of a category 1 hurricane but higher than normal, and expert opinion rating of danger is low; residents and people in FL are advised to stay home and a storm watch for the next 36 hours is issued on air, internet and television. This will enable meteorologists and weather experts study the behavior and attributes of the storm.

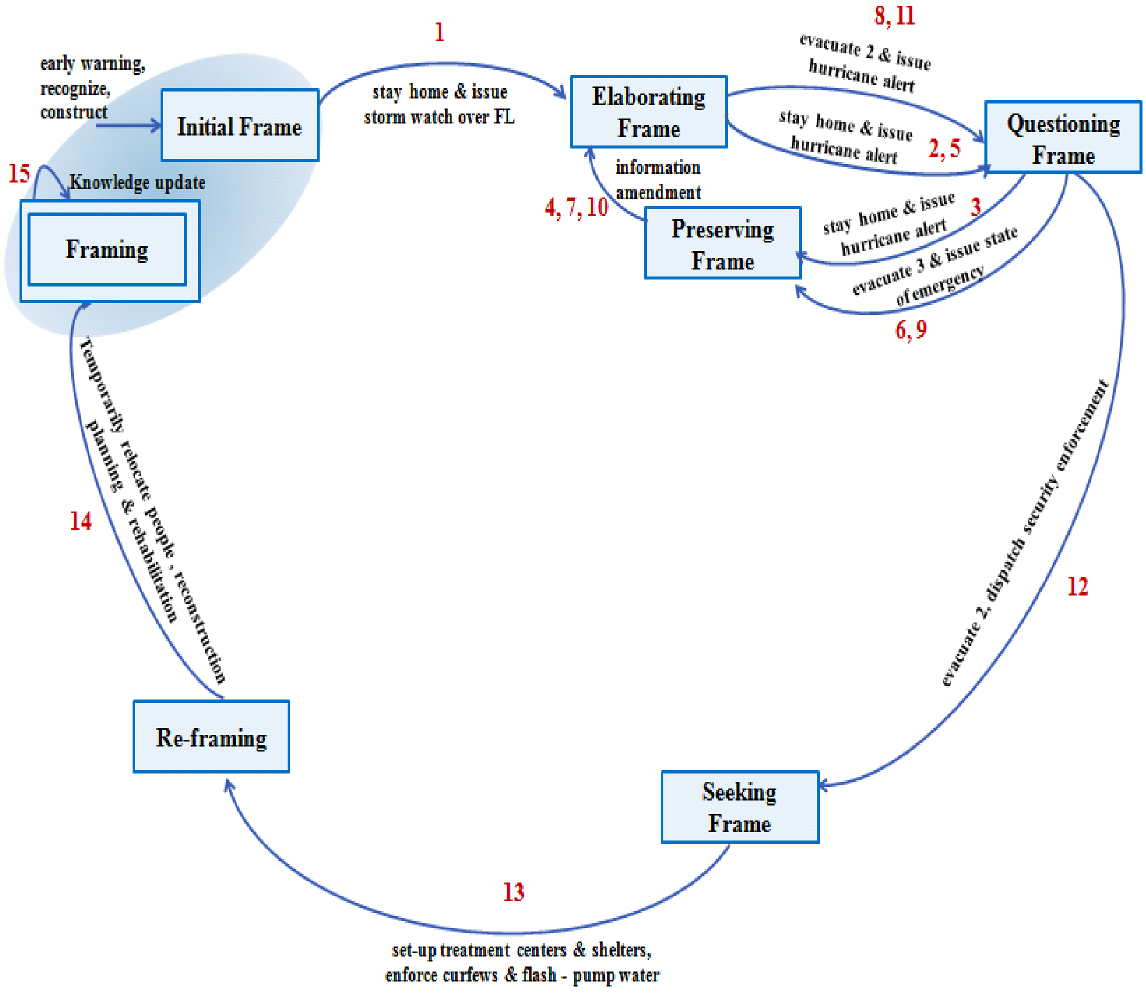


Figure 4.5. Finite State Automaton Simulation of Hurricane Katrina

Stage 2. Elaborating Frame Outcome: As the storm strengthens from a tropical storm into a category 1 hurricane heading towards FL, residents are advised to stay home while a hurricane alert is issued. The status of the hurricane is updated as more information comes in and slots are filled. Some sensemaking questions asked are: what information is missing, what needs to be done, are there any similar hurricanes in the past, what was the behavior of past hurricanes, et cetera.

Stage 3. Questioning Frame Outcome: The sensemaker questions the frame and some sensemaking questions asked are: is this the only eminent danger; is this considered a false alarm; are there any contradictory or inconsistent data? Based on retrospective and available data and experience, residents and people in FL, MS, AL, and LA are advised to stay home and a hurricane alert is issued via radio, internet and television. The path of the evolving hurricane is continuously and cautiously observed.

Stage 4. Preserving Frame Outcome: Frame of storm turned hurricane is preserved and the status of the hurricane and its effects in FL is updated.

Stage 5. Elaborating Frame: The status of the hurricane is updated as more information comes in. Missing slots are filled. Some sensemaking questions asked are: what information is missing, what needs to be done, are there any similar hurricanes in the past, what was the behavior of past hurricanes? Residents and the populace of FL and surrounding states: AL, LA, and MS are advised to stay home and a hurricane alert is issued on air, internet and television.

Stage 6. Questioning Frame Outcome: The sensemaker, questions the accuracy of the frame. Some sensemaking questions asked are what needs to be done as the hurricane is strengthening at a fast pace, is this hurricane bigger than Camille was, is this a false alarm, what are the expectations, et cetera? Based on the behavior of the hurricane, a state of emergency is issued in LA and MS. Fire personnel, National Guard, coast guard, police, army, volunteers, buses, jumbo planes, et cetera are dispatched to LA and MS. Evacuation 3, which is mandatory evacuation, is put into effect and inhabitants of LA and some parts of MS are asked to evacuate the area voluntarily or be forced out involuntarily.

Stage 7. Preserving Frame Outcome: The frame of a destructive hurricane is maintained and the status of orders to evacuate LA and MS is updated.

Stage 8. Elaborating Frame Outcome: The status of the hurricane is changed into a category 4 as more information is received. Some sensemaking questions asked are what information is missing, what else needs to be done, what was the behavior of past hurricanes of this magnitude, et cetera? Evacuate 2, during which responders on site, encourage and assist people to evacuate is issued for LA. A hurricane alert for LA is issued on air, internet and television.

Stage 9. Questioning Frame Outcome: The sensemaker questions the frame for inconsistencies and violated expectations. Some questions asked are what needs to be done as hurricane keeps strengthening, what are the expectations of residents of LA and MS, why are people not evacuating, what will be the effect if landfall is made as a category 5? Based on the behavior of the hurricane, a state of emergency in LA and MS is maintained. Additional fire personnel, National Guard, army, volunteers, buses, jumbo planes, et cetera are dispatched to LA and MS. Evacuation 3 is enforced in LA.

Stage 10. Preserving Frame Outcome: The status of the hurricane is amended as it weakens into a category 4 around LA. The progress of the evacuation process and number of casualties is also updated as more information comes in.

Stage 11. Elaborating Frame Outcome: The status of the hurricane is updated as it weakens. More information comes in and slots are filled. Some sensemaking questions asked are what information is missing, what else needs to be done, what was the behavior of past hurricanes of this magnitude, et cetera? Evacuate 2 is issued for LA and responders on site assist and encourage people to leave. A hurricane alert for LA is issued on air, internet and television.

Stage 12. Questioning Frame Outcome: The sensemaker questions the frame for inconsistencies and violated expectations. Some sensemaking questions asked are do the goals have to be changed, is this frame worth preserving, what are the effects of the hurricane in LA and MS, are there other eminent dangers, et cetera? Based on the behavior of the hurricane and victims, evacuate 2 is issued. Inhabitants are encouraged to leave since New Orleans, LA begins to flood and violence increases as basic needs such as food, clothing and water become deficient. Additional security enforcement is dispatched to New Orleans to maintain order.

Stage 13. Seeking Frame Outcome: With the weakening of the hurricane into a tropical depression, emerging danger of flooding and security leads to the construction of a new frame. An increase in infrastructural (houses, hospitals, schools, churches) and mechanical damage (levee failure) and flash flooding especially in New Orleans leads to the flash-pumping of the floods and the set-up of treatment centers and shelters. An increase in injuries and deaths as well as security issues such as rape, drug and alcohol peddling, weapon possession, gang activity, looting, violent assaults and vandalism lead to the enforcement of curfews and shoot to kill.

Stage 14. Re-framing Outcome: Unnecessary data is discarded and new anchors are found. Sensemaking questions asked here include are there any important discarded data, are the expectations of the current situation met, et cetera? As the numbers of infectious illnesses and deaths increase, the goals are revised to treat and contain the infected and temporarily relocate and settle homeless residents (feed, clothe and accommodate). Victims are assisted with rehabilitation for physical, emotional and psychological scars. Committees are appointed to oversee the reconstruction of the 90,000 square mileages of damaged land, clearing of 118 million cubic yards of debris and to put in place infrastructure and systems that will work in the event of similar disasters.

Stage 15. Framing: Knowledge of the situation such as total number of deaths, security breaches, infectious disease victims and homeless people; and rate of mechanical systems and infrastructural damage is updated as information is turned into knowledge having gained insight. Knowledge is updated.

4.5 Chapter Summary

During any disaster or situation, that causes experts to collaborate, share ideas and experiences in order to completely understand what is going on to make decisions and take actions; there is a glut of data. Such data is processed for the flow of information to gain knowledge and understanding of the subject matter. Analytically, the DFM captures the situation and represents it with a FSA as illustrated in the model of Hurricane Katrina. The model depicts the various stages and transitions of the several conversions of data into information and then finally into knowledge and the subsequent actions accompanying these state transitions. It must be noted however that during the sensemaking process, frames change as the situation evolves and the initial frame constructed might not be the final frame upon completion. FSA captures the state transitions for such a scenario thus; the chapter presented the DFM-FSA simulation process, the foundation of this thesis.

CHAPTER 5

Development, Implementation and Evaluation

5.1 Rationale

Determination of plausible causes of action by a sensemaker during a maelstrom situation may prove to be a complex task that involves several other persons and processes. A sensemaker is provided with context specific data from satellite and radar readings, eye witness reports, on the ground or field expert opinions and media coverage during disaster management such as a hurricane. The sensemaker using this data must be able to extract salient information, which will enable her to comprehend the situation at hand and recommend plausible causes of action to decision makers. The Hurricane Sensemaking Machine (HSM) developed by this research is a user-centered design that aids in situation awareness for the sensemaker utilizing it.

