

FRATRICIDE IN AIR OPERATIONS
OPENING THE BLACK-BOX: REVEALING THE 'SOCIAL'

Thesis submitted for the degree of

Doctor of Philosophy

at the University of Leicester

by

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May 2010

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Abstract

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In a study of accidents among major air carriers, 88% of those involving human error could be attributed to problems with situation awareness (SA); similarly problems with SA were found to be the leading causal factor in a review of military aviation mishaps (Endsley, 1999). Studies of fratricide in air operations reflect similar issues pertaining to pilot error and situation awareness. It is argued in this thesis that pilot error is not an explanation but rather is something to be explained. Through an analysis facilitated by Actor Network Theory (ANT), the ‘black box’ of pilot error is examined revealing a de-centered accident aetiology residing within a network of heterogeneous elements characterized as the ‘hybrid collectif’ (Callon and Law, 1995). ANT is a theoretical perspective that has evolved to address the socio-technical domain. The black box associated with pilot/human error is the result of the relationality that obscures the fact that the black box is dependent on the network of heterogeneous elements and alliances of which it is a part. Within the black box are the silenced, deleted voices associated with the accident aetiology that emerge as hardwired politics and illusions of certainty. We therefore must suspend our traditional conceptualization of causality and rethink its nature in terms of conditions of possibilities. Synthesizing and synergizing perspectives from Systems Theory, Actor Network Theory, and Complexity Theory, the findings are far reaching regarding our understanding of accident aetiology pertaining to fratricide in air operations and complex socio-technical systems.

Acknowledgements

First and foremost I would like to express my gratitude to Dr Simon Bennett, my thesis advisor, for his enthusiasm, guidance and advice during the course of this research. It has most certainly been an honour and privilege to work with him. He has made this a truly enjoyable and rewarding experience.

I would also like to thank the academic and support staff of the Department of Criminology (formerly Scarman Center) at the University of Leicester for their resounding support and encouragement.

This work would have not been possible if it were not for the support of the Department of National Defence. Specifically I would like to extend my appreciation to the leadership at 12 Wing Shearwater including Major-General Hincke, Brigadier-General Martin for their support.

At the Canadian Forces Experimentation Center (CFEC), I would like to thank Captain (N) Liange, Colonel Chekan, Mr Bob Elliott (Synthetic Environment Coordination Office: SECO) for their kind support towards my studies. From the Center of Operational Research (CORA) I would like to thank Dr. Dixon (Canadian Lead on AG 13: Fratricide Study) for his insights into the problem space and Mr. Taylor for his ‘tutorials’ and discussions on System Dynamics and AFD.

I would like to thank members of the International System Safety Society and reviewers of the Human Performance, Situation Awareness and Automation conference for their comments, reflections and discussions regarding my research.

The realization of this journey would not have been possible had it not been for the mentorship, guidance and friendship bestowed upon me during my undergrad and postgraduate studies by Dr Mukherjee and Dr Wiederick from the department of Physics at the Royal Military College of Canada.

“A teacher affects eternity;
No one can tell where his
Influence stops.”
-Henry Adams

Grateful acknowledgement is extended to my parents and family. Their encouragement and support have been most appreciated.

This thesis is dedicated to the soldiers who have fallen as a result of fratricide.
Their courage and service will never be forgotten.

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Abbreviations

AAA	Anti-Aircraft Artillery
AAIB	Aircraft Accident Investigation Board
AA BDE	Anti aircraft
ACO	Air Coordination Order
AFD	Anticipatory Failure Determination
AG	Action Group
ANT	Actor Network Theory
AN/APR-39A(v)	Radar warning receiver
ASW	Anti-submarine Warfare
ATO	Air Tasking Order
AVN	Aviation
AWACS	Airborne Warning and Control Systems
BCIS	Battlefield Combat Identification System
BOI	Board of Inquiry
BTID	Battlefield Target Identification Device
C4ISR	Command, Control, Communication and Computers, Identification, Surveillance and Reconnaissance.
CA	Canada
CAOC	Combined Air Operations Centre
CASE	Canadian Advanced Synthetic Environment
CD&E	Concept Development and Experimentation
CE	Capability Engineering
CFAC	Combined Forces Air Component
CFEC	Canadian Forces Experimentation Centre
CIB	Coalition Investigation Board
CID	Combat identification
CONOPS	Concept of Operations
COTS	Commercial-off-the-shelf
CVR	Combat Vehicle Reconnaissance
DIS	Distributed Interactive Simulation
DND	Department of National Defence (Canada)
DoD	Department of Defence (US)
DRDC	Defence Research and Development Canada
DSB	Defence Science Board
DSTL	Defence Science and Technology Laboratory
DSTO	Defence Science and Technology Organization
EO	Electro-optics
FFIB	Friendly Fire Investigation Board
FLIR	Forward Looking Infrared
FOM	Federation Object Model
GAO	Government Accounting Office
GBU	Guided Bomb Unit
GFAC	Ground Forward Air Controller

GPS	Global Positioning Satellite
HCI	Human Computer Interface
HITL	Human in the loop
HLA	High Level Architecture
HQ	Headquarters
HRO	High Reliability Organization
ICAO	International Civil Aviation Organization
IFF	Identification Friend or Foe
INSAG-4	International Nuclear Safety Advisory Group
IR	Infrared
JCAS	Joint Close Air Support
JFACC	Joint Force Air Component Commander
JFC	Joint Force Commander
JSMARTS	Joint Simulation and Modelling in Acquisition, Rehearsal, Requirements and Training
JTAC	Joint Terminal Attack Controller
JTF	Joint Task Force
LGB	Laser Guided Bomb
LSE	London School of Economics
MALO	Maritime Air Littoral Operations
MES	Multiple Events Sequencing
MIT	Massachusetts Institute of Technology
M&S	Modelling and Simulation
MoD	Ministry of Defence (UK)
NAO	National Audit Office
NASA	National Aeronautics and Space Administration
NATO	North American Treaty Organization
NCA	National Command Authority
NDM	Naturalistic decision-making
NECSI	New England Complex Systems Institute
NFZ	No Fly Zone
NSIAD	National Security and International Affairs Division
NVG	Night Vision Goggles
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
OJT	On the job training
OMT	Object Model Template
OODA	Observe, Orient, Decide, Act
OPC	Operation Provide Comfort
OPLAN	Operation Plan
OPORD	Operation Order
OSI	Office of Special Investigators
PHI	Physical, human, informational
PROE	Peacetime Rules of Engagement
R&D	Research and Development
RA	Resolution Advisory

RAF	Royal Air Force
ROE	Rules of Engagement
RTI	Run Time Interface
RWR	Radar Warning Receiver
SA	Situation Awareness
SAFIRE	Surface to Air Fire
SAM	Surface to Air Missile
SCOT	Social Construction of Technology
SE	Synthetic Environment
SECO	Synthetic Environment Coordination Organization
S&T	Science and Technology
SOL	Safety through Organizational Learning
SOM	Simulation Object Model
SOP	Standard Operating Procedure
SPINS	Special Instructions
SROE	Standing Rules of Engagement
STAMP	Systemic Theoretic Accident Modeling and Processes
STANAG	Standardization Agreement
STEP	Sequentially Timed Events Plotting
TADS	Target Acquisition/Designation System
TAOR	Tactical Area of Responsibility
TBM	Theatre Ballistic Missile
T&E	Test and Evaluation
TCAS	Traffic Collision Avoidance System
TID	Thermal Identification Device
TRADOC	Training and Doctrine Command
TRIZ	Theory of the Solution of Inventive Problems (Russian Acronym)
TSE	Transitional Synthetic Environment
TSR2	Tactical Support Reconnaissance
TTCP	The Technical Cooperation Panel
TTP	Tactics, Techniques and procedures
TAOR	Tactical Area of Responsibility
UAV	Unmanned Air Vehicle
UH-60	Utility Helicopter
UHF	Ultra High Frequency
UK	United Kingdom
US	United States of America
USEUCOM	United States European Command
USCENTCOM	United States Central Command
WBA	Why Because Analysis
WROE	Wartime Rules of Engagement

Chapter 1

Introduction

1.1 INTRODUCTION

Human error is often cited as a major contributing factor or cause of incidents and accidents. Accident surveys in aviation have attributed 70% of incidents to crew error citing pilot error as the root cause of an aviation accident (Woods, Johannesen, Cook and Sarter, 1994:2; Helmreich, 2000:781; Shappell and Wiegmann, 2001:60). In a study of accidents among major air carriers, 88% of those involving human error could be attributed to problems with situation awareness (SA); similarly problems with SA were found to be the leading causal factor in a review of military aviation mishaps (Endsley, 1999). Likewise, investigations into friendly fire incidents have cited poor SA as a major contributing factor (Ministry of Defence, 2002). Despite the advent of precision-guided munitions, ‘smart bombs’, and unprecedented navigational accuracy, friendly fire continues to be prevalent. Although Shrader (1982) reports a fratricide rate of 2% to be the norm, the 1991 Desert Storm experience showed this assessment to be unrealistic; in fact during Desert Storm 24% of American lives were lost and 15% wounded in action resulting from ‘friendly fire’. Human error and, in the case of air to ground incidents, pilot error dominates the findings from the accident investigations associated with fratricide.

According to Woods et al. (1994), human error can be characterized either as a cause of failure or as a symptom of a failure. Patterson, Woods, Roth, Cook, Wears and

Render (2006:35) argue that the frequent attribution of human error as a 'root cause' often serves as a stopping point for an investigation. However, in the new view of human error, it becomes a starting point thereby revealing how multiple interacting factors combine in a complex socio-technical system. A systems view of the problem space regards human error as a symptom of '...contradictions, pressures and resource limitations deeper inside the system' (Dekker, 2002a:2). This systems view supports a complexity perspective, whereby the attribution of pilot error is seen as an oversimplification of a complex aetiology resulting from a number of causes (Shappell and Wiegmann, 2001).

The label 'human error' as reported by Woods et al. (1994) is considered prejudicial and unspecific. They argue that the label 'human error' retards rather than advances our understanding of how complex systems fail and the role of the human in both successful and unsuccessful system operations. In support of this, Hollnagel (2004:31) remarks that '...the concept of 'human error' is an artifact of a theoretical development coupled to a technological development'. As reported by Woods et al. (1994:4), the question surrounding the attribution of human error is a complex matter presenting an argument that human performance is a multidimensional issue that is a function of the context in which an incident takes place; that technology shapes human performance thereby creating new pathways and forms of error and failure; that human performance involves a set of interacting people; that competing goals within the organizational context creates dilemmas shaping accident aetiology; and that the attribution of error is a social judgment rather than an objective conclusion. Within

the context of fratricide, this is supported by Gadsden and Outteridge (2006:7-8) who argue that in previous studies of fratricide, investigators tend to take a narrow view of the problem space and consider only the direct and immediate causes of the incident thereby failing to consider the systems context resulting in a limited understanding.

This thesis entitled “Fratricide in Air Operations: Opening the Black Box, Revealing the Social”, applies Actor Network Theory as a lens to facilitate a systems thinking-based (Wickramasinghe, Tumu, Bali and Tatnall, 2007) analysis to examine the key dynamics that reside in the black box of pilot error associated with fratricide. The black box we call pilot error contains, as stated by Latour (1987:285) ‘...that which no longer needs to be reconsidered’. The black box then becomes a substitute for a complex relation such that its opacity is maintained by the concern for only the input and output. Various kinds of elements can be placed in black boxes- ‘thoughts, habits, forces and objects’ (Callon and Latour, 1981:285). It is by opening the black box that we reveal the ‘social’ that characterizes the accident aetiology. Paraphrasing and modifying Dekker (2001:3) we purport that: Pilot error is not an explanation but is something to be explained. Challenging the traditional view of human error, this thesis recognizes that ‘...accidents are seen as emerging phenomena in complex systems and as the result of an aggregation of conditions rather than the inevitable effect of a chain of courses’ (Hollnagel, 2004:xv). This chapter provides an overview of the argument with a focus on the theoretical foundations, methodology and findings associated with this research.

1.2 BACKGROUND

The technical perspective of accident aetiology is rooted within the probability of failure models associated with components of a system. This perspective traces the failure of a system to a chain of events within a system that linearly define the path towards an accident. It has been cited by Leveson (2002) that event-based models provide a poor representation of systemic accident factors and focus primarily on proximate events. According to Leveson (2002:9):

Viewing accidents as chains of events may limit understanding and learning from the loss. Event chains developed to explain an accident usually concentrate on the proximate events immediately preceding the loss. But the foundation for an accident is often laid years before.

The body of knowledge within the social sciences regarding accident aetiology of complex socio-technical systems has increased over the last 20 years, recognizing the social and technical dimensions of accidents.

The term ‘System Accidents’ (Perrow, 1984) describes an aetiology that arises from the interactions among components (electromechanical, digital, and human) rather than the failure of individual components. Accidents involving complex socio-technical systems, such as those resident within the nuclear power industry, aerospace industry and military operations, reflect this aetiology characterized by its nonlinearity and inherent complexity. As a consequence de Almeida and Johnson (2008:1) remark that:

It is becoming increasingly difficult to identify the causes of incidents and accidents back through the complex interactions that lead up to an adverse event. At the same time, there is a growing appreciation of the need to consider a broad range of contextual factors in the aftermath of any mishap.

The features of systems thinking and complexity theory that shape the methodological approach associated with this work stem from the conceptualization that the general system is not simply an aggregation of objects but is rather a set of interrelated, interconnecting parts creating through their interaction new system properties.

Informed by complexity theory, Ottino (2003:293) argues that 'complex systems cannot be understood by studying parts in isolation. The very essence of the system lies in the interaction between parts and the overall behaviour that emerges from the interactions'. The application of complexity theory crosses many domains, thereby reflecting the multidisciplinary perspective inherent within the concept. Within the social sciences, the advent of complexity theory has facilitated a re-examination of the concept of system. As stated by Walby (2003), complexity theory informs the systems perspective by challenging assumptions about equilibrium with a view to dynamic processes of systems. Addressing issues that lie at the foundation of sociological theory, complexity theory facilitates a rethinking regarding systems, inter-relationships, and interdependencies giving rise to dynamic behaviour (Walby, 2003).

Sociology offers an interesting approach for looking at the socio-technical elements of complex systems through the application of Actor Network Theory (ANT). The systems perspective of ANT looks at the inter-connectedness of the heterogeneous

elements characterized by the technological and non-technological (human, social, organizational) elements. The network space of the actor network provides the domain of analysis that presents the accident aetiology as a network of heterogeneous elements that shape and are shaped by the network space. Yeung (2002) notes that much of the work that draws on actor network theory places its analytical focus on unearthing the complex web of relations between humans and non-humans. The interaction of non-human actors with the human actors (such as a pilot) gives shape and definition to identity and action. Latour (1994b:806) argues that ‘...it is impossible even to conceive of an artifact that does not incorporate social relations, or to define a social structure without the integration of non-humans into it. Every human interaction is socio-technical’. The ‘social’ is thereby described as ‘materially heterogeneous’ (Callon and Law, 1997:166).