The sensemaking process in the HSM is identified by eight states, each of which has specific attributes governing its transition, similar to DFM. Weather attributes, such as wind speed, storm surge, storm tide, rain depth, et cetera and other attributes, such as expert opinion ratings of damage and danger, number of reported deaths, and so on were used to categorize identified causes of action. The FSA and its states attributes are represented by decorations or widgets that provide an integrated representation to the sensemaker to prompt recognition.

In the event of a hurricane, possible threats and dangers that occur include, but are not limited to, some or all of the following.

- Entrapment in an area or building caused by the inability to move around freely and sometimes complete isolation from the rest of the world due to flooding, inaccessible roads and destroyed buildings.
- Utility cut-off that could be a result of fallen poles and broken water pipes. It may also be a precautionary measure by the power and water supply companies to shut off supply. Utility cut-off averts water, electricity and broadband supply to consumers in the affected vicinity.
- Flooding from copious rains and/or failure of flood preventative systems may cause various degrees of damage to buildings, vehicles and mechanical systems.
- Tornados also called cyclones or twisters, originate from moist, warm airs and low pressures, resulting in spinning columns of air that suck up anything in their trajectory.
- Death as a result of drowning; electrocution by lightning, live wire or faulty wires in contact with water; trauma; violence; acute ailment; or getting struck by an object such as a building, tree or pole.

The effects and causes of action below are the cues from which the HSM draws state attributes and plausible causes of action. Some possible causes of action that may be executed before, during or after a hurricane include, but are not limited to, the following.

- Stay home and make provisions such as ready meals, drinking water, medication, firewood, candles and lanterns to wait out the hurricane.
- Drainage of flood waters from streets, buildings and vehicles and reinstatement of utilities cut-off.

- Disinfection of contaminated places, treatment of sewage infested waters, vaccinations against the spread of infectious diseases and pest control.
- Temporary evacuation of people and animals from the projected hit or affected areas.
- Provision of relief services such as medical care for the ailing and injured, food, clothing and shelter for the victims.
- Rehabilitation of victims financially, economically, physically, emotionally and psychologically.
- Reconstruction of destroyed amenities, infrastructure and implementation of systems to prevent future devastation.

5.2 Software Description

National Instrument's Laboratory Virtual Instrument Engineering Workbench (LabVIEW) 10.0 was used as the software driving the computational simulation of the quantitative sensemaking model discussed earlier. LabVIEW is a programming environment that creates programs using graphical notation instead of text, unlike conventional programming languages such as *C*++, *C*, Microsoft Visual Basic, Java, et cetera (Travis and Kring, 2007). The graphical programming language usually called "G" makes use of graphical block diagrams that compile into the machine code. It is a robust, interactive and flexible instrumentation and analysis software system that is multiplatform and may be run on Windows, Linux and Mac OS X. The ease of use when programming with LabVIEW aids in problem solving in a considerably shorter period as compared to the generic languages. Application of this software is seen in the sciences, engineering and technology. LabVIEW is essentially useful for monitoring and controlling processes.

5.3. Representation

The computational representation of the quantitative sensemaking model described in Chapter 4, Figure 4.3, is described in detail by the development phase. The development phase of the HSM is in two sections: the set-up phase and the design phase. It gives a description of the selection, assembly and configuration of widgets as well as the operation of the automaton.

5.3.1. Set-up Phase

The various components or widgets making up the HSM interfaces are determined along with their respective behaviors. The choices of widgets for the development of the model's attributes are context specific. Widgets are selected based on basic human factors, fundamental to ensure the ease of use, comfort of the sensemaker and the efficiency of the machine. Most of the widgets are similar to their real world measuring tools. This is not only to increase their aesthetic sensitivity, but also to aid the sensemaker in recognition when using the HSM. The widgets and decorations are selected from the controls palette of the virtual instrumentation in LabVIEW 10.0. Selected widgets for the attributes of the states are configured as controls since their input serves as a trigger for state transitions. Properties such as color, minimum and maximum values, labels, default values, et cetera of the widgets selected for the states attributes are configured at this phase. A total of sixteen unique controls are assigned to represent the various attributes at their respective states in the machine. The decorations used represent the various states diagram and transition lines. The states in the FSA are numbered from one to eight for identification and recognition; likewise the controls on the attributes setting are represented by their labels, then underscore, and their respective numerical state, as in OK_1.

5.3.2. Design Phase

The layout of the main HSM interface consists of strings, tabs, buttons, controls and decorations. The string control is used to input a password, which gives access to the HSM. A string indicator is also used as an activity window for the display of the current state and its respective causes of action. A tab control with multiple pages contains the three sub-interfaces, namely, FSA, attributes setting and reference database. The FSA sub-interface consists of the computational representation of Figure 4.2, discussed in Chapter 4, for the simulation. This sub-interface serves as an output of the sensemaking process that aids in visualization of the evolving causes of action. The breakdown of this sub-interface as illustrated in Figure 5.1 comprises:

a) Eight sensemaking states from DFM built with flat, rounded boxes from the control palette.

b) Round light-emitting diodes (LEDs) superimposed on thin arrows which connect the sensemaking states and serve as the transition lines in the machine.

c) A horizontal toggle switch, that starts the HSM and also serves as an emergency stop switch for the simulation machine.

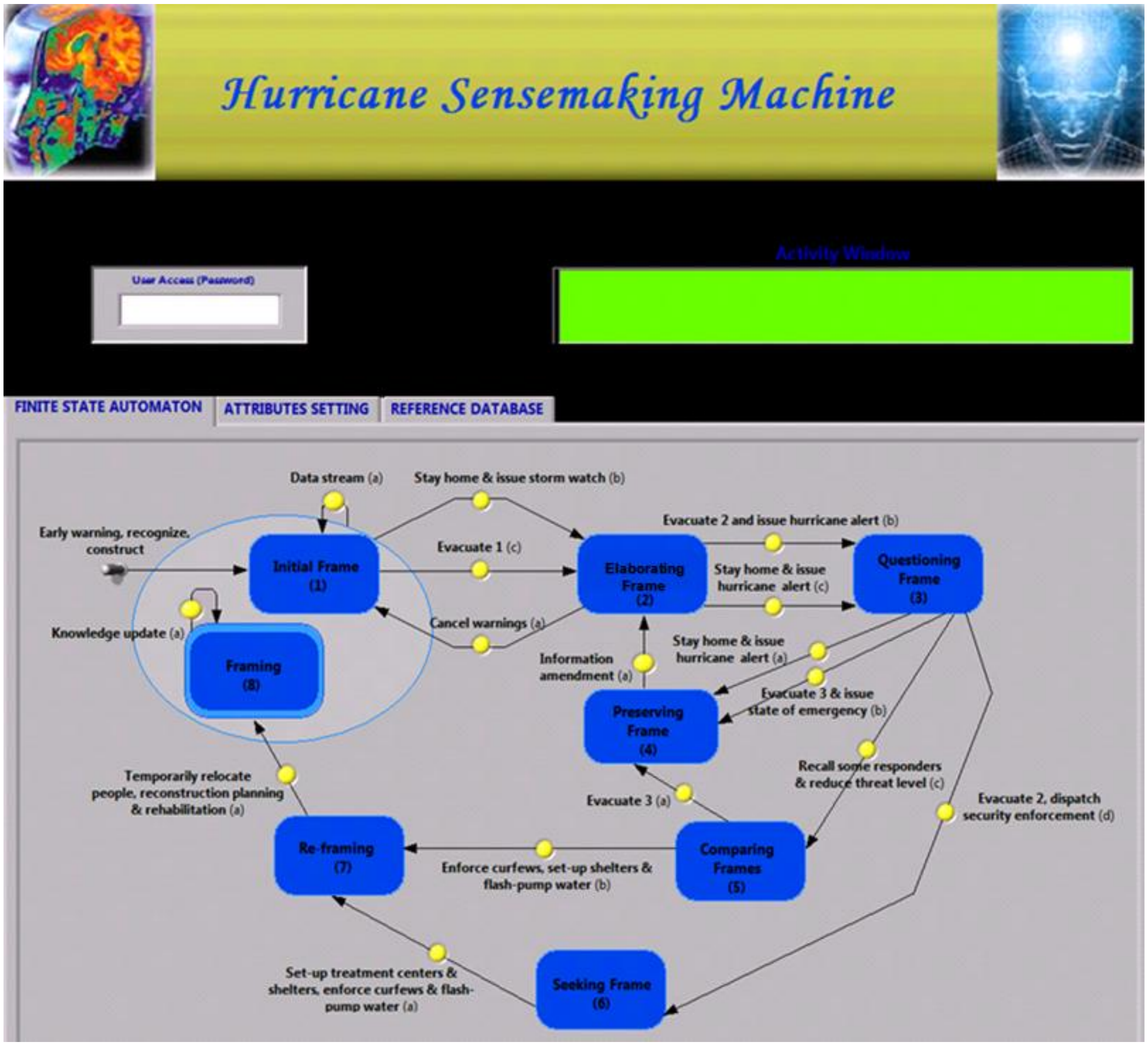


Figure 5.1. Hurricane Sensemaking Machine Finite State Automaton Sub-Interface

The attributes setting sub-interface serves as the input to the HSM. It serves as the information siphoning stage that sieves salient information needed for sensemaking from the pool of data received by the sensemaker. The attributes setting sub-interface comprises the selection of inputs that direct the thinking path of the sensemaker. This interface may be visualized from Figure 5.2. It consists of the following:

a) An eight-page tab control symbolic of the eight sensemaking states where each contains requisite attributes needed to propel it to the next sensemaking state.

b) A total of 16 controls to represent the different attributes identified for the attributes sub-interface. Each tab control page has the respective controls such as square push button for input confirmation, tanks for rains and floods levels, thermometer for sea surface temperature, gauges for wind speed, knob for retrospective data and numeric controls for count and ratings.

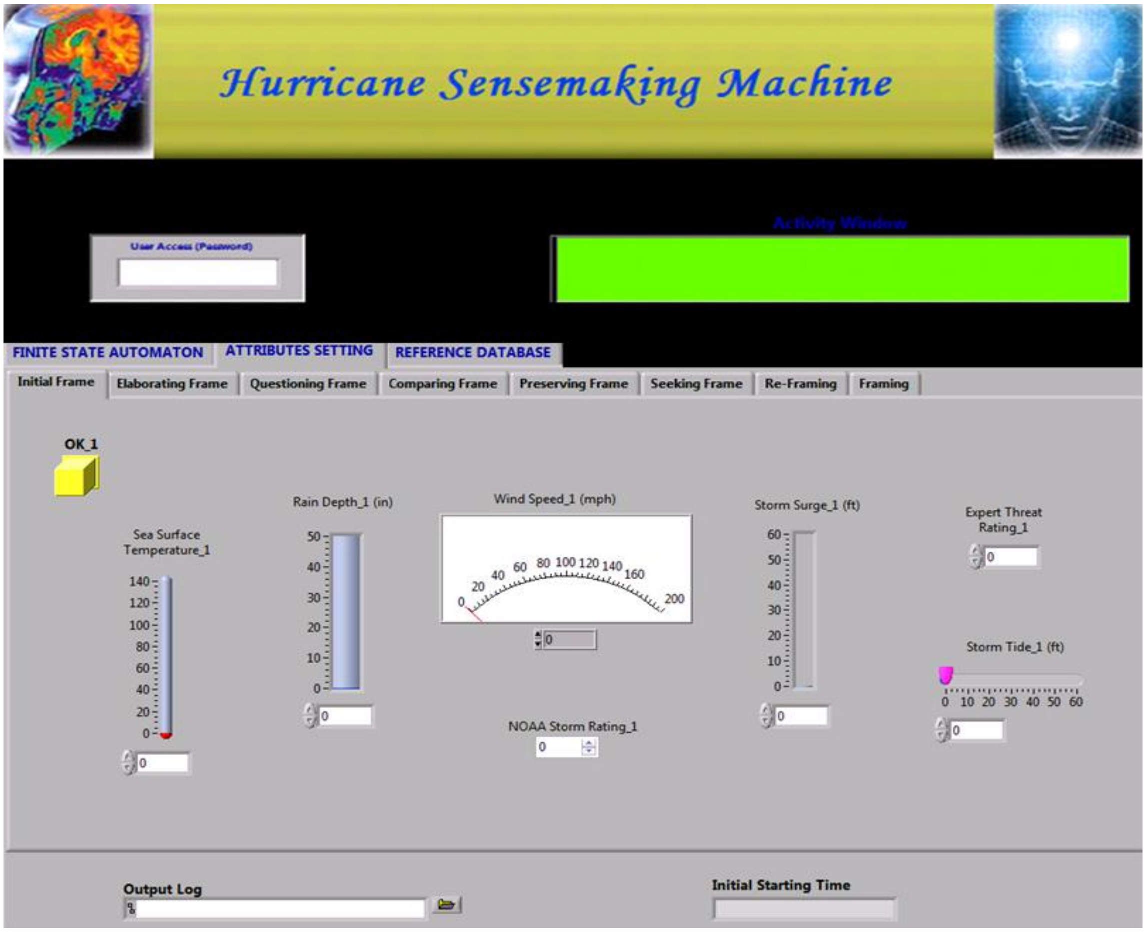
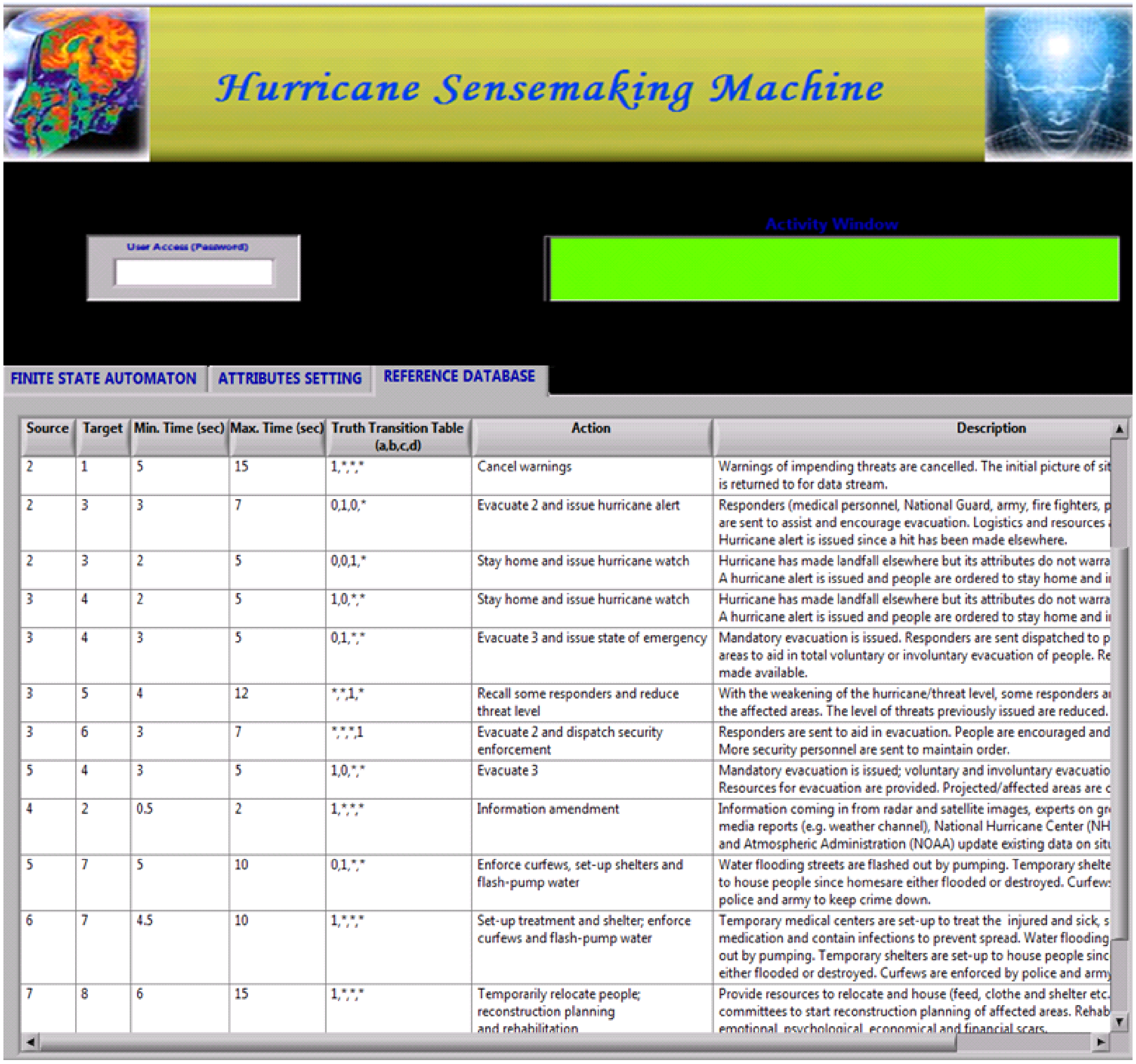


Figure 5.2. Hurricane Sensemaking Machine Attributes Setting Sub-Interface

The last sub-interface illustrated by Figure 5.3 was developed from a tab control superimposed on a thick lowered box with an embedded multicolumn table. The reference database details the several transitions in the HSM. It outlines the source state and target state, the recommended causes of action and also gives an in-depth description of what the respective causes of action entail.



Source	Target	Min. Time (sec)	Max. Time (sec)	Truth Transition Table (a,b,c,d)	Action	Description
2	1	5	15	1,*,*,*	Cancel warnings	Warnings of impending threats are cancelled. The initial picture of sit is returned to for data stream.
2	3	3	7	0,1,0,*	Evacuate 2 and issue hurricane alert	Responders (medical personnel, National Guard, army, fire fighters, p are sent to assist and encourage evacuation. Logistics and resources Hurricane alert is issued since a hit has been made elsewhere.
2	3	2	5	0,0,1,*	Stay home and issue hurricane watch	Hurricane has made landfall elsewhere but its attributes do not warra A hurricane alert is issued and people are ordered to stay home and i
3	4	2	5	1,0,*,*	Stay home and issue hurricane watch	Hurricane has made landfall elsewhere but its attributes do not warra A hurricane alert is issued and people are ordered to stay home and i
3	4	3	5	0,1,*,*	Evacuate 3 and issue state of emergency	Mandatory evacuation is issued. Responders are sent dispatched to p areas to aid in total voluntary or involuntary evacuation of people. Re made available.
3	5	4	12	*,*,1,*	Recall some responders and reduce threat level	With the weakening of the hurricane/threat level, some responders a the affected areas. The level of threats previously issued are reduced.
3	6	3	7	*,*,*,1	Evacuate 2 and dispatch security enforcement	Responders are sent to aid in evacuation. People are encouraged and More security personnel are sent to maintain order.
5	4	3	5	1,0,*,*	Evacuate 3	Mandatory evacuation is issued; voluntary and involuntary evacuatio Resources for evacuation are provided. Projected/affected areas are
4	2	0.5	2	1,*,*,*	Information amendment	Information coming in from radar and satellite images, experts on gr media reports (e.g. weather channel), National Hurricane Center (NH and Atmospheric Administration (NOAA) update existing data on sit
5	7	5	10	0,1,*,*	Enforce curfews, set-up shelters and flash-pump water	Water flooding streets are flashed out by pumping. Temporary shelte to house people since homesare either flooded or destroyed. Curfew police and army to keep crime down.
6	7	4.5	10	1,*,*,*	Set-up treatment and shelter; enforce curfews and flash-pump water	Temporary medical centers are set-up to treat the injured and sick, s medication and contain infections to prevent spread. Water flooding out by pumping. Temporary shelters are set-up to house people sinc either flooded or destroyed. Curfews are enforced by police and army
7	8	6	15	1,*,*,*	Temporarily relocate people; reconstruction planning and rehabilitation	Provide resources to relocate and house (feed, clothe and shelter etc. committees to start reconstruction planning of affected areas. Rehab emotional, psychological, economical and financial scars.

Figure 5.3. Hurricane Sensemaking Machine Reference Database Sub-Interface

5.4 Implementation

Controls and decorations visible on the front panel of the HSM generate icons that are used for coding the virtual instrumentation's block diagram. Local variables and re-initialization icons are generated from these icons and used in coding the block diagram. The coding of the machine is engulfed by a decision loop within which all other relationships are established. The block diagram of HSM makes use of multiple case structures, which enable binary coding of cases when they are either true or false. A second decision loop and a stack of event structures allow the coding of the eight identified states in the HSM. Multiple case structures within these individual event structures facilitate the binary coding of each state and the re-initialization to the default states of controls and attributes used.

A formula node with logic for the pre-determined production rules governing state transitions is connected to each case structure within the second decision loop. The logic of the production rules is written in *C* programming language. The local variables of the respective state attributes are connected as input to the formula node and a corresponding output variable is wired to case structures with corresponding number of pages as to the number of paths of that state. The various causes of action are embedded within these case structures on multi-framed flat sequence structures. Each flat sequence structure had added frames for the blinking property and activity window of each of the causes of action, time stamp and delay time.