Germane to this work, the socio-technical system is a topic of inquiry within sociology that combines the social and technical paradigms and examines the relationship between them. As described by Coakes (2003:2), ‘Socio-technical thinking is holistic in its essence; it is not the dichotomy implied by the name; it is an intertwining of human, organizational, technical and other facets’. Senge (1990) argues that since the world exhibits qualities of wholeness, the relevance of systemic thinking is captured within its paradigm of interdependency, complexity and wholeness. Although events can be considered to be discrete occurrences in time and space ‘...they are all interconnected. Events can be understood only by contemplating the whole’ (Flood, 1999:13). The holistic perspective of ANT makes it well suited to facilitate an

examination of the complex socio-technical systems associated with accident aetiology.

1.3 SYSTEM THINKING

Systems thinking is both a worldview and a process in the sense that it informs ones understanding regarding a system and can be used as an approach in problem solving (Edson, 2008:5). As a cross-disciplinary domain, systems thinking spans from the physical sciences and engineering to the social sciences, humanities and fine arts. Because of this feature of systems thinking, there is no universally agreed definition of a ‘system’ that satisfies all domains, although they may share similar defining characteristics (Checkland, 1981). A system according to Hall and Fagen (1956:18) is described as ‘...a set of objects together with relationships between the objects and between their attributes’.

“Systems theory” represents a theoretical framework, a perspective and a set of methodological tools that may be applied to any field of study. The systems perspective reveals properties of the whole that are not evident with an examination of the components thereby revealing emergent behaviour that arises from the dynamic interaction of components. Systems theory as discussed in Senge (1990) emphasizes interconnectedness, causal complexity and the relation of parts to the whole (Ackoff, 1994), thereby challenging traditional linear thinking and simple causal explanations. A systems perspective of accident aetiology emphasizes, as Hollnagel (2008:8) remarks that ‘...explanations cannot be found nicely tucked away in a single part of a

socio-technical system, such as the operator or the interface, but are rather due to the ways in which normal performance variability can combine in unexpected ways’.

With the advent of complexity theory, a new vocabulary and understanding regarding systems has evolved, providing a new set of concepts for describing complex nonlinear systems (Capra, 2005). Urry (2003) describes how complexity recognizes the emergent properties that result from the dynamic interaction within a system, thereby developing collective properties that are not reflected in the individual components. As such, complexity argues against reductionism. Complexity theory recognizes that previous situations influence future ones and that small changes in the system may cause disproportional change throughout the system. As noted in Styhre (2002), the complexity perspective recognizes that changes result from a multiplicity of interconnected causes and effects. The traditional linear perspective makes comprehension of the interrelationships difficult to conceive of.

As a guiding methodology for this thesis, the systems approach as a foundation perspective informed by complexity theory facilitates a break from ‘...mechanistic, linear, and causal methods of analysis towards viewing interdependence and interrelation rather than linearity and exclusion’ (Dennis, 2007:140).

1.4 ACTOR NETWORK THEORY

Actor Network Theory is a theoretical perspective that has evolved to address the socio-technical domain and in particular the conceptualization of the ‘social’. This

perspective challenges the way we think of agency, the human and non-human. The application of the ANT perspective (terms and concepts) has been instrumental in revealing insights within such fields as information technology, organizational theory, geography, medical anthropology and psychology. Latour (2005) introduces ANT as a 'relativistic perspective' that challenges the current paradigm associated with the sociology of the social. It is through this examination of the 'social' that the inherent complexity associated with understanding accident aetiology is revealed.

ANT treats both human and machine (non-human) elements in a symmetrical manner, thereby facilitating the examination of the situation (such as an accident) where Callon (1999:183) argues, '...it is difficult to separate humans and non-humans, and in which the actors have variable forms and competencies'. As noted by Ashmore, Woolfitt and Harding (1994:735), through ANT '... the assumption of the ontological primacy of humans in social research and theory is suspended. Non-human entities, traditionally overlooked in sociological accounts of the social world, take their rightful place as fully fledged actants in associations, relations, and networks'.

Fundamental concepts within ANT are the conceptualization of the Actor and the Network. An actor-network as described by Latour (1987), Callon (1986, 1991) is characterized as a network that is inherently heterogeneous, where the relations between the actors are important, rather than their essential or inherent features. The actor, whether technical or non-technical, is examined within the context of a heterogeneous network. In fact the actor is a network in itself '...in the same way,

elements in a network are not defined only by their “internal” aspects, but rather by their relationships to other elements, i.e., as a network’ (Aanestad and Hanseth, 2000:360). The actors or actants of ANT can be humans, organizations, cultures, ideas, animals, plants or inanimate objects and are described in terms of the alliances and exchanges they exhibit in the interconnected network of relations. Latour (1987:180) defines the word network as that which ‘...indicates that resources are concentrated in a few places the knots and the nodes-which are connected with one another- the links and the mesh: these connections transform the scattered resources into a net that may seem to extend everywhere’. The network, from an ANT perspective, may not have the characteristics idealized by the technical perspective. Williams-Jones and Graham (2003:279) argue that:

ANT is an approach that is interested in the tensions between actor, network and technology, and how they manifest in practice (Latour, 1997; Law, 1999). Failed networks are thus often a fruitful place for study, because it is here that the actor-networks reveal themselves and the norms and values built into technologies are made apparent.

Viewed through the lens of ANT the world is seen to consist of numerous heterogeneous elements, demonstrating that nature and society are not so much causes, but outcomes that emerge from a complex set of relations (Murdoch, 1997).

As a piece of research informed by sociology, complex systems are seen as heterogeneous actor-networks that consist of a particular configuration of more or less aligned human and non-human components. Within this conceptualization, actors may

have different interests and agendas that are inscribed in both material and social actors/arrangements such that they enroll other actors through the process of translation (Roland and Aaenstad, 2003). Examination of actors such as those characterized traditionally as technologies, facilitates an exploration of how these 'actors' mediate action and how they are entangled in local techno-social configurations. By virtue of this, it challenges our traditional conceptualization of agency. For example Latour (1992) describes how the door groom (a barely noticeable technology) shapes the action of human users by virtue of such qualities as the strength of the spring. As noted in Michael (2003:131) the door groom '...prescribes and proscribes what human actors must do in order to get through the door'. The three elements from ANT that are particularly relevant to the study of pilot error and fratricide include the principal of symmetry; the focus on actor-networks and dissolving dualisms; and the emphasis on processes of translation (Van der Duim, 2005: 86) in which is hereby explored throughout this body of work.

With regards to the context of a cockpit filled with computers, glass displays, and the pilot, we leverage the comments from Harbers (2005:10) who asks the question 'Where does one draw the line between man and machine, between human responsibility and technical inevitability, between the subjective world of politics, culture and morality and the objective world of science, technology and nature?'. Harbers (2005:10) argues that '...we are confronted here with a hybrid situation in which human beings and technology are tightly interwoven- a mixture, a muddle of man and machine'. We address these questions and arguments through the concept of

the ‘hybrid collectif’ that emerges from the analysis. We introduce here an entangled state that represents our system of interest, our problem space of analysis thereby challenging current notions of agency, space, time and causality. Blamism is not the same as causality. Pilot error is not an explanation, but is something to be explained.

1.5 RESEARCH PERSPECTIVE

Chapman (2005:350) argues that accidents involving socio-technical systems are difficult to mitigate ‘...because the nature of complexity in these systems is not well understood by those who design, manage and operate them’. Chapman (2005:350) further argues for the requirement to progress better conceptual models and frameworks that reveal the inherent complexity and thereby make these complex socio-technical systems more transparent. The ANT framework, supported by Systems Dynamics Modelling and Anticipatory Failure Determination, applied in this thesis takes this challenge by facilitating a rethinking of how we view human error and in particular pilot error within complex socio-technical systems. The theoretical perspective of ANT challenges the fractured view of the world that stems from the deficiencies of dualistic thinking as described in Murdoch (1997). Murdoch (1997) argues that ANT presents a nondualistic position by focusing on the relations and associations that characterize the heterogeneous network of elements that combine the social and the material. The perspective described here presents new ways of viewing the world of accident aetiology associated with complex socio-technical systems which is complementary to other approaches as detailed in Ladkin and Loer (1998), Leveson (2002), Busse (2002), Johnson (2003), and Strauch (2004).

1.6 SCOPE OF THESIS

The scope of this thesis focuses on fratricide in air operations. This thesis does not claim to characterize all accidents involving complex socio-technical systems, but rather focuses on the problem space defined by the bounds detailed in chapter 4.

1.7 RESEARCH STRATEGY

From the domain of physics it has been argued that how we look at the world determines what we see (Heisenberg, 1962; Barad, 2007). Hollnagel (2004) argues that ‘cause fixation’ rather than explanation is shaped by the methods applied in the conduct of an accident investigation. The application of a Root Cause Analysis approach, by the very nature of the method and vocabulary, implies a linear decomposition and a principle of causality ‘derived from the Axioms of Industrial Safety’ (Hollnagel, 2004:27) whereby the root cause is considered as an abstraction or artefact. Challenging the linear decomposition of complex socio-technical systems it is recognized as noted by Urry (2002), that there exists a disproportionality of causes and effects such that history matters and past events are never forgotten. Through complexity theory, we recognize that the systemic perspective reveals the interdependencies and interactions among the elements that create the whole. This suggests that the key to understanding complex socio-technical systems is derived from an analysis of the patterns of relationships and interactions comprised of the heterogeneous elements. A systems thinking perspective informed by complexity theory is therefore applied as an integrating element of this research strategy.

Qualitative analysis, as described in Denzin and Lincoln (2005), characterizes this research which involves the analysis of a variety of materials including case study and participant observation involving distributed simulations. The case study strategy is a powerful tool for increasing our understandings regarding aviation accident aetiology (Anderson, Crabtree, Steele and McDaniel, 2005:673). As a sociological informed piece of research, Actor Network Theory provides a conceptual foundation with regards to the approach towards the problem space. ANT is used where it is difficult to separate human and non-human elements (Callon, 1999:183) in a world which is full of hybrid entities (Latour, 1993). It is applied, within the context of this thesis, to a socio-technical system whereby the traditional dichotomy between the social and the technical is no longer a priori assumed such that thinking in terms of human/non-human binaries is challenged.

Building on in-depth analyses of a number of existing case studies and relevant social, psychological and cognitive theory, we characterize pilot error associated with fratricide as a de-centered accident aetiology, where the unit of analysis that emerges from the study is the 'hybrid collectif' (Callon and Law, 1995). Through a distributed simulation, we garner insights into matters pertaining to trust, situation awareness and decision making that supports and informs the case study analysis. The overall analysis provides a new characterization of the aetiology associated with fratricide through the application of ANT. The methodological guidance purported by ANT is to follow the activities of both human and non-human actors (Callon, 1986; Latour,

1987). Within the framework of ‘follow the actor’, thematic analysis of the data was conducted (Boyatzis, 1998; Braun and Clarke, 2006). This was supported by insights from system dynamic modelling and Anticipatory Failure Determination (AFD) modelling (appendix B).

1.8 THESIS OUTLINE

The thesis is organized in 6 chapters with 4 appendices.

Chapter 1: Introduction. This chapter introduces the problem space and analysis perspective. It presents the foundational theoretical perspectives of System Thinking, Complexity Theory, and Actor Network Theory and describes the thesis structure.

Chapter 2: Foundational Theory/ Literature Review. This chapter presents the theoretical foundations necessary for the analysis. This includes discussion regarding human error, and accident aetiology in order to establish the context of the problem space. To shape the perspective of the thesis an introduction into systems theory and complexity theory are followed by a detailed introduction into Actor Network Theory. Concepts from the cognitive domain are introduced as complementary material that enriches the analysis and provides insights into the problem space.

Chapter 3: Methodology-A discussion of research design. This chapter presents the methodology inherent within the Actor Network Theory perspective. The case study approach is managed within an iterative spiral research development plan. Insights

derived from modelling and simulation experiments inform the case study research findings.

Chapter 4: Research Data: Defining the Problem Space. This chapter presents the contextual problem space of the thesis: fratricide in air operations. Quantitative data regarding fratricide is introduced to capture the extent of the problem space. A number of case studies are presented from which the results of this thesis are based upon. The primary case studies include: 1991 Apache helicopter fratricide; 1994 Black Hawk fratricide; and 2002 Tarnak farms fratricide. Additional case studies are included to help validate the findings and provide additional theoretical development. They include: 2001 B-52 fratricide; 2005 Patriot missile fratricide; and the 2006 A-10 fratricide.

Chapter 5: Discussion- Opening the Black Box. In this chapter an analysis of the case studies is presented drawing upon the theoretical foundations discussed in chapter 2. The chapter is organized along the salient findings derived from the case study analysis interweaving concrete substantiation in the evolving discourse.

Chapter 6: Conclusion. This chapter presents a summary of the research contributions and conclusions stemming from the analysis as well as outlines opportunities for future work.

Appendices A-D: Represent background/supplemental material that is referred to in the thesis.

Appendix A: Papers Published

Appendix B: Anticipatory Failure Determination

Appendix C: JSMARTS II/ MALO TDP Overview

Appendix D: Future Research

1.9 CONTRIBUTIONS

The results from this thesis reflect contributions to the body of knowledge associated with sociology and our understanding of accident aetiology. In particular the results contribute to three broad areas: further developing and informing the theoretical perspective of Actor Network Theory; presenting accident aetiology associated complex socio-technical systems through the lens of the ANT perspective; and providing insights into the solution space of fratricide.

1.10 CONCLUSION

As described in this chapter, the nature of this research is truly an interdisciplinary effort. It draws upon various domains of inquiry to shed light upon the problem space of fratricide in air operations and aviation accident aetiology. Chapter 2 begins our analysis by presenting the theoretical foundations upon which this work is based.

Chapter 2

Foundational Theory/Literature Review

2.1 INTRODUCTION

The anatomy of disasters and accidents involving socio-technical systems depicts an aetiology that reflects an inherent complexity that involves elements beyond the temporally and spatially proximate thereby requiring a holistic or systemic view of disasters and accidents. The reductionist paradigm that focused on the parts of a system and how they functioned is replaced by a paradigm that embraces the complex. As such the focus is on the interrelationships and the interactions of the actors in an analysis of the behaviour, dynamics and topology of the system.

The complex socio-technical domain presents challenges to the linear event based models of accident causation and the attribution of human error. It is common in the literature to focus on a chain of failures models to describe the accident aetiology. As Leveson (2005:37) remarks:

...this approach may have been satisfactory for the relatively simple electromechanical and industrial systems for which the model was developed, it does not explain system accidents (arising from interactions among system components rather than individual components failures) and is inadequate for today's complex, software intensive, human machine systems.

Supporting this Dekker (2006:78) argues '...it is critical to capture the relational dynamics and longer term socio-organizational trends behind system failure'.

Sociology offers an interesting approach for looking at the socio-technical elements of complex systems through the application of Actor Network Theory (ANT). The systems perspective of ANT examines the inter-connectedness of the heterogeneous elements characterized by the technological and non-technological (human, social, organizational) elements. The network space of the actor network provides the domain of analysis that presents the accident aetiology resident in a network of heterogeneous elements that shape and are shaped by the network space.

This chapter presents the underlying theoretical foundations of this thesis. In section 2.2 we begin with the theoretical perspectives associated with accident aetiology providing an overview of some of the contemporary issues regarding human error. This is followed in section 2.3 by an introduction to systems thinking, thereby defining the foundational elements of the analysis. Building upon the systems thinking paradigm, in section 2.4 we introduce complexity theory detailing the concepts and vocabulary that challenges the inherent linearity resident within the social sciences and in particular accident aetiology. We then introduce the social theoretical foundations that facilitate the analysis of aviation accident aetiology. In section 2.5 Actor Network Theory is introduced and explained as a ‘relativistic’ perspective that will shape and guide the analysis of fratricide aetiology. In section 2.6 we end this chapter with an overview of some concepts stemming from the cognitive domain associated with accident aetiology exploring the concepts of situation awareness, decision theory and

trust thereby providing a theoretical linkage to current thoughts regarding aviation accidents.

2.2 ACCIDENT AETIOLOGY: Accident Models and Perspectives

Accident models have over the last 70 years slowly developed from linear cause-effect sequences to systemic descriptions of emergent phenomena. The different perceptions of accident phenomenon stem from interpretations based on accident models. This section highlights the current thinking on accident causation perspectives and models.

Event, linear sequential approach to understanding accident aetiology stems from a desire to search for specific causes and well-defined cause-effect relations. This approach paradigm focuses on some 'root' cause that underlies the accident aetiology. The domino theory (Bird, 1974) depicted in figure 2.1 represents a linear aetiology that, although intuitively apropos for simple mechanical description of physical failures, proves to be inadequate for more complex systems (Leveson, 2002).

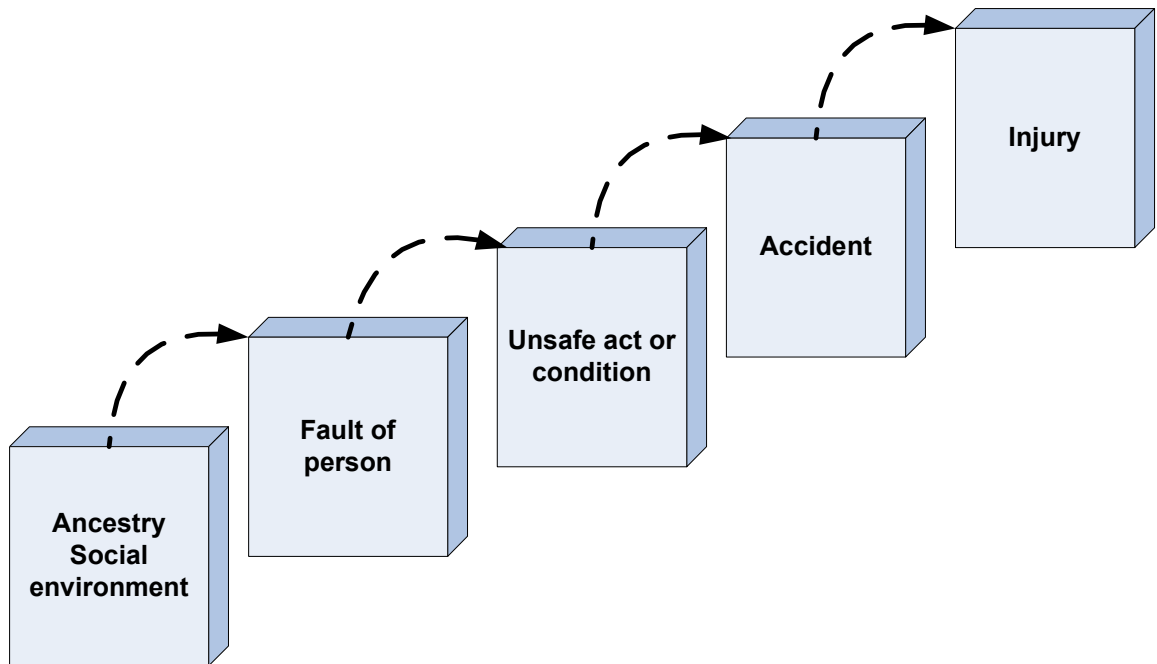


Figure 2.1- Bird's Domino Model (adapted from Wiegmann and Shappell, (2003:38))

Accident analysis utilizing such techniques as fault trees work within a worldview characterized by temporal and spatial linearity. By virtue of this worldview, these models tend towards an explanation of the aetiology with a concentration on the proximate events and actors immediately preceding the loss (Leveson, 2002).

Leveson (2002:25) characterizes event-based models as best suited for component failures rather than explaining systemic factors such as '...structural deficiencies in the organization, management deficiencies, and flaws in the safety culture of the company or industry'. Leveson (2002:25) argues that 'new models that are more effective for accidents in complex systems will need to account for social and organizational factors, system accidents and dysfunctional interactions, human error and flawed decision making, software errors, and adaptation'.

Perrow (1984) coined the phrase ‘systems accident’ to describe an aetiology that resides within complex relationships between elements comprising a system. The complexity that resides in current systems creates what Perrow (1984) refers to as “normal accidents”. Perrow (1999:12) remarks that:

We have produced designs so complicated that we cannot anticipate all the possible interactions of the inevitable failures; we add safety devices that are deceived or avoided or defeated by hidden paths in the systems. The systems have become more complicated because either they are dealing with more deadly substances, or we demand they function in ever more hostile environments or with ever greater speed and volume.

What characterizes “normal accidents” as an inevitable event are the precursors of what Perrow (1984) calls “interactive complexity” and “tight coupling”. Tight coupling refers to a system in which as Perrow (1984:4) argues ‘...processes happen very fast and can’t be turned off; the failed parts cannot be isolated from the other parts’. Interactive complexity refers to a system design ‘...so complicated that we cannot anticipate all the possible interactions of the inevitable failure’ (Perrow, 1984:11). In what Perrow (1984) classifies as high-risk systems, accidents are inevitable or normal stemming from the way failures interact and tie a system together. His introduction of the term ‘normal accident’ refers to the inherent characteristics of the system.

Challenging this perspective of Normal Accident Theory, High Reliability Theorists argue that if organizations are properly designed and managed then they can

compensate for shortcomings of the human and can therefore be more effective than can individuals (Sagan, 1993). High Reliability Organizations (HRO) represents a subset of hazardous organizations characterized by records of high safety over long periods of time. The key design feature in HRO is redundancy. Sagan (1993:19) argues that 'multiple and independent channels of communication, decision making and implementation can produce, in theory, a highly reliable overall system, even if each component of the organization is subject to error'. The High Reliability perspective was derived from analysis of problem spaces such as air traffic control and aircraft carrier operations. Recognizing that High Reliability environments are characterized by uncertainty in which errors can propagate quickly, Weick and Sutcliffe (2007:9-16) identify five defining principles of HRO: Preoccupation with Failure; Reluctance to Simplify; Sensitivity to Operations; Commitment to Resilience; and Deference to Expertise. It is argued that organizations can avoid system accident and embrace high reliability by creating the appropriate behaviours and attitudes that are congruent with the five defining principles (Leveson, Dulac, Marais and Carroll, 2009:228).

Reason (1997) builds upon Perrow (1984) normal accident theory through his description of organizational accidents. Reason describes organizational accidents as arising from multiple causes involving people operating at different levels of their organizations. Although a large proportion of the accidents can be attributed to human error, Reason proposes a view that many accidents are catalyzed by persons not present at the time of the event (Bennett, 2001). Reason (1997) argues that human

decisions and actions are implicated in all organizational accidents, since people design, manufacture, operate, maintain and manage complex technological systems. The complex nature associated with the aetiology of aviation accidents supports the requirement for a systemic approach to accident causation. Viewing errors as consequences rather than causes, Reason identifies two types of errors: active errors and latent conditions. Active errors are unsafe acts committed by people who are in direct contact with the system. These active errors include slips, lapses, fumbles, mistakes and procedural violations. For example forgetting to lower the landing gear or failure to use a checklist would constitute procedural violations and mistakes. Usually active failures are characterized as being immediate and relatively short-lived (Reason, 1997) whereas latent conditions can lie dormant for a time doing no harm until they interact with local circumstances to defeat system defences. Reason (1997) argues that latent conditions are always present in complex systems and are seeded into the systems, products of strategic decisions. Latent failures arise from poor design, gaps in supervision, undetected defects, unworkable procedures, clumsy automation, short fall in training, and less than adequate tools. As well they can also stem from government decisions, and decision making associated with regulators, manufacturers, designers, organizational managers. It is these decisions that can shape the corporate culture and creating error-producing factors (Reason, 1997:10).

As described by Reason (1997) the systems approach to human error contains safeguards and defences in a layered schema in order to mitigate the danger to potential victims from local hazards. Hazards associated with complex socio-technical

systems such as that found within the aviation and nuclear power industry are mitigated through the advent of barriers and safeguards. These barriers however can be breached/eroded through human, technical and organizational factors thereby precipitating a catastrophic event. Reason's Latent Failure Model (Reason, 1997), conceptualizes the defensive layers within the system (figure 2.2). The holes represent the active and latent conditions present in the system such that the alignment of the holes permits a trajectory of accident opportunity. A characteristic of such defences is that they do not always respond to individual failures. As articulated by Reason (1997), the failure can be either countered or concealed without the individual's awareness. This can facilitate the build-up of latent conditions or "resident pathogens" that may subsequently combine with local conditions and sharp end errors to breach or bypass the defensive layers precipitating into an accident or disaster (Reason, 1997). Like Turner (1978), Reason (1990) uses the concept of 'organizational accident' and latent failures as a central theme in his accident causation model. His model 'Reason Swiss Cheese model' (figure 2.2) has become an industry standard (ICAO 1993) for use in investigating the role of management policies and procedures in aircraft accidents and incidents (Zotov, 1996).

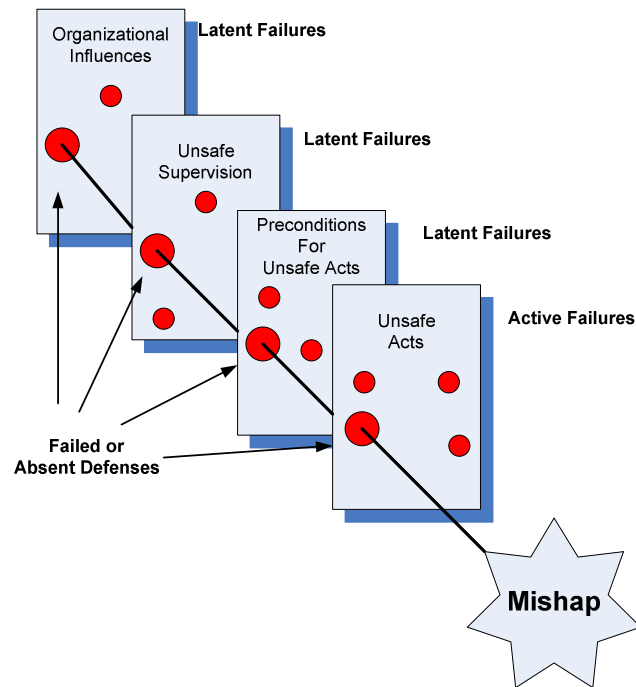


Figure 2.2- Reason's Swiss Cheese Model (adapted from Reason (1990))

The Swiss Cheese model is an apt metaphor in that it illustrates how defences, barriers and safeguards can be penetrated creating a 'trajectory' of aligned 'holes' precipitating a mishap.

Turner (1978) provides a systemic perspective of accidents involving socio-technical systems. He introduces the idea of latent failures and a period of incubation whereby social and technical elements of a system representing separate features of a system, together incubate over a period of time, creating an environment where an accident can be triggered. He approaches the problem space in terms of organizational theories and information flows and argues that accidents must be understood with consideration of the systems perspective. Turner and Pidgeon (1997:3) argue that '...it is better to think of a problem of understanding disasters as a socio-technical problem with social organizational and technical processes interacting to produce the

phenomena to be studied'. Turner's (1978) incubation model highlights the plethora of preconditions that fall into place creating an underlying causal chain. The effect of these factors, '...a multiplicity of minor causes, misperceptions, misunderstandings and miscommunications accumulate unnoticed during this incubation period....ready to contribute to a major failure' (Turner, 1994:216). He argues that disasters are rarely the result of technical factors alone, but rather arise from failures of the complex system.

Rasmussen's (1997) approach to accident causation stems from a systemic perspective that involves the entire socio-technical system. He notes that when focusing on accidents that consider the socio-technical system, the accident analysis must embrace a 'systemic' perspective taking into account the relationships between the parts of the system and how they fit together, thereby challenging the reductionist paradigm (Leveson, 2004:11). According to Rasmussen (1997:190):

The stage for an accident course of events very likely is prepared through time by normal efforts of many actors in their respective daily work context, responding to the standing request to be more productive and less costly...an explanation of the accident in terms of events, acts, and errors is not very useful for design of improved systems.

New thinking that embraces capturing and describing the processes by which organizations drift into failure requires systems thinking. Within this paradigm, Dekker (2005b:8) views the '...socio-technical system not as a structure consisting of

constituent departments, blunt ends and sharp ends, deficiencies and flaws, but as a complex web of dynamic, evolving relationships and transactions’. The simple cause and effect paradigm does not account for the interdependent nature of the system. Rather emergent properties are only visible when viewing the problem space from a systems perspective. Viewing the accident aetiology in terms of ‘drift into failure’, Dekker (2005a:x) argues that:

Drift into failure is associated with normal adaptive organizational processes. Organizational failures in safe systems are not preceded by failures; by the breaking or lack of quality of single components. Instead, organizational failure in safe systems is preceded by normal work, by normal people doing normal work in seemingly normal organizations.

Dekker (2002b) differentiates between an Old and New thinking regarding human factors, system safety and accident aetiology as shown in table 2.1.

Table 2.1 Old View/ New View of human error (Dekker, 2002b:vii)

The old view of human error	The new view of human error
Human error is a cause of accidents	Human error is a symptom of trouble deeper inside a system
To explain failure you must seek failure	To explain failure, do not try to find where people went wrong
You must find people’s: inaccurate assessments, wrong decisions, bad judgments	Instead, find how people’s assessments and actions made sense at the time, given the circumstances that surrounded them.