5.4.1 Mode of Operation of HSM

Mode of operation of the HSM when in run mode is as follows:

1. Enter a valid password in the “User Access (Password)” box in order to access the machine. In the event where an inaccurate password is entered, the machine will emit a shrill sound of 4000 Hz for 200 milliseconds and stop automatically.
2. Select a location to record the output log data on the attributes setting sub-interface.
3. Turn the horizontal toggle switch on for HSM to respond to inputs otherwise, it will be unresponsive to all stimuli inputted. Once on, the FSA sub-interface and attributes setting sub-interface become activated. If the horizontal toggle switch is turned off at anytime during operation, the HSM stops completely.
4. Enter values for the attributes on the pane of the initial state as the weather evolves and data is reported.
5. Press the “OK_1” button upon completion of attributes setting. A two button message box prompts the sensemaker to either “OK” to confirm input data is accurate and proceed or “CANCEL” to re-initialize all attributes on that pane to their default values for re-entry. The “OK” button changes from its default color yellow to red when switched on.
6. Confirmed values of attributes in conjunction with pre-determined production rules transit the initial state to the next state.
7. Identify the transition paths with the recommended causes of action by the blinking round LED from the default highlighted color yellow to red.

8. Report activity feed of recommended causes of action automatically projected in the form “source state: causes of action” to decision makers.
9. Upon receipt of new data, go to the pane of elaborating frame (the next state transited to) and update settings. Transitions in the HSM to next states inform the sensemaker of which state attributes to set next. For example, if the initial frame transits to elaborating frame along the path “evacuate 1”, the next batch of attributes to be set with incoming data will be those on the elaborating frame pane of the attributes setting sub-interface.
10. Press “OK_2” button upon completion of attributes setting.
11. Press “OK” to confirm input data are accurate and proceed or “CANCEL” to re-initialize all attributes to their default values for re-entry.
12. Identify path of transition with the recommended causes of action by the blinking round LED and report activity feed of recommended causes of action to decision makers.
13. Repeat steps eight (8) through eleven (11) as needed until you get to the final state.
14. Print or save the output log data for analysis and future reference.

5.5 Evaluation

Assessment of the HSM was done by running the events progression of Hurricane Katrina from August 23, 2005 to September 1, 2005. Reports of radar and satellite images of the hurricane and its accompanying rains, winds, surges, et cetera from NHC, NOAA, NWC, expert meteorologists and eyewitnesses were fed into the HSM as would have been done by a sensemaker during the actual event in 2005. The final FSA output and the recommended causes of action after each state transition were logged and compared with that of the illustrative simulation results of Hurricane Katrina described in Section 4.4.

Input events for the simulation were the same values of attributes as those used for the illustrative example of FSA simulation of Hurricane Katrina discussed in Section 4.3.2. Subsequent to the operation of the HSM with Hurricane Katrina's data, the FSA interface produced an output of 15 stages, transitions similar to the expected illustrative simulation depicted by Figure 4.5. Figure 5.4 illustrates a visual representation of the resulting FSA captured consequent to the running of the Hurricane Katrina simulation with HSM.

The walk of interest was indicated by blinking LED paths highlighted from the default color yellow to red. The confirmed attributes settings produced a transition along a highlighted path of red LEDs. Each set of confirmed attributes inputted instigated a transition between states. A sensemaking loop was formed among the states: elaborating frame, questioning frame and preserving frame. This occurred while the frame of dealing with the approaching and occurring hurricane was maintained until the hurricane passed and its impact and remnants became the revised prime focus. The activity window provided a recommended cause of action feed each time a state transited to another. Figure 5.4 shows a feed of the recommended cause of action "knowledge update" for the final or end state, framing on the FSA sub-interface.

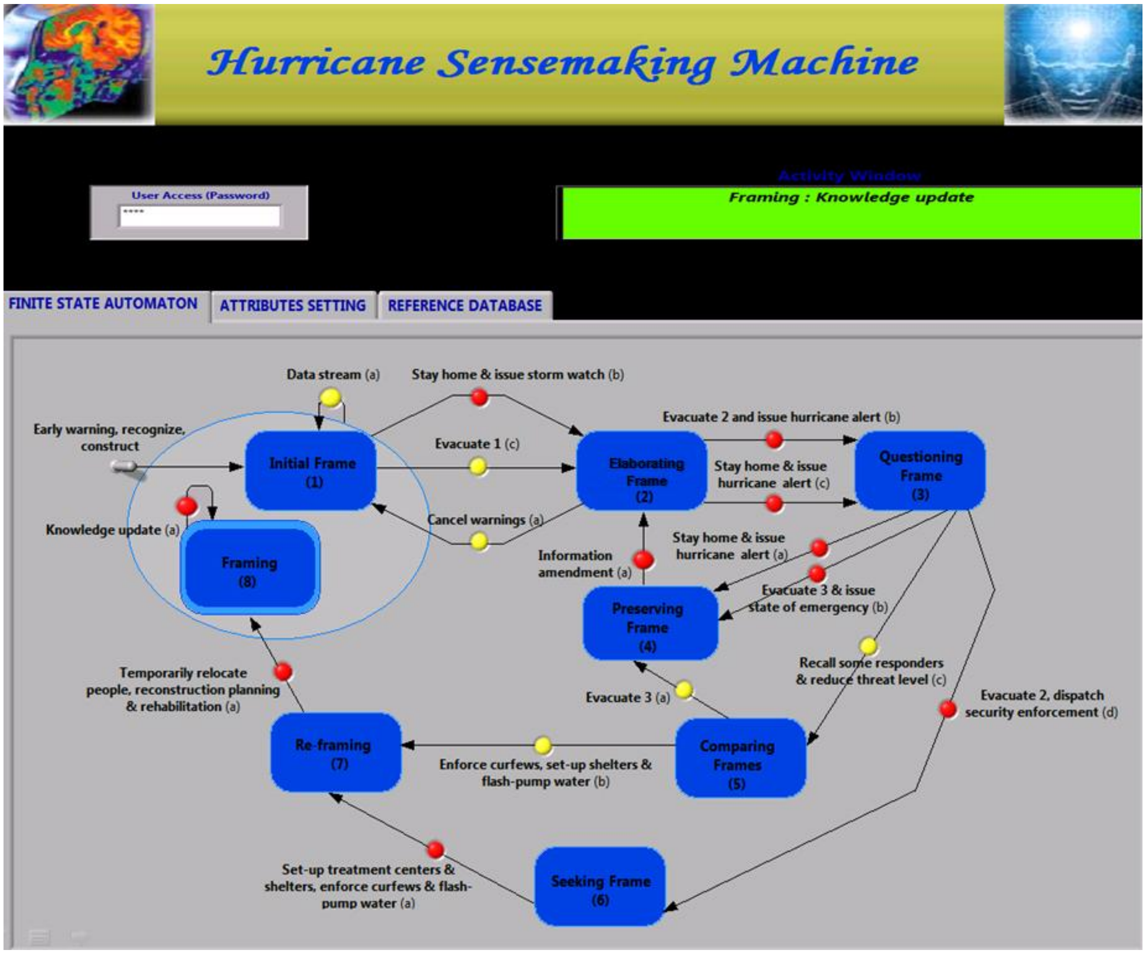


Figure 5.4. Finite State Automaton of Information Flow during Hurricane Katrina

5.6 Chapter Summary

The HSM is fashioned to aid a sensemaker connect dots and make sense out of a complex evolving situation similar to the qualitative DFM. This chapter delves into the building blocks and layout of HSM, its mode of operation and evaluation using the Hurricane Katrina case study. A user’s mini-manual is presented. The next chapter presents some data analysis from using HSM.

CHAPTER 6

Data Analysis and Discussion

6.1 Scenario Description

Three scenarios of varying information flow complexities were used for experimental evaluation. Each scenario was replicated four times to increase the sample size, reduce variance and increase the robustness of the design. The three scenarios were high complexity (HC), medium complexity (MC) and low complexity (LC) situations. These three situations were contrasted with the real life Hurricane Katrina (HK) situation, which was also replicated four times using HSM. The magnitude of information flow for the various scenarios determined the resultant thinking paths. See the appendix section for a complete list of the various scenarios data inputs.

The situation of HC was one with multiple data coming in from various sources such as experts on the field, NHC, NOAA, media reports, et cetera. Readings for the various state attributes reported were of extreme values. As the hurricane evolved over time, reports of wind speed ranged from as high as 137 mph to 84 mph. Death toll, security breaches and mechanical systems and infrastructure damage also increased in number and rate. The number of attributes manipulated for each of the active states in this scenario ranged from five to ten with each state attribute actively involved. The MC situation had information flow from several sources but not as extensive as that for the HC situation. Input data for this scenario were of medium values and a comprehensive list may be seen in the appendix section. Reported values of wind speed ranged from as high as 88 mph for a category 1 hurricane to a tropical storm of 60 mph. The number of attributes manipulated for each of the active states in this scenario ranged from four to six. Information flow for the LC situation had the relatively lowest attributes values compared to the HC and MC situations. Wind speed ranged from a category 1 hurricane to a tropical depression. Attributes manipulated ranged from three to five. Most states involved only received data for the minimum attribute requirements needed to activate transition among states. A complete list of the information flow is included in the appendix of this document.

6.2 Data Collection

In order to perform any form of analysis either descriptive or inferential, data had to be collected. Each of the 20 simulation runs for the four complex situations generated an output log file. The output log files from the HSM for the three different scenarios and HK had different thinking paths and contained the following data:

- Source state: This informs the analyst of the state recommending the causes of actions triggering the transition.
- Causes of action: These are the recommended actions from the sensemaker that may be passed on to decision makers for execution.
- Initial start time: This is a record of the current real time instantaneously logged when the machine is switched on. It also serves as the start time for the initial frame.

- Start time: This is a measure of real-time (current time) as the blinking LED activates the causes of action.
- Duration: This is a mimic of the human cognitive delay time. It is calculated by multiplying a randomly generated number between zero and one with the difference between maximum and minimum assigned execution times for causes of action plus minimum time.
- End time: This is a real-time record of end of transition. It also serves as the new start time for the next transition.

Problem stage time (PST), which is the simulated time of how long a sensemaker takes to realize and recommend the causes of action, is a generated measure from the logged output data. Likewise, node-to-node (NTN) time is the simulated transition time from one state to the other. PST for the initial frame is computed by subtracting the initial start time from the start time. All the other PSTs are computed by subtracting the previous state's end time from the current start time. NTN time for the initial frame is calculated by subtracting the initial start time from the end time. All other NTN times are calculated by subtracting the previous state end time from the current state end time.

The simulated thinking paths varied for the different scenarios. The HC situation completed the sensemaking process in nine stages as shown in Table 6.1. The MC completed the sensemaking process in six stages as illustrated by Table 6.2. The LC situation completed the sensemaking process in seven stages, whereas HK output had a thinking path with 15 stages at the end of the simulation run. These are represented by Table 6.3 and Table 6.4, respectively.