Within the paradigm of old thinking Dekker (2005a:7) argues that:

The choice between human cause and material cause is not just a product of recent human factors engineering or accident investigations. The choice is

firmly rooted in the Cartesian-Newtonian worldview that governs much of our thinking to this day, particularly in technologically dominated professions such as human factors, engineering and accident investigation.

Hollnagel (1998) examines accidents in terms of events and conditions that result in breaching barriers. Hollnagel (1999:175) defines a barrier as ‘...an obstacle, an obstruction, or a hindrance that may either (1) prevent an action from being carried out or an event from taking place, or (2) prevent or lessen the impact of the consequences, for instance by slowing down the uncontrolled release of matter and energy, limiting the reach of the consequences or weakening them in other ways’. Hollnagel (1999) proposes four different types of barriers: material, functional, symbolic and immaterial barriers systems. These barriers have a functionality in terms of: ‘containing, restraining, keeping together, dissipating, preventing, hindering, regulating, indicating, permitting, communicating, monitoring and prescribing’ (Hollnagel, 1999:175). From this perspective an accident occurs when one or more barriers have failed.

Hollnagel (1999) describes how physical barriers prevent action from being carried out or consequence spreading such as that exhibited by buildings, walls, fences, railings, bars. Essentially it provides a physical hindrance. A functional (active or dynamic) barrier impedes action from being carried out and sets up pre-conditions that must be met, such as a lock. A symbolic barrier works by requiring an act of interpretation (visual signs, aural signs). An immaterial barrier is enacted through rules, guidelines, restrictions and laws.

The systems perspective considers accidents as arising from the interactions between components of a system. As an emergent property of the system, safety arises from the interrelated system components. Leveson (1995:203) argues for a control theory model that views safety as an issue of control:

In these models, systems are viewed as interrelated components that are kept in a state of dynamic equilibrium by feedback loops of information and control.

Accidents occur when disturbances are not adequately handled by the control system.

The Systems-Theoretic Accident Model and Processes (STAMP) recognizes that accidents involving complex socio-technical systems do not result from independent component failures, but rather represent dysfunctional interactions among system components. STAMP views accidents resulting from flawed processes involving complex interactions between people, processes and technology. Accidents thereby result ‘...from inadequate control of safety-related constraints on the development, design, construction and operation of the socio-technical system’ (Leveson et al., 2006:97). Rather than a root cause being the initiating event in a chain of events, ‘... accidents are viewed as resulting from interactions among components that violate the system safety constraints’ (Leveson et al., 2006:98).

The linear perspective of accident causation that has shaped much of human factors is oriented towards finding failures and modeling and explaining the mishap in terms of a sequence of events. This model does not take into account the latent failures and drift toward failure. It represents the dichotomy between static and dynamic models of

accident aetiology. The systems perspective facilitates a holistic view that contributes to our understanding of accident aetiology. The emergent behaviour and dynamic topology within a systemic view reflects the complexity inherent within socio-technical systems. Comparing the linear event based models with the systems perspective, the literature is clear that systems perspective challenges the reductionism inherent within linear models. Rather than focusing on a single domain and thread of aetiology, systems analysis is holistic and recognizes the inherent relational connectivity. It recognizes that each part of the system is in fact affected by being in the system and is changed if it leaves the system.

From the preceding discussion, three categories of accident models emerge: sequential, epidemiological and systems models. The sequential models characterize an accident aetiology that is derived from a series of steps/events in a specific order. This can also be expanded to include an event tree representation and essentially support thinking and worldviews in terms of causal series. The domino model for example is useful for providing a linear understanding regarding accidents but ‘...reinforces the misunderstanding that accidents have a root cause that can be found by searching backwards from the event through the chain of causes that preceded it’ (Hollnagel, 2006:11). As such this model purports that ‘...system safety can be enhanced by disrupting the linear sequence, either by ‘removing’ a domino or by spacing the dominos further apart’ (Hollnagel, 2006:11). Hollnagel (2006:15) further argues that:

Most major accidents however are due to complex concurrences of multiple factors, some of which have no apparent a priori relations. Event and fault trees

are therefore unable fully to describe them – although this does not prevent event tree from being the favorite tools for Probabilistic Safety Assessment methods in general.

As reported in Hollnagel and Goteman (2004:155-156) sequential models once adequate for early industrial accidents are no longer sufficient in explaining accidents involving complex systems.

The epidemiological model is characterized by the analogy of a spreading disease, whereby accidents arise stemming from latent factors and the interaction of a host, agent and environmental factors. From this perspective, these models account for more complex interactions compared to the sequential models. One of the strengths of this model is the implications of the metaphor ‘resident pathogen’ which ‘...emphasizes the significance of casual factors present in the system before an accident sequence actually begins’ (Reason, 1990:197). The Swiss cheese model highlights the latent conditions ‘...but has problems in accounting for the gradual loss of safety that may also lead to accidents’ (Hollnagel and Woods, 2006:354).

The systemic model of accident aetiology, challenges the structural decomposition associated with the sequential models and views safety as an emergent property. The perspective focuses on the system as a whole ‘... rather than on the level of specific cause effect “mechanisms” or even epidemiological factors’ (Hollnagel and Goteman 2004:155-156). When accidents are beyond the explanatory power of complex linear models, systemic models with their view of accidents as nonlinear phenomena

emerging from complex systems are used providing a holistic view of the problem space. Each model described carries with it a set of assumptions that make the selection of use applicable for certain views of the problem space. For the purpose of this work, the systems perspective is used to meet the challenges associated with complex socio-technical systems characterizing nonlinear accident aetiology.

These three categories of accident models (sequential, epidemiological and systems) provide a basis that shape accident investigation processes and protocols. As described by Frei et al. (2005:2):

Within investigations, there are many types of task. Among this variety are four main types to which analytical tools are applied (note that these categories that are not mutually exclusive): organising facts sequentially; generating hypotheses; identifying norms, novelties and deviations; and delving into root cause.

The overall process of incident investigation within the safety field is similar across many of the methodologies reviewed. The differences arise within the area of focus such as management and organisational issues or consideration of human performance issues. The first stage of the incident investigation involves obtaining a full description of the sequence of events which led to the failure. The use of techniques such as Events and Causal Factors Charting, Multiple Events Sequencing (MES) and the Sequentially Timed Events Plotting Procedure (STEP), facilitate a systematic and structured framework to aid the collection of information. These sequencing techniques can also be used in conjunction with methods such as Barrier Analysis, Change Analysis and Fault Tree Analysis to ascertain the critical events and actions, and thus the direct causes of the incident (Livingston, Jackson and Priestley, 2001:4).

The sequencing task characterizes the accident in terms of a chronological based cause and effect relationships. The causal analysis approach described by Johnson (2003) focuses on the accident event itself as well as the reasons why the accident occurred. For example employment of a Root Cause Analysis encompasses a methodology that ‘...provides a means of distinguishing root causes from contributory factors and contextual details’ (Johnson, 2003:342). Whereas a Root Cause Analysis methodology focuses on finding a single root cause associated with the accident, Gerdsmeyer, Hohl, Ladkin and Loer (1997) argues that ‘normally many causal factors explain the occurrence of an event, and that one cannot distinguish between ‘more necessary’ and ‘less necessary’ factors’.

There are several different accident analysis methods available to the investigator, depending on the level and type of analysis required. These are described in detail in Blackett (2005:35) and include: Event Causal Factors (ECF); Multilinear Events Sequencing (MES); Sequentially Timed and Events Plotting (STEP); Management Oversight and Risk Tree (MORT); Systems Theoretic Accident Modelling and Process (STAMP); Why-Because Analysis (WBA); Safety through Organisational Learning (SOL); and Multilinear Events Sequencing (MES). As described in detail in Blackett (2005), in all investigative methods listed, the aim is to understand why the accident occurred. As Ferry (1988:116) explains, the investigator must be able to break down the entire sequence of events into the individual events that led to the accident. This linear representation of the accident aetiology is normally presented in flow charts and diagrams (figure 2.3) thereby reducing the accident to a description of

a collection of events and conditions chronologically ordered into cause and effect relationships. It is from this common point that further analysis can be conducted within the context of the linear event sequence to reveal many of the non-linear causal influences.

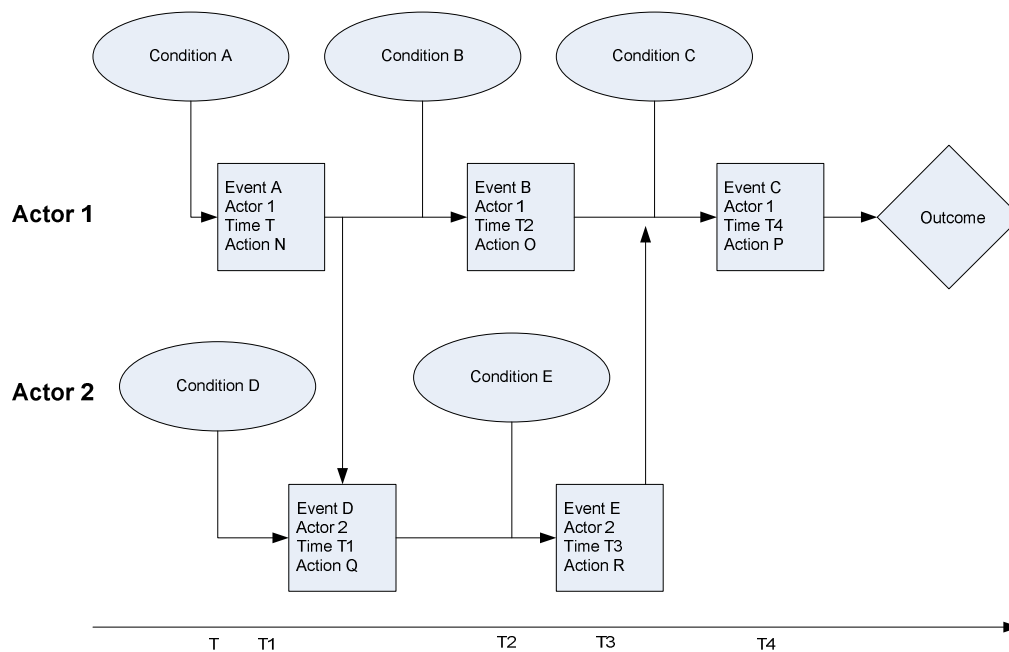


Figure 2.3 Simplified MES Diagram (Johnson, 2003:439)

From the evolution of these perspectives presented we see the recognition that to study human error in real world situations such as that associated with pilot error one must move beyond the study of individual cognition associated with sharp end analysis to include the resources, constraints and artifacts resident within the system. The attribution of human as a root cause often serves as a stopping point of an investigation with recommendations to improve safety. However when the label 'human error' becomes the starting point then the complexity of the problem space emerges. Solutions stemming from such an examination can lead to new insights into

matters pertaining to human performance within the greater socio-technical frame of reference.

Human error/ pilot error is viewed from the systems perspective as a label and represents a symptom, not a cause. As Wood et al. (1994:26) argues: 'The label error is often used in a way that simply restates the fact that the outcome was undesirable. Error is a symptom indicating the need to investigate the larger operational system and the organizational context in which it functions'. What is challenged here is the notion that 'human error, is our default when we find no mechanical failures, as described in equation 2.1 (Dekker, 2005a:6).

$$\text{Human error} = f(1\text{-mechanical failure}) \quad (2.1)$$

To conclude this section, we recognize how the systems worldview has permeated the safety community and how it has impacted our views of accident aetiology and human error. What the preceding section of accident models highlights is that accident aetiology is multidimensional and can be viewed from different perspectives. But given the complexity associated with accidents involving socio-technical systems and the inherent interrelationships between the social and the technical, the systems perspective facilitates a methodology to understand the complexity, relationality and emergent behaviour.

2.3 SYSTEM THINKING

Anderson and Johnson (1997:2) define a system as:

...a group of interacting, interrelated, or interdependent components that form a complex and unified whole. A system's components can be physical objects...and can also be intangible, such as processes; relationships, policies, information flows; interpersonal interactions; and internal states of mind such as feelings, values, and beliefs.

Systems thinking, according to Senge (1990:68) 'is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static snapshots'. As a worldview, systems thinking recognizes that systems cannot be addressed through a reductionist approach that reduces the systems to their components. The behaviour of the system is a result of the interaction and interrelationships that exists thereby acknowledging emergent behaviours and unintended consequences. As a process, systems thinking recognizes the requirement to assess the system within its environment and context (Senge, 2006). The intellectual tradition of systems thinking stem from the interest in the holistic property that is different from that of its constituent parts. Systems thinking emerged from the domains of biology and information technology in the 1930s and has since had a significant impact on various domains of inquiry. As cited in Mingers (2006:1) such contributions include: General Systems Theory (Von Bertalanffy, 1971), Cybernetics (Weiner, 1948), living systems approach (Miller, 1978), dialectical systems (Churchman, 1968, 1971), purposeful systems (Ackoff and Emery, 1972), engineering

systems (Hall, 1962), autopoiesis and cognition (Checkland, 1981), social system theories (Buckley, 1967; Luhmann, 1995), critical systems thinking (Flood, 1991; Jackson, 2000; Midgley, 2000) chaos and complexity (Kaufmann, 1995). Central to systems thinking is the concept of interrelationships of objects that form a whole and in which show a property unique to the whole that is not a property of the components. Systems thinking purports that, although events and objects may appear distinct and separate in space and time, they are all interconnected. Senge (1990) remarks that, because the world exhibits qualities of wholeness, our investigation of it should stem from a paradigm of the whole.

Within the application domain of accident aetiology, systems thinking recognizes that the ‘whole is greater than the sum of the parts’ and that understanding accident aetiology requires a holistic perspective stemming from the interrelationships and interconnectivity that so characterises aviation accidents. This is reflected in the work of Perrow (1984), Reason (1990), Hollnagel (1993, 2004), Hollnagel et al. (2006), Bennett (2001), Dekker (2002), Leveson (2002, 2004), Johnson (2007, 2008). The attributes of systems thinking make it a fundamental element of this thesis as it directly supports and embraces an ANT and complexity perspective.

2.4 COMPLEXITY THEORY

The objective of this section is to develop an understanding of complexity as it pertains to accident aetiology. Of particular interest is the nature of the complex system and the system behaviour that emerges. Complexity theory is an

interdisciplinary field of research that has become recognized as a new field of inquiry focusing on understanding the complexity inherent within the behaviour and nature of systems. The interest and importance of this complexity perspective has given rise to research initiatives and communities of interest such as the Santa Fe Institute and the New England Complex Systems Institute (NECSI).