Table 6.1. Initial Simulation Results for a High Complexity Sensemaking Situation

Stages	Transitions	Source State	Causes of Action	Initial Start Time (p.m.)	Start Time (p.m.)	Duration (s)	End Time (p.m.)	PST (hr:min:s)	NTN (hr:min:s)	NTN (s)
1	$1 \xrightarrow{c} 2$	Initial Frame	Evacuate 1	4:52:07	4:55:36	7.84E+00	4:55:44	0:03:29	0:03:37	217
2	$2 \xrightarrow{b} 3$	Elaborating Frame	Evacuate 2 & issue hurricane alert	--------------	5:00:18	6.07E+00	5:00:24	0:04:34	0:04:40	280
3	$3 \xrightarrow{b} 4$	Questioning Frame	Evacuate 3 & issue state of emergency	--------------	5:05:06	5.33E+00	5:05:11	0:04:42	0:04:47	327
4	$4 \xrightarrow{a} 2$	Preserving Frame	Information amendment	--------------	5:07:49	5.47E-01	5:07:50	0:02:38	0:02:39	159
5	$2 \xrightarrow{b} 3$	Elaborating Frame	Evacuate 2 & issue hurricane alert	--------------	5:14:47	3.39E+00	5:14:51	0:06:57	0:07:01	421
6	$3 \xrightarrow{d} 6$	Questioning Frame	Evacuate 2, dispatch security enforcement	--------------	5:19:50	6.32E+00	5:19:56	0:04:59	0:05:05	305
7	$6 \xrightarrow{a} 7$	Seeking Frame	Set-up treatment centers & shelters, enforce curfews & flash-pump water	--------------	5:26:04	4.74E+00	5:26:09	0:06:08	0:06:13	373
8	$7 \xrightarrow{a} 8$	Re-framing	Temporarily relocate people, reconstruction planning & rehabilitation	--------------	5:31:41	1.22E+01	5:31:53	0:05:32	0:05:44	344
9	$8 \xrightarrow{a} 8$	Framing	Knowledge update	--------------	5:34:01	2.91E-01	5:34:01	0:02:08	0:02:08	128
NTN is node-to-node							Total	0:41:07	0:41:54	2554

Table 6.2. Initial Simulation Results for a Medium Complexity Sensemaking Situation

Stages	Transitions	Source State	Causes of Action	Initial Start Time (p.m.)	Start Time (p.m.)	Duration (s)	End Time (p.m.)	PST (hr:min:s)	NTN (hr:min:s)	NTN (s)
1	$1 \xrightarrow{b} 2$	Initial Frame	Stay home & issue storm watch	4:35:53	4:39:28	3.88E+00	4:39:32	0:03:35	0:03:39	219
2	$2 \xrightarrow{c} 3$	Elaborating Frame	Stay home & issue hurricane alert	--------------	4:43:12	2.09E+00	4:43:14	0:03:40	0:03:42	222
3	$3 \xrightarrow{d} 6$	Questioning Frame	Evacuate 2, dispatch security enforcement	--------------	4:49:10	6.17E+00	4:49:16	0:05:56	0:06:02	362
4	$6 \xrightarrow{a} 7$	Seeking Frame	Set-up treatment centers & shelters, enforce curfews & flash-pump water	--------------	4:55:34	8.02E+00	4:55:42	0:06:18	0:06:26	386
5	$7 \xrightarrow{a} 8$	Re-framing	Temporarily relocate people, reconstruction planning & rehabilitation	--------------	5:01:16	1.10E+01	5:01:27	0:05:34	0:05:45	345
6	$8 \xrightarrow{a} 8$	Framing	Knowledge update	--------------	5:03:35	8.94E-01	5:03:36	0:02:08	0:02:09	129
NTN is node-to-node							Total	0:27:11	0:27:43	1663

Table 6.3. Initial Simulation Results for a Low Complexity Sensemaking Situation

Stages	Transitions	Source State	Causes of Action	Initial Start Time (p.m.)	Start Time (p.m.)	Duration (s)	End Time (p.m.)	PST (hr:min:s)	NTN (hr:min:s)	NTN (s)
1	$1 \xrightarrow{a} 1$	Initial Frame	Data Frame	4:23:43	4:25:02	1.12E+00	4:25:03	0:01:19	0:01:20	80
2	$1 \xrightarrow{b} 2$	Initial Frame	Stay home & issue storm watch	--------------	4:28:22	3.91E+00	4:28:26	0:03:19	0:03:23	203
3	$2 \xrightarrow{c} 3$	Elaborating Frame	Stay home & issue hurricane alert	--------------	4:31:59	2.89E+00	4:32:02	0:03:33	0:03:36	216
4	$3 \xrightarrow{a} 4$	Questioning Frame	Stay home & issue hurricane alert	--------------	4:35:55	2.69E+00	4:35:58	0:03:53	0:03:56	236
5	$4 \xrightarrow{a} 2$	Preserving Frame	Information amendment	--------------	4:37:55	1.23E+00	4:37:56	0:01:57	0:01:58	118
6	$2 \xrightarrow{a} 1$	Elaborating Frame	Cancel Warnings	--------------	4:41:38	6.96E+00	4:41:45	0:03:42	0:03:49	229
7	$1 \xrightarrow{a} 1$	Initial Frame	Data Frame	--------------	4:43:17	9.65E-01	4:43:18	0:01:32	0:01:33	93
NTN is node-to-node							Total	0:19:15	0:19:35	1175

Table 6.4. Initial Simulation Results for Hurricane Katrina Situation

Stages	Source State	Causes of Action	Initial Start Time (a.m.)	Start Time (a.m.)	Duration (s)	End Time (a.m.)	PST (s)	NTN Time (s)
1	Initial Frame	Stay home & issue storm watch	9:57:35	10:00:44	4.84E+00	10:00:48	189	193
2	Elaborating Frame	Stay home & issue hurricane alert	------------	10:04:42	4.09E+00	10:04:46	234	238
3	Questioning Frame	Stay home & issue hurricane alert	------------	10:11:01	2.57E+00	10:11:03	375	377
4	Preserving Frame	Information amendment	------------	10:14:55	1.68E+00	10:14:56	232	233
5	Elaborating Frame	Stay home & issue hurricane alert	------------	10:18:54	2.77E+00	10:18:56	237	239
6	Questioning Frame	Evacuate 3 & issue state of emergency	------------	10:24:33	1.59E+01	10:24:48	338	353
7	Preserving Frame	Information amendment	------------	10:30:23	1.75E+00	10:30:24	334	335
8	Elaborating Frame	Evacuate 2 & issue hurricane alert	------------	10:35:27	5.41E+00	10:35:32	304	309
9	Questioning Frame	Evacuate 3 & issue state of emergency	------------	10:41:56	1.75E+01	10:42:13	384	401
10	Preserving Frame	Information amendment	------------	10:46:01	9.40E-01	10:46:02	228	229
11	Elaborating Frame	Evacuate 2 & issue hurricane alert	------------	10:49:26	3.32E+00	10:49:29	204	207
12	Questioning Frame	Evacuate 2, dispatch security enforcement	------------	10:52:20	5.03E+00	10:52:25	172	177
13	Seeking Frame	Set-up treatment centers & shelters, enforce curfews & flash-pump water	------------	10:55:29	9.61E+00	10:55:38	184	193
14	Re-framing	Temporarily relocate people, reconstruction planning & rehabilitation	------------	10:58:14	8.07E+00	10:58:22	156	164
15	Framing	Knowledge update	------------	11:01:37	4.52E-01	11:01:37	194	194
NTN is node-to-node						Total	3765	3842

A summation of the various NTN times after each scenario gave the sensemaking time for that particular scenario. Sensemaking time, therefore, is defined as the total duration from the initial start of HSM until its final stop. NTN results and sensemaking times for replicates of HC, MC, LC situations and HK are represented by Tables 6.5, 6.6, 6.7 and 6.8, respectively. The sensemaking times for replicates of the HC ranged from 2,557 seconds to 2,758 seconds. MC situation ranged from 1,424 seconds to 1,577 seconds. LC situation ranged from 1,279 seconds to 1,466 seconds. HK ranged from 3,653 seconds to 3,887 seconds.

Table 6.5. Simulation Results for Replicates of the High Complexity Situation

Stages	**Source State**	**Causes of Action**	**Node-to-node Times of Replicates (s)**			
			1	**2**	**3**	**4**
1	Initial Frame	Evacuate 1	312	311	242	157
2	Elaborating Frame	Evacuate 2 & issue hurricane alert	237	258	282	360
3	Questioning Frame	Evacuate 3 & issue state of emergency	298	371	339	365
4	Preserving Frame	Information amendment	382	153	249	133
5	Elaborating Frame	Evacuate 2 & issue hurricane alert	228	257	441	339
6	Questioning Frame	Evacuate 2, dispatch security enforcement	323	381	321	399
7	Seeking Frame	Set-up treatment centers & shelters, enforce curfews & flash-pump water	303	451	334	354
8	Re-framing	Temporarily relocate people, reconstruction planning & rehabilitation	354	295	342	380
9	Framing	Knowledge update	120	118	208	113
Sensemaking Times for Replicates =			2557	2595	2758	2600

Table 6.6. Simulation Results for Replicates of the Medium Complexity Situation

Stages	Source State	Causes of Action	Node-to-node Times of Replicates (s)			
			1	2	3	4
1	Initial Frame	Stay home & issue storm watch	204	76	201	149
2	Elaborating Frame	Stay home & issue hurricane alert	161	164	224	356
3	Questioning Frame	Evacuate 2, dispatch security enforcement	226	404	342	232
4	Seeking Frame	Set-up treatment centers & shelters, enforce curfews & flash-pump water	308	327	335	302
5	Re-framing	Temporarily relocate people, reconstruction planning & rehabilitation	277	305	330	320
6	Framing	Knowledge update	248	162	145	154
Sensemaking Times for Replicates =			1424	1438	1577	1513

Table 6.7. Simulation Results for Replicates of the Low Complexity Situation

Stages	Source State	Causes of Action	Node-to-node Times of Replicates (s)			
			1	2	3	4
1	Initial Frame	Data Frame	165	130	87	80
2	Initial Frame	Stay home & issue storm watch	169	194	184	158
3	Elaborating Frame	Stay home & issue hurricane alert	253	264	203	204
4	Questioning Frame	Stay home & issue hurricane alert	203	123	343	216
5	Preserving Frame	Information amendment	222	209	156	214
6	Elaborating Frame	Cancel Warnings	90	287	133	295
7	Initial Frame	Data Frame	177	259	219	127
Sensemaking Times for Replicates =			1279	1466	1325	1294

Table 6.8. Simulation Results for Replicates of Hurricane Katrina Situation

Stages	Source State	Causes of Action	Node-to-node Times of Replicates (s)			
			1	2	3	4
1	Initial Frame	Stay home & issue storm watch	114	106	105	123
2	Elaborating Frame	Stay home & issue hurricane alert	189	223	344	252
3	Questioning Frame	Stay home & issue hurricane alert	182	327	186	302
4	Preserving Frame	Information amendment	351	269	173	159
5	Elaborating Frame	Stay home & issue hurricane alert	183	252	237	325
6	Questioning Frame	Evacuate 3 & issue state of emergency	334	390	349	403
7	Preserving Frame	Information amendment	290	81	148	143
8	Elaborating Frame	Evacuate 2 & issue hurricane alert	348	277	307	311
9	Questioning Frame	Evacuate 3 & issue state of emergency	290	252	255	257
10	Preserving Frame	Information amendment	183	155	132	156
11	Elaborating Frame	Evacuate 2 & issue hurricane alert	272	351	249	211
12	Questioning Frame	Evacuate 2, dispatch security enforcement	318	306	371	398
13	Seeking Frame	Set-up treatment centers & shelters, enforce curfews & flash-pump water	300	269	335	342
14	Re-framing	Temporarily relocate people, reconstruction planning & rehabilitation	305	225	333	376
15	Framing	Knowledge update	166	170	140	129
Sensemaking Times for Replicates =			3825	3653	3664	3887

HK had the highest sensemaking times out of the four scenarios analyzed with its highest sensemaking time recorded after the fourth replication at 3,884 seconds. The lowest recorded sensemaking time was 1,175 seconds after the initial run of LC situation. The extended sensemaking process duration for HK was attributed to the complexity of its information flow.

DFM nodes for the HC, MC and LC situations and HK are displayed in Tables 6.9, 6.10, 6.11 and 6.12 below. These nodes describe the sensemaking processes undertaken during the breakdown of the respective situations. The activation of a DFM node is subject to the thinking path of the sensemaking process. The table of results from the HC scenario has seven active nodes out of the eight. The inactivity of comparing frames node is due to the nature of the situation. There was no competing alternate frame available for contrast with the initial frame. DFM nodes during the MC situation simulation were three-fourths active with six out of its eight states active. A total of four out of the eight DFM nodes were active for the LC situation. Active DFM nodes during the HK simulation were similar to those of the HC situation. This is attributed to level of complexity introduced via information flow.

MC had the shortest thinking path of six stages; however, it did not record the lowest sensemaking time. Its lowest sensemaking time of 1,424 seconds after its first replication was higher than LC situation's sensemaking time after the initial simulation of 1,175 seconds. This may be due to the quantities of information flow used in the scenarios to introduce a degree of complexity.

Table 6.9. Data/Frame Model Activities for a High Complexity Situation

DFM Nodes	Action	DFM Nodes	Action
Initial Frame	On	Comparing Frame	Off
Elaborating Frame	On	Seeking Frame	On
Questioning Frame	On	Re-framing	On
Preserving Frame	On	Framing	On

Table 6.10. Data/Frame Model Activities for a Medium Complexity Situation

DFM Nodes	Action	DFM Nodes	Action
Initial Frame	On	Comparing Frame	Off
Elaborating Frame	On	Seeking Frame	On
Questioning Frame	On	Re-framing	On
Preserving Frame	Off	Framing	On

Table 6.11. Data/Frame Model Activities for a Low Complexity Situation

DFM Nodes	Action	DFM Nodes	Action
Initial Frame	On	Comparing Frame	Off
Elaborating Frame	On	Seeking Frame	Off
Questioning Frame	On	Re-framing	Off
Preserving Frame	On	Framing	Off

Table 6.12. Data/Frame Model Activities for the Hurricane Katrina Situation

DFM Nodes	Action	DFM Nodes	Action
Initial Frame	On	Comparing Frame	Off
Elaborating Frame	On	Seeking Frame	On
Questioning Frame	On	Re-framing	On
Preserving Frame	On	Framing	On

6.3 Statistical Analysis and Discussion

NTN times computed from the generated start and end times of each scenario were used in the statistical analysis. PST was not used in the statistical analysis because the thinking time for each state was captured by its NTN time. Differences and, in some cases, similarities among the generated sensemaking times and thinking paths prompted the following research questions:

- Do different sensemaking processes vary in their sensemaking times due to complexities?
- What is the classification of Hurricane Katrina's complexity?

In answering these research questions, both descriptive and inferential statistics were conducted.

6.3.1 Descriptive Statistics

Statistical Analysis Software (SAS) by SAS Institute Incorporated (Montgomery, 2009) was used as the statistical tool for the data analysis. The mean NTN times and their standard deviations for the four different scenarios, including HK, were calculated. Their results are represented in Table 6.13. The resulting mean and standard deviation values for HK and the HC situation were very similar with a difference between means of 19 seconds. Similarities were attributed to the values of input data, active DFM nodes during transitions and the various paths of transition during the sensemaking process. HK and LC had the highest difference between means of 122 seconds. This is indicative of their dissimilarity. Further analyses were conducted to find out if they were either statistically significant from each other or the same.

Table 6.13. Means and Standard Deviations of Scenarios

Scenario	Mean Node-to-node Time (s)	Standard Deviation (s)
Low Complexity	187	65
Medium Complexity	254	88
High Complexity	290	92
Hurricane Katrina	309	91

6.3.2 Inferential Statistics

Initial simulations of the four scenarios were each replicated four times, which gave a total of 185 observations. The dependent variable in this analysis was NTN time (in seconds) and the independent variable was sensemaking information flow represented by scenario complexity. The four scenarios, HC, MC and LC situations and HK, served as the four levels of the independent variable.

The hypothesis is that the mean NTN times of the different levels of sensemaking information flow; HC, MC, LC and HK, were the same. The alternate hypothesis is that at least one mean NTN time of one of the four levels is different from the others. A significance level of 0.05 is used as the probability-value (p-value) threshold, upon which the hypothesis is being rejected if the generated p-value is less than that of the significance level or accepted if it is greater.

An analysis of variance (ANOVA) was performed on the data using SAS. The NTN time output data was checked for the standard model adequacy requirements. These were normality, homogeneity, randomness and independence prior to the acceptance or rejection of the null hypothesis. A simulation run served as a blocking factor to eliminate the effect of nuisance factors, such as the time of day the simulation was run. The blocking technique is also used when the experimenter suspects that treatments are not homogeneous. SAS results from a plot of residuals versus sensemaking information flow are illustrated by Figure 6.1. This plot has a confirmed homogeneity or constant variance of NTN time within all four treatment levels.

A normality check was performed on the residuals of NTN times using a normal probability plot. The plot showed no irregularities without unusualness. The plot of the univariate procedure and an accompanying box plot validate the normality of the residuals, which is representative of a normally distributed data. A normality plot of the normally distributed residuals is illustrated by Figure 6.2.

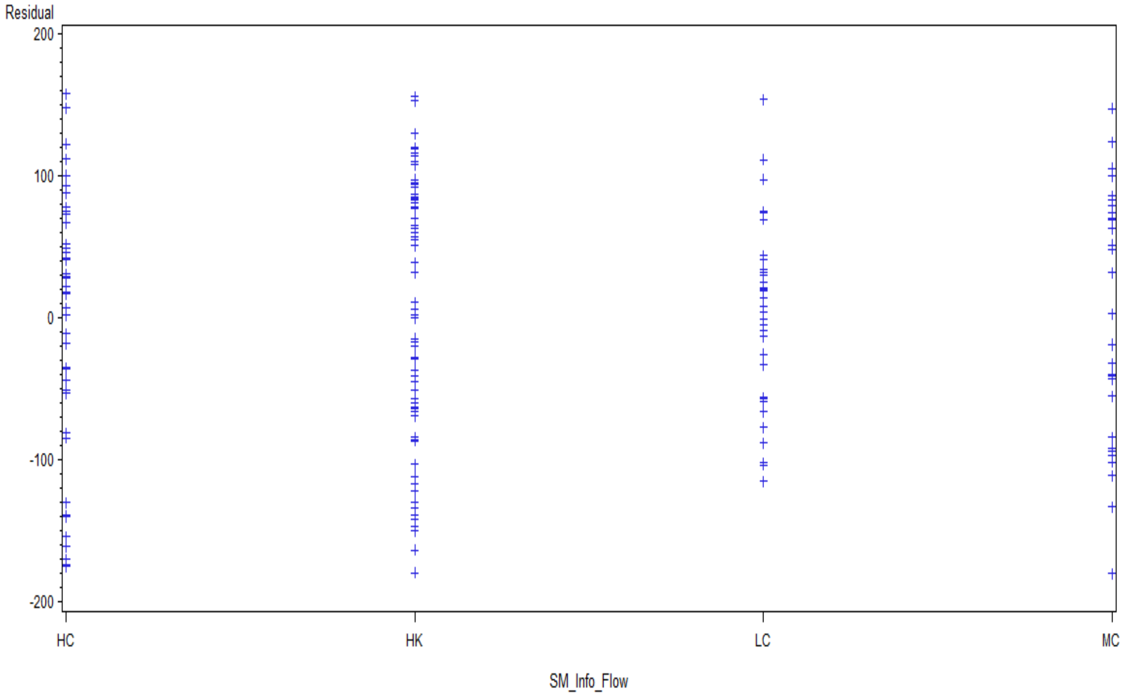


Figure 6.1. Model Adequacy Test for Homogeneity of Node-to-node Times

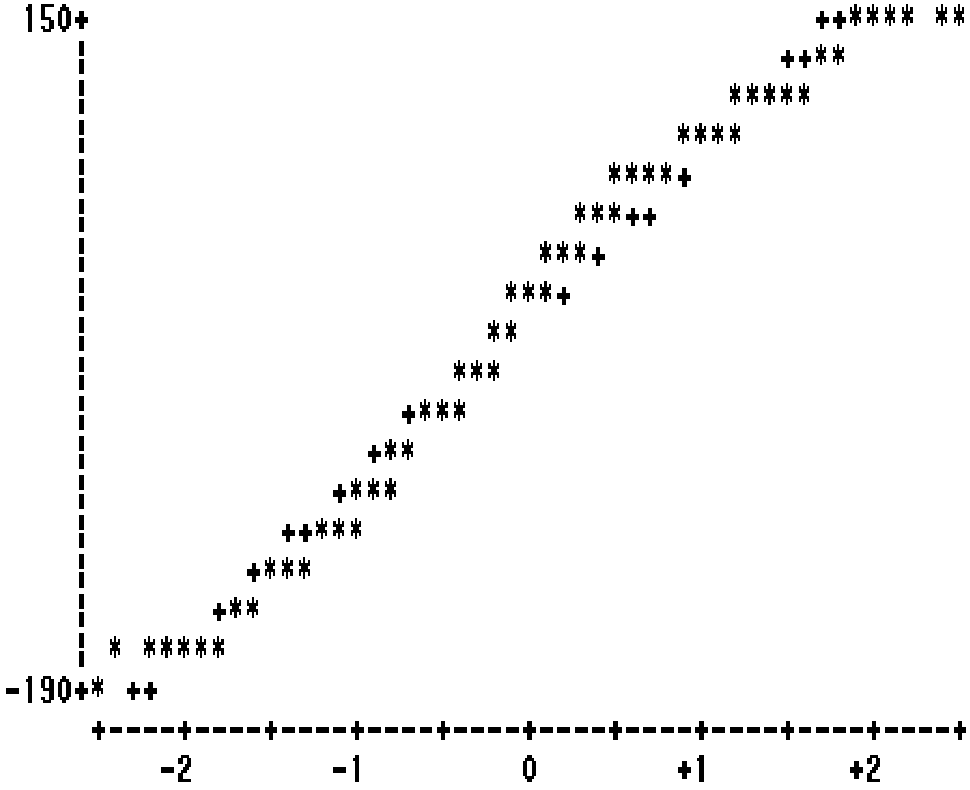


Figure 6.2. Normal Probability Plot of Residuals

A test for randomness of data was performed by plotting a graph of residuals versus predicted value (Yhat). The plot represented by Figure 6.3 shows nothing unusual. The distribution was neither skewed towards a positive nor negative correlation. A final model adequacy test for independence was done since inferences are not robust to dependence. The normality and randomness tests also require independence of experimental units. A plot of residuals versus time represented by Figure 6.4, indicates the residuals are independent. There is no need for transformation of the data since the residuals in Figure 6.3 are “structureless.”