The word complexity is derived from the Latin 'complexus' meaning braided together and is therefore associated with the intricate intertwining or inter-connectivity of elements within a system and between a system and its environment. The inherent complexity of a system is such that the system cannot be fully understood by simply studying its constituent parts. Cilliers (1998:2) remarks that a complex system '...is not constituted merely by the sum of its components, but also by the intricate relationships between these components. In cutting up a system, the analytical method destroys what it seeks to understand'. As a field of inquiry in its own right, complexity theory crosses disciplinary domains from the physical sciences to the social sciences, humanities and fine arts. In the field of social science, there is a growing interest regarding the integration of complexity theory as a means to generate insights. One of the key contributions of the complexity theory paradigm is the departure from linear models (Anderson, 1999; Morel and Ramanujam, 1999) to the acknowledgement of the inherent nonlinearity associated with social and natural systems thereby facilitating new views of the problem spaces. As a paradigm in its own right, complexity theory/thinking challenges the linear, mechanistic view of physical systems and causality.

Complexity, Systems and Social Theory

In Chesters and Welsh (2006:8) it was remarked that complexity theory has permeated the social sciences reflected in the relevance to quantitative empirical social science (Eve et al., 1997; Byrne, 1998); metaphorical extension for theory building (Thrift, 1999); and recognition of emergent social complexity (Urry, 2003; Chesters and Welsh, 2006). In particular, complexity thinking has facilitated a new thinking about the concept of system and offered a new set of conceptual tools. It is not about importing ideas from the “hard sciences” but rather shedding light on the dynamic nonlinearity and emergent behaviour of systems. The theoretical developments in systems theory shaped by the complexity paradigm is described by Walby (2003) as a re-thinking of the concept of ‘system’ rejecting traditional notions, with a focus on dynamic processes of systems far from equilibrium. Within the socio-technical domain, the acknowledgement of nonlinearity enables new views on causality, agency and space/time, all of which are relevant to the topic of this thesis. It has been shown in the literature across various domains of inquiry how small changes to a system can produce large effects (Casti, 1994; Massen and Weingart, 2000). Urry (2003) cites how much of the physical world is characterized by ‘nonlinearity’. Key features of the complex system are listed in table 2.2:

Table 2.2: Key features of Complex systems (Sweeney and Griffiths, 2002:2)

- Complex systems consist of multiple components. Such systems are understood by observing the rich interaction of these components, not simply understanding the system's structure.
- The interaction between components can produce unpredictable behaviour
- Complex systems have a history and are sensitive to initial conditions
- Complex systems interact with and are influenced by their environment
- The interactions between elements of the system are non-linear. Small inputs may have large effects, and vice versa.
- The interactions generate new properties, called emergent behaviours of the system, which cannot be explained through studying the elements of the system
- In complex systems such emergent behaviour cannot be predicted.

What is germane to this thesis in terms of complexity thinking is not only the introduction of the descriptive terminology associated with complexity theory but also recognition of uncertainty and unpredictability. In terms of understanding accident aetiology, embracing a complexity perspective challenges the linear event based models. Making use of concepts such as emergence and nonlinearity enables an alternative image of accident aetiology that departs from the traditional linear, mechanical explanations and ontology.

2.5 ACTOR NETWORK THEORY

Introduction/ Background

Actor Network Theory (ANT) emerged from the sociological studies of science and technology through the contributions of Serres and Latour (1995), Callon and Law (1995) and influenced by the work of Foucault (1980, 1986), Deleuze and Guattari (1987) with a focus on the socio-technical domain. The study of the socio-technical domain is not new to sociology. Bijker and Pinch (1984) introduced the notion of the

Social Construction of Technology (SCOT) arguing that artifacts are socially constructed by social groups and that the process of interaction among these groups enters into interpretations of success and failure. ANT offers an alternative approach to SCOT arguing that the social and the technical are considered inseparable and argues that people and devices should be analysed using the same conceptual apparatus (the principle of symmetry). Developed to analyse situations where separation of the social and technical elements is difficult (Callon, 1999), ANT provides a 'relativistic' approach to sociology (Latour, 2005). Inherent within the approach is a fundamental 'complexity' shift that challenges the traditional paradigm of linearity and reductionism.

As a methodological approach to analysing the socio-technical domain, ANT shares fundamental principles with other qualitative approaches, such as ethnography. Shaping the methodological approach of ANT, Latour (2005:5) traces the etymology of the 'social' realigning the definition with its origins associated with a 'trail of associations'. In this sense he describes the 'social' not as a designated thing among other things, but rather as a '...type of connection between things that are not themselves social'. In line with this train of thought Latour (2005:24) argues that we must '...be prepared to cast off agency, structure, psyche, time and space along with every other philosophical and anthropological category, no matter how deeply rooted in common sense they appear to be'. This has a methodological impact on how one is to conduct 'social' analysis. Latour (2005:29) argues that '...the choice is thus clear: either we follow social theorists and begin our travel by setting up at the start which

kind of group and level of analysis we will focus on, or we ‘follow the actors’ own ways and begin our travels by the traces left behind by their activity of forming and dismantling groups’. ‘Following the actors’ (Callon 1986a; Callon 1991; Latour 1996) lies at the foundation of the ANT methodology. ‘Following the actors’ allows the researcher to investigate those actors that have been ‘silenced or deleted’ and ‘...to bring them back to light by using archives, documents, memoirs, museum collections’ (Latour, 2005:81). With this in mind Latour (2005:82) argues that ‘...if objects are not studied it is not due to a lack of data, but rather to a lack of will’.

Within the ANT paradigm, Latour (2005) makes a clear and important distinction between what he terms intermediaries and mediators. As described by Latour (2005:39):

An intermediary is what transports meaning or force without transformation: defining its inputs is enough to define its outputs. For all practical purposes, an intermediary can be taken not only as a black box, but also as a black box counting for one, even if it is internally made of many parts.

A mediator as described by Latour (2005:39):

Their input is never a good predictor of their output; their specificity has to be taken into account every time. Mediators transform, translate, distort, and modify the meaning or the elements they are supposed to carry. No matter how apparently simple a mediator may look, it may become complex; it may lead in multiple directions which will modify all the contradictory accounts attributed to its role.

This distinction between intermediaries and mediators has profound effects on our understanding of ANT and its application in this thesis as is discussed in chapter 5.

Network/ Relations/Topology/Time and Space

One of the key attributes that shaped the choice to employ ANT in this thesis is its inherent challenge to the binary distinction that leads one to a priori designate an actor as either technical or social. In place of this ANT presents a schema of a network that is characterised by relations, fluidity and dynamics. This network schema has far reaching implications beyond the visual representations to include how we conceptualize space and time. The traditional conceptualization of networks views them as a collection of nodes and connections, which form a web-like structure (Barab, Hay, and Yamagata-Lynch, 2001). ANT departs from this perspective of network to support rather a fluid topology characterized by an inherent complexity that focuses on the relations. A topological understanding reflects a non-metric geometry whereby the properties of the shapes are examined without considering distance or measurement. A topological space considers the relationality inherent within its form (Mingers, 2006:73). Within this topological construct, Urry (2003:122) describes how the micro/macro distinction loses its meaning since ‘....both micro and macro are local effects of hooking up to circulating entities (Latour, 1999b:19)’. As such, this challenges our notions of far/close, small scale/ large scale and inside/outside (Latour, 1996:370) and to think in terms of associations and relations thereby raising questions of how we view time and space. ANT as a ‘relativistic sociology’ paints an image of a flat landscape such that there is no above or below, no

micro or macro. We therefore approach this landscape without some a priori decision regarding size and scale.

One may say that the relationality is brought about ‘...through a wide array of networked or circulating relationships that are implicated within different overlapping and increasingly convergent material worlds’ (Urry, 2005:245). This inherent relationality is central to our understanding of ANT. Arguing this point, Latour (2005:184) remarks that ‘...it is of little use to respect the actors’ achievements if in the end we deny them one of their most important privileges, namely that they are the ones defining relative scale. It’s not the analyst’s job to impose an absolute one’. The spatial and temporal implications are profound. The actor network recognizes that ‘what is acting at the same moment in any place is coming from many other places, many distant materials, and many faraway actors’ (Latour, 2005:200). Hence we begin to see the emergence of systems thinking and complexity thinking inherent within the actor network theory.

The relational approach of ANT (Latour, 2005), emphasizes as argued by (Neu, Everett, Rahaman, 2009:322) that it is ‘...not only the micro processes of assembling a network but also how such assembled networks consist of human and non-human actants – an idea that is also present in *Anti-Oedipus* and *A Thousand Plateaus*’. Deleuze and Guattari (1987) present the assemblage as having a supple and diffuse microsegmentarity (the rhizomatic) in which it can extend in all directions. The Deleuzian ‘rhizome’ has influenced ANT (Callon, 1986b; Latour, 1987; 1999;

Law,1992; Law and Hassard, 1999) creating a lens that characterizes networks as essentially heterogeneous reality made up of multidimensional and constantly evolving entanglements (Grabher, 2006). Crawford (1993: 26) reports that the ‘...rhizome is the perfect word for network’. In fact it is argued that ‘...Actor-network theory should be called actant/rhizome ontology...it is about actants, and it is about rhizomes’ (Crawford, 1993:26). As Grabher (2006) notes, the rhizome as developed by Deleuze and Guattari (1987) facilitates a reconceptualization beyond the established dualisms of structure/agency, subject/object, human/non-human and to move further towards topological understandings of space and networks. Described by Deleuze and Guattari (1987:7), the ‘rhizome’ ‘...is a non-hierarchical, horizontal stem that develops underground, operates by variation, expansion, conquest, offshoots, and which is ‘absolutely different from roots and radicals’ contrasting the rhizome with the structure of a tree. It represents an interlocking knotted complex space without a beginning or an end: ‘...Any point of a rhizome can be connected to anything other, and must be. This is very different from the tree or root, which plots a point, fixes an order’ (Deleuze and Guattari, 1987:7). Visually, this is depicted as a decentered system of points or lines, which can be connected together in any order and without hierarchy (figure 2.4). As argued by Seijo (2005:187) ‘...The law of both the rhizome and the network lies in the connections: each of the actors is related to all the others’.

Within *Anti-Oedipus* (Deleuze and Guattari, 1983), their ‘schizoanalysis’ emphasizes not the psyche but rather the primacy of part, or heterogeneous multiplicities

(Colebrook, 2002:5). This influence is noted in ANT in terms of interconnectivity, relationality and translation. The introduction of the Rhizome in *A Thousand Plateaus* (Deleuze and Guattari, 1987) illustrates a social fluidity and infinite potentiality. Here Deleuze and Guattari (1987) shift the unit of analysis of the social world from individual agents to include a fusion of people, groups, things, and ideas representing a decentered system. As noted in Dolwick (2009:33-34):

Against this logic, a rhizome is chaotic and based on difference, allowing for all possible forms of association. The point of doing exploratory rhizomatic analysis is to see how social units are related and arranged (or rather to see their potentialities). Furthermore, there is no top or bottom to a rhizome.

Whatever is in it is always in the middle.

Deleuze and Guattari (1983) regard the concept of desire as one of the most important social bonds connecting a heterogeneous actors such as people, and things. In this sense desire is understood as a ‘...circulating entity enlarging or shrinking people, denying access to a building, or more generally, making people act’ (Seijo, 2005:197).

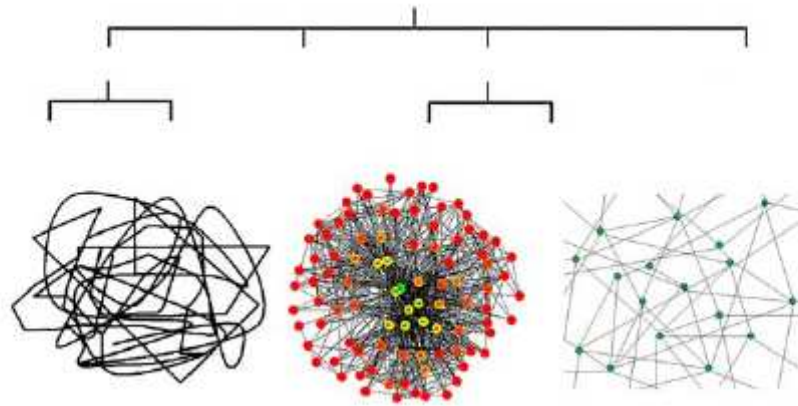


Figure 2.4 - Top: standard tree structure. Bottom: different depictions of rhizome
(from Dolwick, 2009: 34)

In a rhizomatic or topological geography, Grabher (2006:178-179) argues that ‘time-space consists of multiple pleats of relations stitched together’. Topology as the science of nearness and rifts’ as articulated by Murdoch (1997:358), ‘interweaves time and space with a heterogeneous network of actants that has been differentiated, for example, into regions, networks and fluid spaces (Mol and Law, 1994)’. Van Loon (2006:307) describes the network as a trope deployed to depict a nonlinear grid of multiple connections and marked by multiplicity. Like complexity thinking, the relational milieu of the rhizome presents a powerful way of viewing multiplicity. The network space, so defined within the ANT perspective defines its objects and dynamics such that it ‘...undermines the reifications of Euclidean space’ (Law, 2000). As reflected in ANT, the social is characterized as fusions or couplings of ‘people-groups-things-ideas’ thereby extending the social to encompass the material world. In fact as noted in Dolwick (2009: 33) ‘...the social world itself is regarded as an

interactive assemblage, an open creative process of connections, exchanges and divergences'. Battersby (1998:192) describes the features of the rhizome that is relevant to its application in describing accident aetiology: the rhizome involves the bringing together of diverse elements; the rhizome brings together elements that are not usually thought of as belonging together: it is based on heterogeneity; the rhizome is not reducible to a series of points or individual parts: it is a non-localizable relation sweeping up the two distant or contiguous points, carrying one into the proximity of the other; the rhizome cannot be traced back to a principal root or source.

The genealogy of ANT (Callon, 1986a; Latour, 1992, 2005; Law, 1999) recognizes the contributions of Deleuze and Guattari (1983, 1987). The rhizome as described in ANT (leveraged from Deleuze and Guattari) informs our understanding of accident aetiology involving complex socio-technical systems.

Actor

Fundamental to our understanding of ANT are the conceptualization of the Actor and the Network. An actor-network, as cited in Aanestad (2003:6-7), '...is a heterogeneous network of human and non-human actors... where the relations between them are important, rather than their essential or inherent features (Latour, 1987; Callon, 1986, 1991)'. The actor, whether technical or non-technical, is examined within the context of a heterogeneous network. In fact the actor is a network in itself '...in the same way, elements in a network are not defined only by their "internal" aspects, but rather by their relationships to other elements, i.e., as a

network' (Aanestad and Hanseth, 2000:360). Latour (1987:180) defines the word network as that which '...indicates that resources are concentrated in a few places- the knots and the nodes-which are connected with one another- the links and the mesh: these connections transform the scattered resources into a net that may seem to extend everywhere'. The Actor Network becomes a network of aligned interests formed by the heterogeneous actors, characterised as full of hybrid entities (Latour, 1993) comprised of both human and non-human elements.