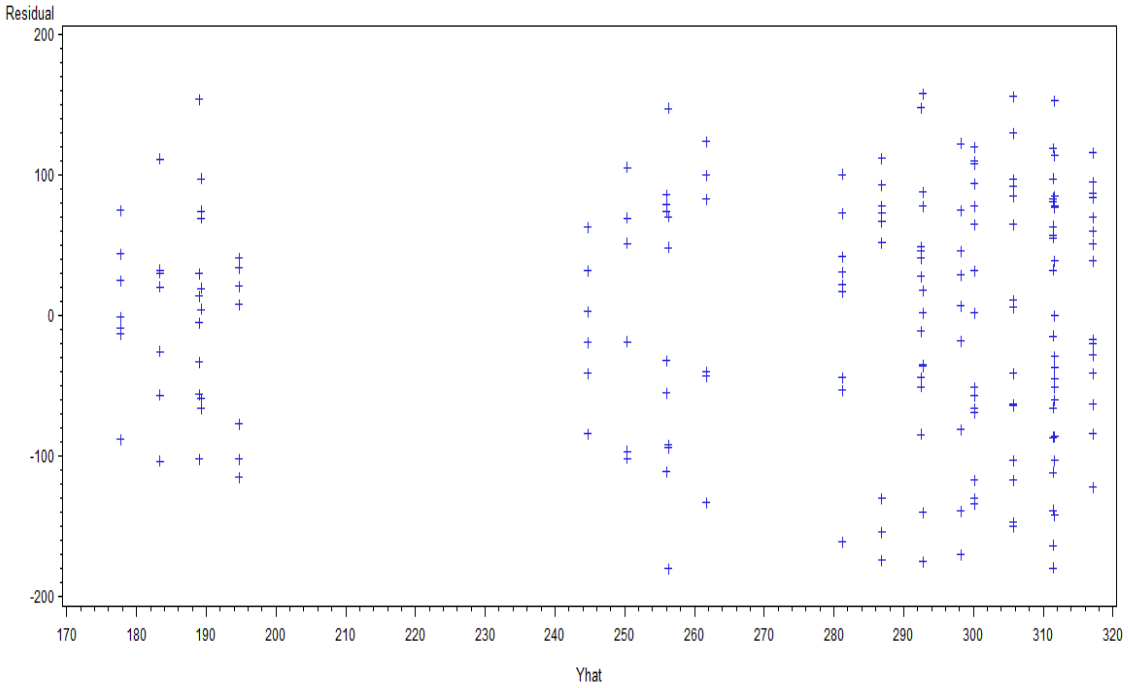


Figure 6.3. Model Adequacy Test for Randomness

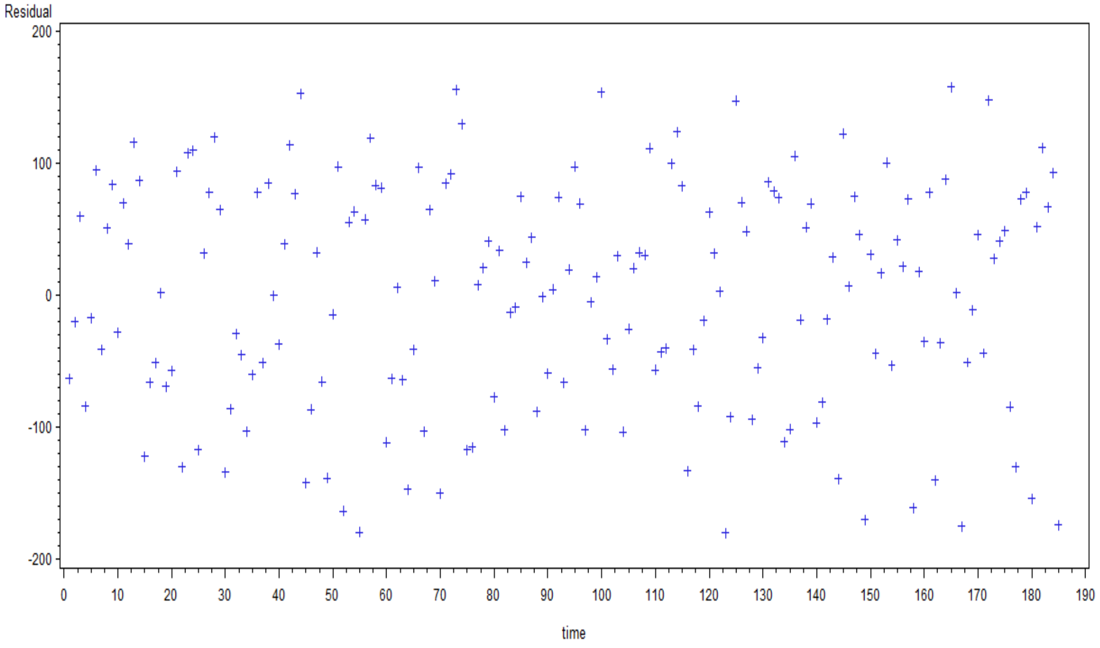


Figure 6.4. Model Adequacy Test for Independence

An ANOVA test was conducted to check the significance of the treatment effect. This SAS output is illustrated in Table 6.14. The output table from the general linear model (GLM) procedure is comprised of an ANOVA table and a test of effects table. The model is significant with an *F* (7,177) equal to 7.31and p-value less than 0.0001. The low p-value signifies the importance of the model. The test of total treatment effect, which is the overall total effect of sensemaking information flow on the NTN time in seconds, is significant. Based on the p-value being less than 0.0001, the decision is to reject the hypothesis. In conclusion, at least one of the mean NTN times of the treatment levels is not the same as the others, meaning that the level of sensemaking information flow has an effect on the respective sensemaking times. It can be inferred therefore that a situation's complexity affects its sensemaking time. The simulation run, which is the blocking factor, is insignificant with a p-value of 0.9357. This infers that the number of simulations and time of day do not matter. The simulation run, however, was not of interest to the statistical study.

Table 6.14. Output of the General Linear Model Procedure

Source	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	***F* Value**	**P Value**
Model	7	388922.133	55560.305	7.31	<.0001
Error	177	1345492.050	7601.650		
Corrected Total	184	1734414.184			
Source	**Degrees of Freedom**	**Type III Sum of Squares**	**Mean Square**	***F* Value**	**P > *F***
Simulation Run	4	6217.3189	1554.3297	0.20	0.9357
Sensemaking Information Flow	3	382704.8146	127568.2715	16.78	<.0001

Knowledge that the level of complexity of the situation affects the sensemaking time was not enough since the source of the difference was unknown. A pairwise comparison of the difference between NTN mean times was done using a Tukey’s Studentized Range Test. This was done to ascertain which of the pairs of means were significantly different or the same. The results of this post hoc test are represented in Table 6.15. Comparisons significant at the 0.05 significance level are indicated by three asterisks.

Table 6.15. Tukey's Studentized Range Test for Pairwise Comparisons

Information Flow Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		Indicator of Significant Comparisons
HK – HC	18.90	-23.74	61.54	
HK – MC	55.38	6.53	104.23	***
HK – LC	122.38	76.09	168.67	***
HC – HK	-18.90	-61.54	23.74	
HC – MC	36.48	- 16.82	89.78	
HC – LC	103.48	52.52	154.45	***
MC – HK	-55.38	-104.23	-6.53	***
MC – HC	-36.48	- 89.78	16.82	
MC – LC	67.00	10.74	123.27	***
LC – HK	-122.38	-168.67	-76.09	***
LC – HC	-103.48	-154.45	-52.52	***
LC – MC	-67.00	-123.27	-10.74	***

The pairwise comparison table above indicates that the complexity of HK was not significantly different from that of the HC situation used to validate the simulation model. at 0.05 significance level. HK’s complexity was significantly different from those of MC and LC situations. These findings place HK statistically in the same complexity as the high information flow situation. Interestingly, even though the complexity of the medium information flow situation was significantly different from that of HK and low information flow situation, it was not significantly different from that of the HC situation. This can be due to the choice of MC information flow. It can also be that there are more levels of complexities than the three selected; high, medium and low. Unidentified levels may exist under which HC and MC may fall. The complexity of the low information flow situation was significantly different from those of high and medium information flow situations and HK.

6.4 Chapter Summary

The statistical analysis of sensemaking simulation data indicates that the test of total treatment effect on the NTN time in seconds is significant. The decision is to reject the hypothesis of equal mean NTN times among the four levels of information flow, HC, MC, LC and HK given a p-value less than 0.0001 and an F (3,177) of 16.78. A pairwise comparison of treatment means reveal that HK and HC situation and HC and MC situations are statistically the same. The other comparisons between situations, HK and LC, HK and MC, HC and LC, and MC and LC, are statistically significantly different.

The nature of information flow into the HK situation as it occurred places Katrina and similar events of that nature into a group of highly complex situations that require longer sensemaking times. Each scenario had a noticeably different thinking path that was indicative of the fact that different situations require different approaches to the construction of their meaning and understanding.

CHAPTER 7

Summary, Conclusion and Future Research

7.1 Thesis Summary

Current human factors research views sensemaking as a qualitative process of imparting retrospective knowledge to the understanding of complex or chaotic situations. Chapter 1 of this thesis introduced the concept of sensemaking, giving the background and definitions. Applications of sensemaking as an aspect of information foraging, as an information fusion tool, and as support for situation understanding were discussed. The background and possibility of quantifying the process of sensemaking and providing for analytical assessments of sensemaking break points and equivocality reduction were explored. The use of FSA was adopted based on the representation similarity to the DFM addressed in this thesis.