Latour (1996:373) describes the actor in ANT as '...a semiotic definition – an actant – that is, something that acts or to which activity is granted by others'. The principle of symmetry inherent within ANT supports the notion that people and machines should be treated as equal and thereby introduces the term actor. Further Latour (2005:71) defines the actor as:

... (e.g. person, group, idea, material object, plant, animal, etc.) is something that acts, or to which activity is granted by others. It may not necessarily be the source of an action, but something that modifies a state of affairs by making a perceptible difference. Additionally, it may have as many dimensions as it has attachments. Thus, an actor may be regarded as an intricate 'network' in its own right.

Law (1999:3-4) describes the notion of an actor as:

... taking its form and acquire their attributes as a result of their relations with other entities. In this scheme of things entities have no inherent qualities....For the semiotic approach tells us that entities achieve their form as a consequence

of the relations in which they are located. But this means that it also tells us that they are performed in, by, and through those relations.

Latour (2005) describes the actor network in terms of attachments first and actors second. It is that which is made to act by a large star-shaped web of mediators flowing in and out of it thereby reflecting the fluid dynamic nature (figure 2.4). An actor is therefore a network of heterogeneous elements, interactions and associations. For example Law (1987:114-116) describes the Portuguese carrack as simultaneously an actor within a much wider network, ‘...such as the spice trade, and a network of wood planks, mast(s), sailcloth, crewmembers, investors, wind, stars, and navigational equipment, etc. In turn, each of these actors may be regarded as networks, and so on’.

The dynamic nature of the actor network is described by Latour (2005) in terms of an actor on stage. Latour (2005:46) remarks:

If we accept to unfold the metaphor, the very word actor directs our attention to a complete dislocation of action, warning us that it is not a coherent, controlled, well-rounded, and clean-edged affair. By definition, action is dislocated. Action is borrowed, distributed, suggested, influenced, dominated, betrayed, and translated. If an actor is said to be an actor-network, it is first of all to underline that it represents the major source of uncertainty about the origin of action.

Within the context of pilot error, this establishes the notion of the relational and distributed actor network that characterizes the black box.

Hybrid Collectif

With the imagery of the rhizome and its inherent multiple entanglements, ANT examines the established binary juxtapositions of structure/agency, subject/object, and human/non-human and thereby gives meaning to action that is not solely embodied in human actors. Action rather takes place in ‘hybrid collectifs’ (Callon and Law, 1995) that entangle human actors as well as non-human actants in multiple ways. Tools, for example, are not just things that are used to achieve certain ends: ‘They contribute to the making of the universe of possibilities that make action itself’ (Callon and Caliskan, 2005:18). In Actor Network Theory the network is not purely social, but is constructed by hybrids of social (human) and non-social (technological, natural, material) elements simultaneously. Law (1994:23) argues that the social world is ‘materially heterogeneous’, ‘there would be no social ordering if the materials which generate these were not heterogeneous...Left to their own devices human actions and words do not spread very far at all’. The tenet of ‘free association’ within ANT, rejects a priori distinctions between ‘the social’ and the non-social’, and thereby facilitates an examination of the ways in which people and things are associated in networks. From this viewpoint we see that ‘...there are not a few hybrids but that there are only hybrids’ (Crawford, 1993:261).

ANT Processes

Fundamental processes within ANT are inscription and translation. Inscription refers to the way technical artifacts embody patterns of use: Technical objects thus simultaneously embody and measure a set of relations between heterogeneous

elements (Akrich, 1992:205). Monterio (2000:77) argues that although ‘inscription’ might sound deterministic, ‘...the artifact is always interpreted and appropriated flexible, the notion of inscription may be used to describe how concrete anticipations and restrictions of future patterns of use are involved in the development and use of a technology’. Inscriptions enable action at a distance by creating ‘technical artefacts’ that ensure the establishment of an actor’s interests such that it can travel across space and time and thereby influence other work (Latour, 1987). Inscribed artifacts such as texts and images are central to knowledge work (Wickramasinghe et al., 2007:270) and thereby can shape sensemaking, decision making and action.

The process of translation has been described as pivotal in any analysis of how different elements in an actor network interact (Somerville, 1997). As a transformative process, translation emphasizes ‘...the continuous displacements, alignments and transformations occurring in the actor network’ (Visue, 2005:115). Translation rests on the idea that actors within a network will try to enroll (manipulate or force) the other actors into positions that suit their purposes. When an actor’s strategy is successful and it has organized other actors for its own benefit, it can be said to have translated them. Translation as argued by Callon (1991:143) ‘...are embodied in texts, machines, bodily skills [which] become their support, their more or less faithful executive’. This process of translation comprises undertones of power mechanisms as described in Callon (1986a). Hernes (2005:117) argues that translation can be regarded as ‘...negotiations, intrigues, calculations, acts of persuasion and violence, thanks to which an actor or force takes, or causes to be conferred on itself,

authority to speak or act on behalf of another actor or force'. The actor network is therefore comprised of human and non-human elements through a series of negotiations such that actors seek to impose definitions of the situation on others (Callon, 1986b).

The Social and Politics/power

If we think of the social in the traditional way as something of an object, then the associations and relations that we trace in ANT become hidden and, as articulated by Latour (2005:248), '...there is no way to inspect their content, to check their expiration dates, to verify if they really possess the vehicles and the energy to be transported all the way to what they claim to explain'. It is through the actor network lens that we begin to understand the nature of power as a relation. Power is an emergent characteristic property of the network space that cannot be defined a priori but rather emerges from the inscription and translation process of the actor network. Foucault's (1977) notion of disciplinary power helps to explain the inscription and translation processes within ANT as applied to socio-technical systems. Roland and Aanestad (2003) note that according to Foucault, power is embodied in heterogeneous micro-practices and power is seen as enacted and discontinuous rather than stable and exercised by a central actor. As articulated by Yeung (2002:6), 'Actors in these relational geometries are not static "things" fixed in time and space, but rather agencies whose relational practices unleash power inscribed in relational geometries and whose identities, subjectivities, and experiences are always (re)constituted by such practices'. Combining ANT with its inherent complexity and Foucault's

conceptualization of power, highlights how the micro-practices get configured and re-configured as disciplinary technologies (Rolland and Aanestad, 2003), as reflected in design and organizational decisions. Power becomes the dynamic property of the actor network that relationally integrates and interconnects the social, political, economic and technical. One effect of this, as argued by Rolland and Aanestad (2003:21) is

...that power is delegated to material structures and thereby made durable.

...Thus, in this way, we should think of power as performed and changing – and not a zero-sum game where one actor gains power at the expense of another. In this case there are constantly changing coalitions and the different actors attempt to enroll other actors – both human and non-human in order to strengthen their networks – to support particular “regimes of truth” .

Through ANT one recognizes that power resides within the network of heterogeneous elements and is characterized as relational, emergent and distributed. Power is perceived as the capacity to influence that is realized only through the process of exercising this influence. In this sense, considering the relationality inherent within ANT, power can be conceived as a practice rather than a position. Willcocks (2004:255) argues that ‘...power must be analyzed as something that circulates...that functions only when it is part of a chain. It is never localized here or there, it is never in the hands of the some, and it is never appropriated in the way that wealth or a commodity can be appropriated’.

What is important to take away from this discussion is that ANT challenges the notion of the dualism between human and non-human and as such does not a priori assume

any such distinction in the conduct of the analysis ‘follow the actor’. As Latour (2005: 72) states:

ANT is not the empty claim that objects do things ‘instead’ of human actors: it simply says that no science of the social can even begin if the question of who and what participates in the action is not first of all thoroughly explored, even though it might mean letting elements in which, for lack of a better term, we would call non-humans.

Thus as articulated by Law (1992:381), the social ‘...is nothing other than patterned networks of heterogeneous materials’. ANT thereby facilitates a unique lens on the problem space of fratricide. As discussed, the three elements from ANT that are particularly relevant to the study of pilot error and fratricide include the principle of symmetry; the focus on actor-networks and dissolving dualisms; and the emphasis on processes of translation (Van der Duim, 2005:86). These three elements shape the ensuing analysis of fratricide.

2.6 COGNITIVE DOMAIN (Situation Awareness, Decision-making, Trust)

Introduction

Complex socio-technical systems represent many challenges to operators. Strauch (2004:197) notes that deficiencies in decision-making within the context of complex socio-technical systems contribute to errors and accidents. Because accidents are implicated with decision errors and situation awareness, understanding these is essential to our understanding of ‘pilot error’. The cognitive domain has provided the main thrust in the study of situation awareness and decision-making. Recently

however, the hegemony of the cognitive approach within the field of Human Factors is being enriched by innovative applications from sociology such as symbolic interactionism, ethnomethodology, cultural-historical theory and phenomenology. These perspectives encourage us to re-examine the ontological and epistemological foundations of the traditional paradigm (Bannon, 1998:K2-3). As an interdisciplinary research project, this thesis draws upon the cognitive domain in order to better understand the problem space of ‘pilot error’ within the context of fratricide. In this section we will examine contributions from the cognitive domain to include situation awareness, decision-making and trust.

Situation Awareness

It is well documented in the literature that maintaining situation awareness (SA) is one of the most critical and challenging features for those operating complex socio-technical systems such as that within aviation, medicine and the nuclear industry (Endsley, 1999). In fact, the challenges associated with the introduction of new technology is one of the main factors that contributed to the growth in interest in SA (Endsley, 2000). In a study of accidents among major air carriers, 88% of those involving human error could be attributed to problems associated with situation awareness, similarly problems with SA were found to be the leading casual factor in a review of military aviation mishaps (Endsley, 1999). As noted in Bosse, Roy and Wark (2007:28) ‘...bad perception of needed information is present in 76% of SA errors, while a problem with comprehension of the information perceived was noted in 20% of SA errors’. As articulated by Stout and Salas (1998), SA should be regarded as an essential requirement for competent performance in dynamic environments, with

inaccurate and incomplete SA often leading to dangerous and life-threatening consequences. Given the problems and consequences associated with human error in aviation, current strategies to address SA often focus on aircraft systems design and training programs in order to improve the efficacy and safety of flight operations. In complex domains such as aviation, situation awareness is inherently distributed over multiple people and groups and over human and nonhuman actors. Bosse et al. (2007:28) cites an example to contextualize SA:

When a pilot neglects to check the flaps at take-off and consequently crashes, the error can hardly be attributed to inadequate training, lack of practice (because that task has been practiced hundreds, if not thousands, of times), or scarce cognitive resources. Considering the risk of a deadly error, such a mistake is certainly not the consequence of a gross negligence. Inappropriate SA has been suggested as a prime explanation for such accidents.

Within the context of aviation and pilot error, SA then becomes a relevant attribute of the problem space as pilot performance, errors, expertise and decision making are implicated. SA can be seen as both product and process. 'As product, it is the state of the active schema- the conceptual frame or context that governs the selection and interpretation of events. As process, it is the state of the perceptual cycle at any given moment. As process and product, it is the cyclical resetting of each by the other' (Salmon, Stanton, Walker and Jenkins, 2009:13). The importance of SA in the study of human work is well reported in the literature (Endsley, 1995, 1997, 1999; Klein, 2000; Wright, Taekman and Endsley, 2004). Klein (2000) specifies four reasons why

SA is important: SA appears to be linked to performance; Limitations in SA may result in errors; SA may be related to expertise; and SA is the basis for decision making in most cases.

To establish effective SA within the military aviation domain, certain classes of elements are required such as geographical SA, spatial/temporal SA, system SA, environmental SA and tactical SA (Endsley, 1997:4). When we consider the problem space of this thesis, accident aetiology (specifically associated with fratricide), we recognize that it is characterized by ‘...ill-structured problems, changing and stressful conditions, technological advances in threat technology, the increasing tempo and diversity of scenarios, and the volume, rate, imperfect nature, and complexity of the information among other things’ (Bosse et al., 2007:119).

As proposed by Endsley (1995, 1999) SA encompasses three elements as depicted in figure 2.5. The three key elements of SA include: Level 1 SA- Perception of elements in the current situation; Level 2 SA- Comprehension of current situation; and Level 3 SA-Projection of future status. The information perceived (Level 1 SA), comprehended (Level 2 SA), and projected (Level 3 SA) is a function of not only the cognitive limitations of the aircrew but also socio-technical elements of the system (environment). Both the individual cognitive attributes coupled with the socio-technical system play a role in the mental model associated with SA. As shown in figure 2.5, the development of SA encompasses a socio-technical dimension that affects all three levels. Endsley’s (1995, 1999) approach to SA is one rooted in

individual psychological phenomenon, whereby SA is something that can only exist in the mind. Within the model of SA, Endsley (1995) links elements stemming from the psychological domain such as perception, attention, working memory, long-term memory, automaticity, goals, plans, mental models, scripts, decision making and action as described in (Stanton, Salmon, Walker and Jenkins., 2010:31). As reported by Strauch (2004:204), ‘Operators with deficient or inaccurate SA have difficulty interpreting system-related information and are likely to commit errors’. It has been reported extensively in the literature that an operator’s mental model is the foundation of situation awareness (Endsley, 1999, 2000; Bosse et al., 2007). Expectancies have a significant impact on decision-making based on SA. If expectancies did not match the cues encountered because of incorrect mental models the operators often failed to perceive cues critical to situation awareness, and hence they retained inaccurate situation awareness (Jones and Endsley, 2000:369). In situations of high workload, operators may lack the spare cognitive capacity to attend to multiple cues, thereby affecting their SA. To compensate for this apparent limitation, automation has been integrated into the systems, however in some cases to the detriment of maintaining SA. This arises due to the opacity of the automation and subsequent delegation of responsibility of the operator to the automation. Adams et al. (1995) suggest that when presented with ambiguous or incomplete information, operators may expend considerable cognitive effort to interpret the information. This may result in distortion, diminishing, or even blocking their ability to perceive and comprehend arriving information.

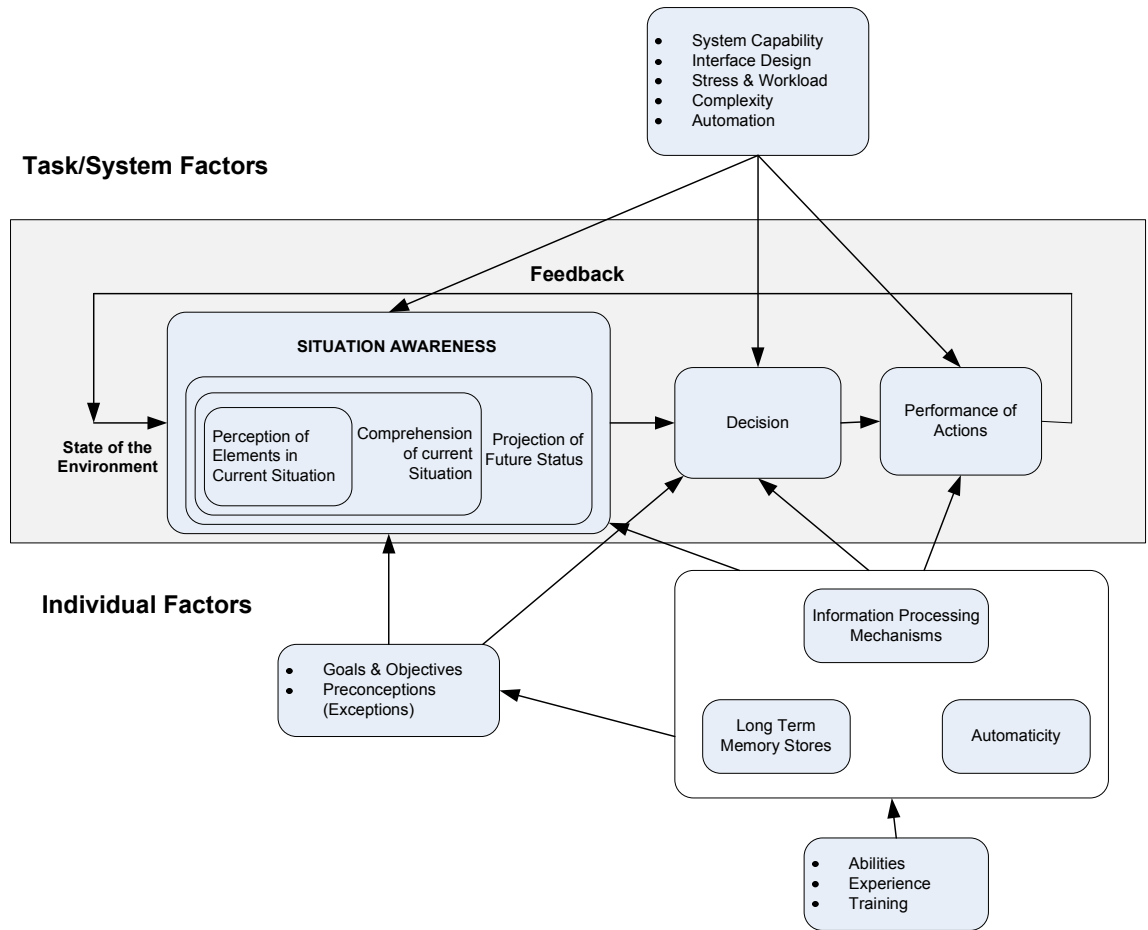


Figure 2.5- Model of Situation Awareness (Endsley, 1995).

Equation (2.2) (Bosse et al., 2007:93) succinctly characterizes the composition of SA and indicates that SA is the combined product of perception, comprehension and projection.

$$SA = \text{Perception} \cup \text{Comprehension} \cup \text{Projection} \quad (2.2)$$

Endsley's definition of situation awareness has, however, been criticized for its strictly individual perspective. For example, Artman and Garbis (1998:151) maintain that situation awareness should be defined in a perspective of interaction between

individuals, artifacts, rules and culture, as a system that makes decisions. Hence Artman (2000:1113) gives the following definition of SA, focusing on a common and active process: 'Two or more agents' active construction of a situation model which is partly shared and partly distributed and, from which they can anticipate important future states in the near future'. Alternate views are provided by the engineering perspective in which SA is situated in the world and represented in the artefacts and objects that people use. The alternate systems view places emphasis on the interaction between people and the artefacts they use (Stanton, 2010:2). This approach is informed by distributed cognition (Hutchins, 1995a).

SA has very much to do with what Weick (1995) refers to as sensemaking defined as how meaning is constructed at both the individual and group levels. Hutton, Klein and Wiggins (2008:1) defines sensemaking as '...the deliberate effort to understand events and is typically triggered by unexpected changes or surprises that make a decision maker doubt their prior understanding. Sensemaking is the active process of building, refining, questioning and recovering situation awareness'. Alberts and Hayes (2003:102) note that '...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 course of action'. Distributed cognition (Hutchins, 1995a, b) resonates with the concepts of SA and sensemaking and has inspired the notion of distributed SA (Stanton, 2010:32). Hutchins (1995b) applied the distributed cognition framework to the field of aviation

by showing ‘...how the cockpit system performs the cognitive tasks of computing and remembering a set of correspondences between airspeed and wing configuration’ (Hutchins, 1995b: 266). This involved the integration of pilots, their physical surroundings, and tools working as one functional system. Distributed cognition emphasizes the distributed nature of cognitive phenomena across individuals, tools/technologies, and internal/external representations. What makes distributed cognition so applicable to this study is that the focus goes beyond the cognitions of a single individual and focus on the functional system as a whole. As Hansberger (2008:1) notes, ‘...distributed cognition examines the relation between individuals, the task environment, and artifacts used for task completion’.

Within the context of this thesis as we begin to open the black box of pilot error the significance of sensemaking becomes apparent with its view as ‘...a paradigm, a tool, a process, or a theory of how people reduce uncertainty or ambiguity; or to socially negotiates meaning during decision making events’ (Ntuen and Leedom, 2007:2). In terms of situation awareness and distributed cognition, sensemaking is significant as ‘...the process of being aware of a situation by using information in context to predict the consequences of the individual and team actions relative to the interpretation and assignment of meaning to that context, while doing so through progressive enactment of knowledge management process’ (Ntuen and Leedom, 2007:2).

Decision-Making

Military operations are characterized as an information-rich environment whereby information is received from multiple sources with various formats in highly dynamic

and unpredictable environments, needing rapid data fusion and recovery, high reliability and dissemination. The management of information and knowledge becomes an essential role of all components within the organization. Unreliable, misleading, false or poorly disseminated information threatens operational effectiveness. As discussed, data/information quality and timeliness are essential features of SA, which is key in shaping the decision-making process as argued by Endsley and Garland (2000). SA represents the ‘mental model’ of the environmental state acting as a precursor to decision-making (Bosse et al., 2007:40).

In the literature there are various schemas that describe the decision-making process. To help explain the SA as it pertains to pilot error, we will discuss Boyd’s OODA loop and Naturalistic decision-making (NDM). Boyd’s (1987) Observe, Orient, Decide and Act (OODA) loop was developed as a schema to help support the analysis of pilot decision-making at a tactical level and reflects an iterative process. As shown in figure 2.6, the decision-making process begins in the physical domain whereby observations are made and contextualized in order to orient the operator. From this phase of the process, the operator then makes a decision as a precursor to an act.

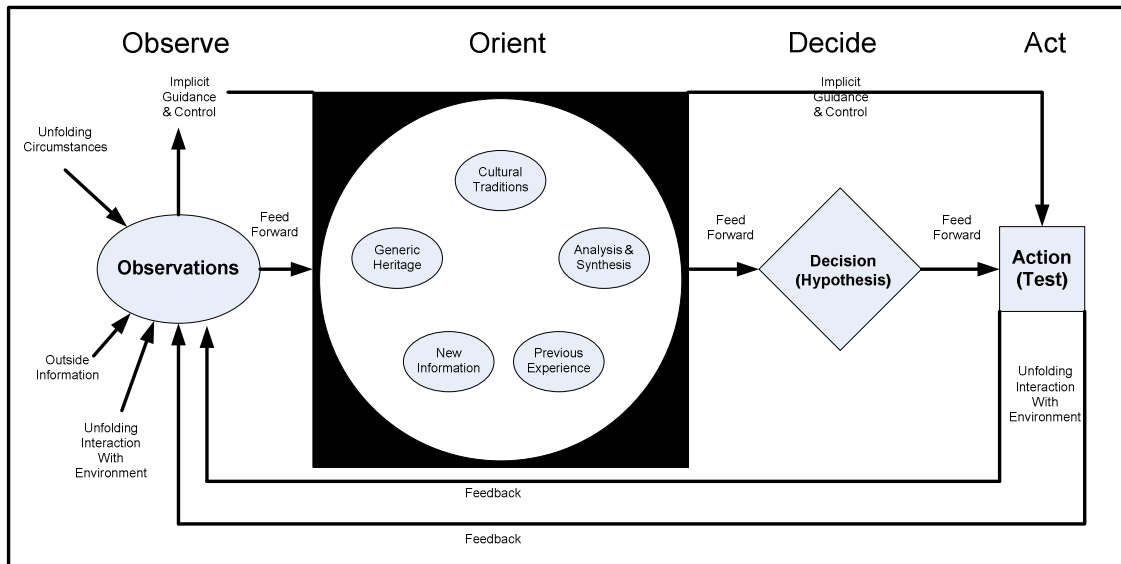


Figure 2.6 - Boyd's OODA loop (Brehmer, 2005:3)

The environment associated with military flight operations is characterized as a dynamic environment of complex systems, where time pressure, uncertainty and ambiguity describe the natural state. Central to the OODA loop, Klein (1993) suggests that decision makers in such dynamic situations employ what is referred to as naturalistic decision-making. Naturalistic decision-making (NDM) emerged from the study of decision makers in real-world setting such as fire commanders and military decision makers. The decision context in these domains is characterized as fast-paced, complex in dangerous situations where optimization is not available (Lipshitz, Klein and Carroll, 2006:917). NDM facilitates an examination of how decision makers approach real decisions that thereby guide actions with real consequences. Models and research in NDM are based on some particular factors that appear to characterize and influence decision-making in natural settings. These contextual factors are: nonstructured (that is nonartificial) situations and problems; uncertain and dynamic environments; ill-defined, conflicting, or changing objectives; a decision-action-

feedback cycle; time pressure; involvement of several individuals; existence of organizational norms and objectives; presence of high and potentially personal stakes (Bosse et al., 2007:16).

The dominant process model in the naturalistic mode is Klein (1993) Recognition-Primed Decision model (RPD) shown in figure 2.7. Klein (1993) focused on how proficient decision makers manage to be effective under high stress and time pressure. Klein's principal conclusion is that, contrary to the traditional definition of decision making as choosing among alternatives, proficient decision makers rarely compare among alternatives. Instead they assess the nature of the situation and, based on this assessment, select an appropriate course of action. The model depicted in figure 2.7 shows how the situation generates cues that are recognized as patterns from which action scripts are developed and played that shapes the decision and the evolving situation. Some of the limitations of the RPD model are that it does not address cognitive processes such as metacognition, it does not explain how the pattern matching or judgment of typicality occurs, it doesn't explain what happens when people do have to compare courses of action, and it doesn't account for the generation of new courses of action. It does explain however how people can make decisions without analyzing strengths and weaknesses of alternative courses of action. It explains how people can use their experience to adopt the first action they consider. It shows how expertise can affect decision making (Klein, 1999:16).

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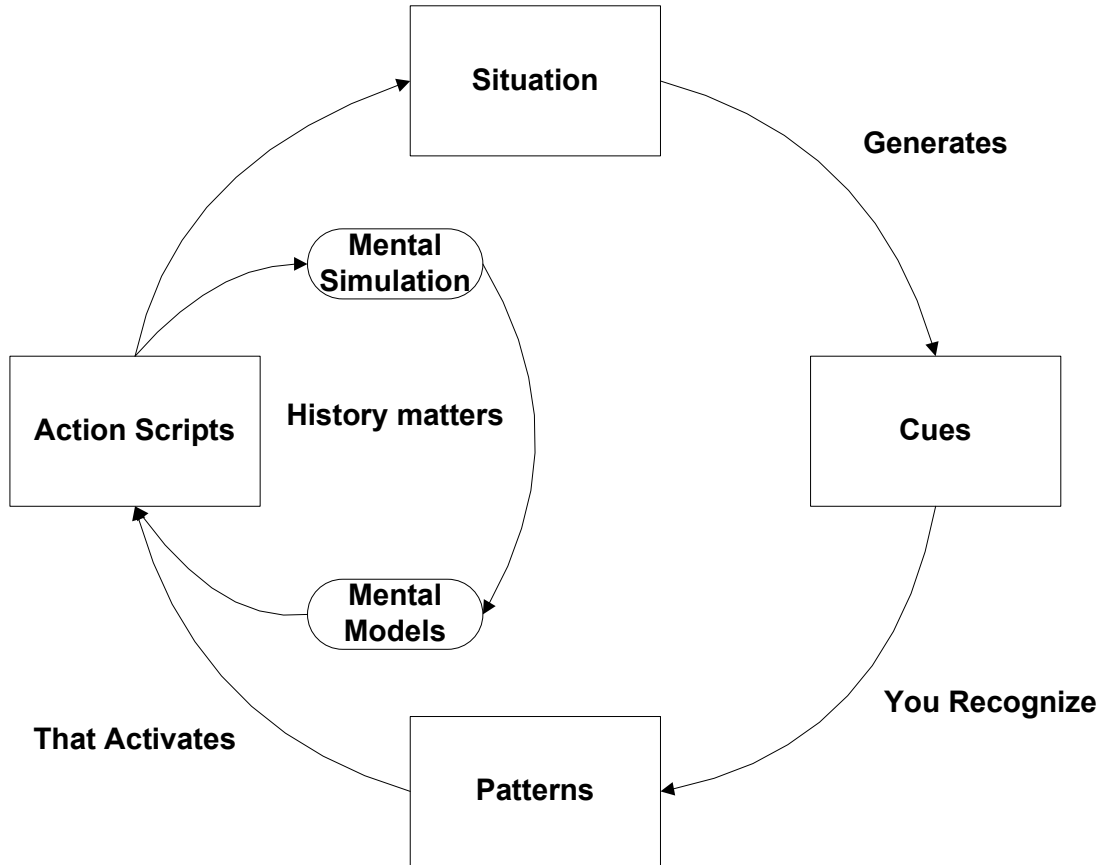


Figure 2.7- Recognition Primed Decision Cycle (modified from Greitzer, Podmore and Robinson (2010:281))

The decision-making processes described reveal the complexity resident within the domain of aviation. In chapter 5 we will examine the accident aetiology through the ANT perspective to provide insights to help explain pilot error within the context of decision-making.

Trust

Exploring the notion of trust within the actor network sheds light on understanding situation awareness and decision-making processes that are examined within the case studies. The investigation of trust as a phenomenon crosses many domains of inquiry such as economics, political sciences, personality research and social psychology. As cited in de Vries (2005:5), each of these domains treats the topic in a contextual manner viewing trust in various schema ‘...whether it is seen as an dependent, independent, or interaction variable, whether it is static or dynamic, or whether it is studied on the institutional, group or individual level’. The concept of system trust that is explored in this thesis ‘...can be seen as a special case of interpersonal trust’ (de Vries, 2005:5) and is developed within the actor network perspective recognizing the inherent symmetry of the actor network, neither privileging human or non-human actors.