Literature review on sensemaking, highlighting previous research and works dated from 1967 to 2006, were detailed in Chapter 2. Significant models of interest that aided in this thesis research are OODA Model, Situation Handling Model, DMSC, DFM and the Sensemaking Process Model. Gaps in the existing sensemaking models and avenues, and how this research bridges those gaps, were described.

The cognitive aspects of sensemaking, which tie what people do, the thinking processes involved, and the sense they make of it, were explored with simulation construction in Chapter 3. This chapter also described the challenges associated with the design of simulation models for a sensemaking process. Difficulty associated with the distinction between knowing and doing were stressed. Effects of our personal and self-reflexive constructs on the definition of a sensemaking process and its representation for a computer simulation modeling were discussed. Challenges associated with the ability to capture and represent the individual and/or team expertise were examined in the chapter, detailed by the theory of expertise for building simulation models for a sensemaking process.

The idea behind analytical modeling of sensemaking as a cognitive process was discussed in Chapter 4. The HK situation was described as a case study. DFM was identified as a model for quantitative modeling of a complex situation and six sensemaking functions, along with temporal paths linking the functions, were noted. The concepts and elements of FSA were discussed with respect to DFM. This led to the conceptual framework and computational model for FSA-DFM. An illustrative application of the conceptual framework to HK was emphasized.

A computational model known as HSM was developed from the principles of DFM-FSA in Chapter 5. HSM is a prototype for sensemaking simulation based on DFM theory. LabVIEW was used as the simulation software for the development of HSM. HSM is a tool that supports a sensemaker during interpretation of a complex hurricane situation. It mimics the thinking paths and cognitive delay times of a sensemaker and recommends plausible causes of action through simulation.

Chapter 6 presents anecdotal, statistical evaluations with output data generated from the HSM data log file after each simulation. The analyses were each replicated four times to give a total number of 185 observations. A performance metric using NTN time in seconds and four levels of problem complexity were analyzed. The results show a test statistic *F* (3,177) of 16.78 and a p-value less than 0.0001. A post-hoc analysis of the observations produced statistically similar means for HK and the HC scenario and the HC and MC scenarios.

7.2 Conclusion

A simulation model for DFM was achieved by using FSA. FSA is an abstract machine that has its foundations in state transitions. DFM nodes are very similar to states in a FSA and this contributed to the effective modeling of the DFM. FSA introduced a dimension of analytical measurements into the model of DFM, which is a generic qualitative model. The combined theories of DFM and FSA were used in the development of the Hurricane Sensemaking Machine (HSM). HSM is a production rule-driven support tool that was developed to validate DFM-FSA simulation and quantify the qualitative process sensemaking. Effective operation of HSM will require some level of expertise. This will be seen in the foraging of input data for the attributes setting, general operation of the automaton and interpretation of output log for analyses and inferences.

Results from the simulation were significant at a 0.05 significance level resulting in the decision to reject the hypothesis that the means of the NTN times in seconds are the same across all four levels of complexities. A significantly low p-value of less than 0.0001 for the levels of complexities HC, MC, LC and HK led to the conclusion that at least one of the mean NTN times of the different levels of complexities was different from the others. The lowest recorded sensemaking time of 1,175 seconds was in the initial simulation run of the LC scenario, whereas the highest was recorded in the fourth simulation run of HK at 3,887 seconds.

Overall, basic research findings indicate that sensemaking can be analytically quantified via cognitive simulation. Based on DFM-FSA, sensemaking can be constructed as a cognitive network and thinking (sensemaking) time can be mimicked by simulation. It is inferred in the analysis that problem complexity influences the sensemaking times of situations. The relationship between these two variables is linearly proportionate with sensemaking time, increasing as problem complexity increases. It can be said that a HC situation, such as HK will have a longer sensemaking time compared to a LC situation. This is illustrated in the below average sensemaking times (Figure 7.1) of 2,612.8, 1,523, 1,307.8 and 3,774.2 seconds for HC, MC, LC and HK scenarios, respectively.

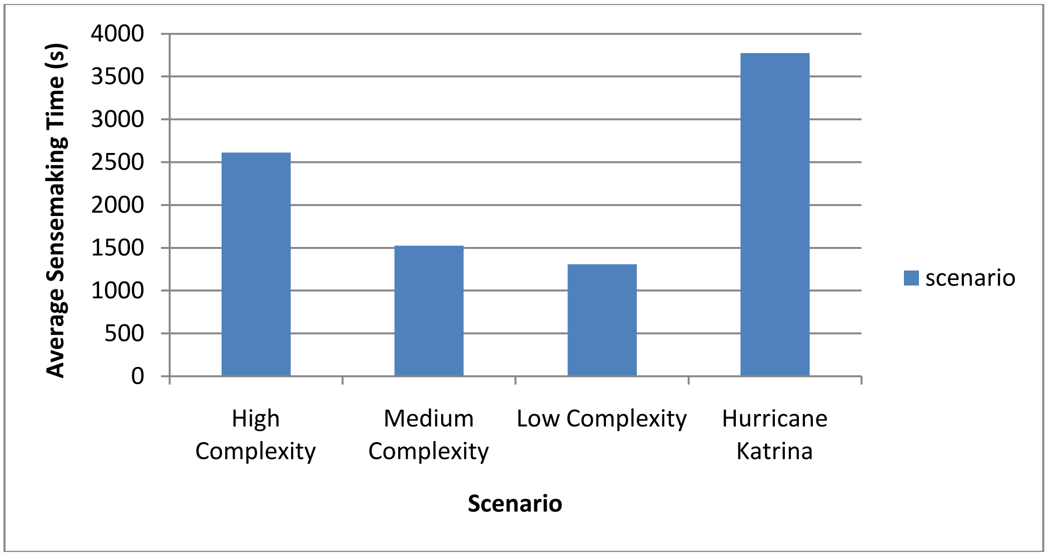


Figure 7.1. Plot of Mean Sensemaking Times for Levels of Complexity

7.3 Future Work

Future research will include the extension of the quantitative model to capture group or collaborative sensemaking processes by upgrading the model to depict the thinking time of team members. The model will also be extended to consider the sensemaker’s behaviors such as biases, prejudices, values and variations in problem perception, otherwise known as equivocality in sensemaking. The computational model will be extended to incorporate realistic human experts from various work domains to generate sets of robust and rich production rules, which will encapsulate different sensemaking instances. Finally, mental models and results in cognitive processing times, for typical daily thinking tasks from cognitive neuroscience models, will be investigated and introduced into the simulation to capture the time dynamics.

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APPENDIX

Table 1. Information Flow for Simple Complexity Scenario

Stage	Attributes Input Settings	Stage	Attributes Input Settings
1	Wind speed = 25mph Sea surface temperature = 68°F Storm tide = 0ft	2	Wind speed = 40mph Sea surface temperature = 82°F Storm tide = 2ft
3	Wind speed = 39mph Sea surface temperature = 82°F Storm tide = 2ft Rain depth = 8in	4	Wind speed = 84mph Sea surface temperature = 83°F Storm tide = 4ft Rain depth = 9in Storm surge = 4ft
5	Wind speed = 10mph Sea surface temperature = 75°F Storm tide = 1ft Rain depth = 4in	6	Wind speed = 10mph Sea surface temperature = 69°F Storm tide = 0ft Rain depth = 3in
7	Wind speed = 10mph Sea surface temperature = 69°F Storm tide = 0ft Rain depth = 2in		

Table 2. Information Flow for Medium Complexity Scenario

Stage	Attributes Input Settings	Stage	Attributes Input Settings
1	Wind speed = 60mph Sea surface temperature = 84°F Storm tide = 3ft Storm surge =3ft	2	Wind speed = 70mph Sea surface temperature = 85°F Storm tide = 3ft Storm surge =4ft
3	Wind speed = 88mph Sea surface temperature = 88°F Storm tide = 6ft Rain depth = 14in Storm surge = 7ft No. of deaths = 10	4	Wind speed = 67mph Sea surface temperature = 82°F Storm tide = 2ft flood depth = 2ft Storm surge = 3ft No. of deaths = 12
5	Mechanical systems & infrastructural damage rate = 60% No. of security breaches = 2 No. infectious disease victims = 11 No. of deaths = 15 Level of utility cut-off = 70%	6	Mechanical systems & infrastructural damage rate = 62% No. of security breaches = 3 No. infectious disease victims = 12 No. of deaths = 17 No. homeless victims = 100

Table 3. Information Flow for High Complexity Scenario

Stage	Attributes Input Settings	Stage	Attributes Input Settings
1	Wind speed = 90mph Storm surge =8ft Expert ratings = 3 NOAA storm ratings = 3 Rain depth = 15in Sea surface temperature = 92°F Storm tide = 6ft	2	Wind speed = 112mph Storm surge =10ft Expert ratings = 4 NOAA storm ratings = 4 Rain depth = 16in Sea surface temperature = 94°F Storm tide = 8ft
3	Wind speed = 135mph Storm surge =12ft Expert ratings = 5 NOAA storm ratings = 5 Rain depth = 26in Sea surface temperature = 95°F Storm tide = 11ft Past weather attributes = 4 No. of deaths = 60 Rate of false alarm = 2%	4	Wind speed = 137mph Storm surge =12ft NOAA storm ratings = 4 Rain depth = 25in Sea surface temperature = 95°F Storm tide = 10ft No. of deaths = 72
5	Wind speed = 120mph Storm surge =9ft Expert ratings = 5 NOAA storm ratings = 3 Rain depth = 18in Sea surface temperature = 91°F Storm tide = 7ft	6	Wind speed = 98mph Storm surge =7ft Expert ratings = 3 NOAA storm ratings = 4 Rain depth = 15in Sea surface temperature = 88°F Storm tide = 6ft Past weather attributes = 3 No. of deaths = 74 Rate of false alarm = 4%
7	Wind speed = 84mph Storm surge =5ft NOAA storm ratings =1 Flood depth = 4ft Sea surface temperature = 84°F Storm tide = 4ft No. of deaths = 75 Mechanical systems & infrastructural damage rate = 70% No. of security breaches = 10 No. mechanical systems & infrastructural damage = 80 (78 buildings & 2 bridges)	8	Mechanical systems & infrastructural damage rate = 75% No. of security breaches = 30 No. infectious disease victims = 100 No. of deaths = 80 Level of utility cut-off = 70%
9	Mechanical systems & infrastructural damage rate = 75% No. of security breaches = 30 No. infectious disease victims = 120 No. of deaths = 82 No. homeless victims = 200		