As described in Lee and See (2004:52) recognition of the importance of trust as a subject of inquiry has grown over the last number of years in recognition of its importance in shaping decision-making, cooperation and communication. In organizational theory trust has emerged as a central topic as noted in contributions from Kramer and Tyler (1996), Jones and George (1998), Corritore, Kracher and Wiedenbeck (2003). In terms of understanding the role of trust in mediating human-automation interaction, some researchers have focused on trust as an attitude or expectation defining trust as: ‘expectancy held of an individual that the word, promise or written communication of another can be relied upon’ (Rotter, 1967:651);

‘expectation related to subjective probability an individual assigns to the occurrence of some set of future events’ (Rempel, Holmes and Zanna, 1985:96); ‘expectation of technically competent role performance’ (Barber, 1983:14). As reported in Riegelsberger, Sasse and McCarthy (2005:7), ‘trust in technology is of particular importance for delegating to or relying on decision aids or software agents (Muir, 1987; Milewski and Lewis, 1997; Dzindolet et al., 2003)’. Trust has been characterized as a nonlinear and dynamic function that is highly contextual individually, organizationally and culturally. A special case and one that is apropos in this thesis is technology trust. It is characterised by Lippert and Swiercz (2005:341) as ‘...an individual’s willingness to be vulnerable to a technology based on person-specific expectations of the technology’s predictability, reliability, and utility as moderated by the individual’s predisposition to trust the technology’. This conceptualization will help in establishing a view of ‘system’ trust described in chapter 5.

As noted in Lippert and Swiercz (2005:342), the notion of trusting an inanimate object is not new. Giffin (1967) suggests that trust can be bestowed on a person, place, event, or object. In another effort along these lines, Muir (1987, 1994), Muir and Moray (1996) employed an interpersonal approach to better understand the nature of trust between humans and machines and to determine the factors affecting this one-sided trust relationship. From the research of Muir (1987, 1994) three common trust elements were identified: the description of trust as an expectation or confidence; the focus of trust toward a specific person, place or object; and the presence of multiple

characteristics of trust referents. Lippert and Swiercz (2005:343) present the argument that 'trust as an expectation is tied to the notion that a technology will function in a consistent manner at a future time leading to an individual's assessment that the technology is predictable'. Factors that affect system trust are: direct information, indirect information, consensus information (when other information was not available). It has been argued that trust mediates not only relationships between people but also between people and automation and has been shown to affect reliance (Lee and See, 2004:51)

The significance of trust in this thesis stems from the issue regarding factors shaping decision making. For example technology trust is linked to socio-technical trust in that '...human trustors are known to treat technological artefacts in similar ways as they treat human ones' (Riegelsberger, 2005:71). From the ANT perspective trust resonates with matters pertaining to inscription and translation and their effects throughout the actor network. As discussed trust has a role within the socio-technical domain in shaping action and decision making as well as sensemaking. In particular we note the extension of trust beyond the person to person to include the inanimate thereby reflecting the impact of the technical on the 'social'. But even more so we see how trust becomes entangled within the socio-technical domain.

2.7 CONCLUSION

This chapter highlighted the salient theoretical dimensions of this thesis, namely human error conceptualizations, accident aetiology models, systems theory,

complexity theory, actor network theory and cognitive theory. Chapter 3 will present the methodology applied during the conduct of this research.

Chapter 3

Methodology

A discussion of research design

3.1 INTRODUCTION

Approaches to research, both quantitative and qualitative have become more holistic in nature, embracing notions of complexity and emergence supporting cross-method collaboration and multi-method work exploring alternative methodological approaches (George and Bennett, 2005:3). Building upon this theme, this chapter introduces the methodological influences associated with systems thinking, complexity theory and actor network theory. Section 3.2 of this chapter begins with a discussion of the systems thinking paradigm that has shaped current sociological thought and methodology. Section 3.3 focuses on qualitative research methodology detailing the *raison d'être* behind the selection of the research approach applied and developed for this work. We begin with a review of qualitative analysis and in particular case study analysis. As case study design is dependent on the research objective and methodological perspective, presented here is an argument for the particular choice, tailored for the study, embracing single (focused) case studies and comparative case studies. Section 3.4 describes the research design developed and applied in this work. The research design is an adaptive, inherently flexible methodology integrating elements from Actor Network Theory and case study analysis. A spiral development methodology facilitates the study by providing a framework for the iterative analysis of complex socio-technical systems.

3.2 SHAPING SOCIOLOGICAL THOUGHT AND METHODOLOGY

Systems Thinking and Complexity

Systems thinking, as discussed in detail in chapter 2, emerged from the successes and unsolved problems within the domains of classical physics and biology. The early development of general systems theory by Bertalanffy (1968) led to a subsequent development of systems thinking as an independent science in mathematics, electrical engineering and computer science in addition to enlightening the social sciences, notably psychology, linguistics, sociology and economics (Altmann and Koch, 1998). The features of systems thinking that shape the methodological approach associated with this thesis stem from the conceptualization that the general system is not simply an aggregation of objects but rather is a set of interrelated, interconnecting parts creating through their interaction new system properties. The realization of this interconnectivity helps us to understand and explain complex phenomena and processes (Altmann and Koch, 1998:186). Within the context of this thesis, Dekker (2005b:7-8) points to the requirement for a systems perspective with regards to understanding accident aetiology. Dekker (2005b:7-8) asserts that:

Systems thinking is about relationships and integration. It sees a socio-technical system not as a structure consisting of constituent departments, blunt ends and sharp ends, deficiencies and flaws, but as a complex web of dynamic, evolving relationships and transactions. ...Understanding the whole is quite different from understanding an assembly of separate components. Instead of mechanical linkages between components (with a cause and an effect), it sees

transactions- simultaneous and mutually interdependent interactions. Such emergent properties are destroyed when the system is dissected and studied as a bunch of isolated components (a manager, department, regulator, manufacturer, and operator).

Complexity theory provides a new set of conceptual tools to help address the classic dilemmas of social science, facilitating new ways of thinking of 'system' as well as challenging the reductionist perspective so resident in scientific enquiry (Walby, 2003). As applied to the social sciences, complexity theory provides a perspective of the 'social world' that as argued by Dooley, Corman, McPhee and Kuhn (2003) reveals emergent properties, nonlinearity, consideration of the 'dynamic system', interactions, interrelations that is transforming the traditional views of the social. This is similarly reflected in Guastello (1995), Dooley (1997), Eoyang (1997), McKelvey (1997), Zimmerman, Lindberg and Plsek (1998), Anderson (1999), and Poole, Van de Ven, Dooley and Holmes (2000). The contribution of complexity theory to sociology is reflected in the attention to the dynamic processes, systems thinking, matters of unpredictability and uncertainty, thereby shaping the research strategies and methods used within the social sciences.

From a methodological standpoint, we must move beyond the view of the system as simply 'a whole equal to the sum of its parts' and consider the interrelations and causal influences, which are often complex and nonlinear, thereby shedding light on the 'system effects' such as emergence, equifinality and mutlifinality. Systems

thinking gives rise to multiple perspectives to facilitate understanding the problem space. The 'systems' paradigm facilitates a cross pollination of analogies and abstractions from one field to another thereby yielding insights and enriching the methodological processes involved in this study giving rise to the interdisciplinary and multidisciplinary crossovers. The application of systems theory facilitates a foundational perspective that guides the development of an accident aetiology model based on insights from ANT and complexity theory.

3.3 QUALITATIVE ANALYSIS

In the social sciences the role, benefits and appropriate use of qualitative research methods has been discussed extensively in the research literature Goode and Hatt (1952), Yin (1984, 2003), Merriam (1988), Guba and Lincoln (1994). Proponents and supporters of qualitative analysis have convincingly argued 'that qualitative methods contribute findings and insights that cannot be derived from 'conventional' or 'quantitative' research methods' (Mittman, 2001:2). Such methods as participant observation, case study, thematic and content analysis, ethnography, and in-depth interviewing characterize qualitative research. Given the nature of the problem space of this thesis, (analysis of accident aetiology associated with complex socio-technical systems: replete with interconnections, relations), qualitative research methodology was selected as it facilitates rich descriptions providing insights into the complexity inherent within the events and experiences. Qualitative research, with its emphasis on understanding complex, interrelated and dynamic phenomena, is particularly relevant to the challenges associated with research of accident aetiology as demonstrated in

such works as Perrow (1984,1999), Sagan (1993), Vaughan (1996), Toft and Reynolds (1999), Snook (2000), Bennett (2001), Leveson (2002), Dekker (2005) and Johnson (2008).

Case Study

Case studies are a common way to conduct qualitative inquiry. The case study method facilitates an in-depth analysis of particular situations, which makes it germane to this dissertation. In situations characterized by complexity, the case study method facilitates the retention of a holistic perspective, giving rise to greater understanding regarding nonlinear, complex and emergent behaviour. As such, Yin (2003:1) argues ‘the case study has been a common research strategy in psychology, sociology, political science, social work (Gilgun, 1994)’. Cronbach (1975:123) denotes ‘interpretation in context’ as that which differentiates case study methodologies from other research designs. This approach facilitates an analysis to uncover key interaction and interconnectivity that resides within the phenomenon of study and thereby focuses on a holistic description and explanation. Yin (1984) observes that case study design is particularly suited to situations in which it is difficult to separate a phenomenon’s variables from its context. As such, observations with the case study problem space take meaning from their time and place, context and conceptions of the actors.

Goode and Hatt (1952:331) provide a classic definition of case study research identifying it not as a specific technique but rather as ‘...a way of organizing social data so as to preserve the unitary character of the social object being studied’.

The versatility of case study design stems from the fact that it can ‘accommodate a variety of disciplinary perspectives; as well as philosophical perspectives on the nature of research itself. A case study can test theory or build theory, incorporate random or purposive sampling, and include quantitative and qualitative data’ (Merriam, 1988:2). Merriam (1988:17) points out that researchers choose case study designs because they ‘... are interested in insight, discovery and interpretation rather than hypothesis testing... One does not manipulate variables or administer a treatment. What one does do is observe, intuit, and sense what is occurring in a natural setting- hence the term naturalistic inquiry’. The main concern associated with the case study is to embrace the detail and complexity inherent within the data. As such, the focus of case studies is not so much on discovering the quantitative variables such as frequency of events but on finding the conditions under which specified outcomes occur, and the mechanisms through which they occur (George and Bennett, 2005). To contextualize this we are reminded that pilot error is not an explanation but rather is something to be explained. We seek to intuit, interpret, and garner insights regarding aviation accident aetiology and in particular fratricide in air operations.

Within the complex socio-technical system, a case study analysis consists of a search for patterns within the data that has been collected (Stake, 2005). The aggregation of this data (from a plethora of sources) provides the researcher with the opportunities to reach new meanings and insights regarding the area of investigation thereby creating conditions whereby ‘emergent behaviour’ is realized. One of the features of case study methods that makes it so applicable to the study of complex socio-technical

systems and in particular fratricide is that it focuses on understanding the dynamics resident within a particular setting and can include either single or multiple cases facilitating numerous levels of analysis (Yin, 1984). As such, the case study methods tailored for this study uses comparative method (the use of comparisons among a small number of cases) and within-case analysis. This is supported by George and Bennett (2005:18) who argue that this approach is ‘...the strongest means of drawing inferences from case studies’.

Multiple sources provide insights into the operation of contextual ‘causal’ mechanisms in individual cases in detail therefore through a combination of within-case studies and cross-case comparisons, the researcher ‘can look at a large number of intervening variables and inductively observe any unexpected aspects of the operation of a particular causal mechanism or help identify what conditions present in a case activate the causal mechanism’ (George and Bennett, 2005:21). This approach facilitates the ability to accommodate complex causal relations such as equifinality, complex interactions effects, and path dependency (Ragin, 1987). As stated in Mingers (2001: 243) and supported by Yin (1994):

Case study inquiry relies on multiple sources of evidence. In studies characterized by complexity one should draw upon a very wide range of disciplines that encompass different research traditions, and advocates ‘strong pluralism’ where ‘all research situations are seen as inherently complex and multidimensional, and would thus benefit from a range of methods.

The decision to utilize a case study method regarding the study of complex socio-technical systems and accident aetiology is well supported.

Actor Network Theory

A theoretical paradigm lies at the foundation of a scientific endeavour and comprises ‘...a loose collection of logically held together assumptions, concepts, and propositions that orientates thinking and research’ (Bogdan and Biklan, 1982:30) and thereby defines a worldview that guides the investigation. The ANT worldview presents a methodology that stems from the interpretation of the word ‘social’ as described in Latour (2005). In the broadest sense ‘...social means association. This is after the Latin word socius, meaning a companion or associate, with the root, sequi, meaning ‘to follow’ (Dolwick, 2009:21). As such, the social is construed as a connection, and interaction which may include ‘...plants, animals and material artefacts as well as humans’ (Dolwick, 2009:21-22). Within this context, actors are regarded as relational effects. Through the application of ANT methodology, we open the black box to reveal the network space, replete with actors and relations and examine the processes of inscription and translation in the construction of the black box, thereby ‘undeleting’ the ‘silenced voices’ that reside within. As we focus on Pilot Error as something to be explained rather than an explanation, ANT provides an avenue whereby the privileged ‘human’ or technical object is relegated the position of an actor within a greater socio-technical system. As Latour (1993) emphasizes, ANT declares that the world is full of hybrid entities containing both human and non-human elements, developed as Callon (1999) remarks to analyse situations where separation

of these elements is difficult. In terms of accident aetiology, human action (or inaction) does not take place in a vacuum; it involves a contextual dimension that situates the event within a holistic perspective. Hence ANT, as a theoretical perspective for this thesis provides a mechanism to examine accident aetiology from a systems viewpoint.

Method

Rooted in ethnography, ANT seeks to understand relational dynamics from the inside-out through qualitative inquiry by following the actors and thereby asking how the world looks through the eyes of the actor doing the work. Through this approach emerge issues pertaining to the roles that tools and other artefacts (actors) play in the actor network in the accomplishments of their tasks (Dekker and Nyce, 2004:1630). The foundational method associated with an ANT study, as suggested by the main proponents of ANT, is to ‘follow the actors’ Callon (1986a), Latour (1996, 2005) and ‘let them set the framework and limits of the study themselves’ (Tatnall, 2000:80). Through this approach we search out the interactions, negotiations, alliances and networks that characterize the network space. Latour (1987:175-176) remarks:

...we have to be as undecided as possible on which elements will be tied together, on when they will start to have a common fate, on which interest will eventually win out over which. In other words, we have to be as undecided as the actors we follow...The question for us, as well as those we follow, is only this: which of these links will hold and which will break apart.

This therefore suggests that we approach the study/analysis without specifying different levels of analysis in advance (Murdoch, 1997).

The steps associated with the ANT approach involve following the actor and then determining the relational significance of their role in the actor network.

In step 1, identifying and tracing the network begins with ‘follow the actor’ (Latour 1996) in order to investigate the relevant ‘leads’ each actor suggests. This is significant in that it is essentially the actor themselves and not the researcher that determines the direction of the investigation. For example a policy or standard operating procedure (SOP) may lead (influence) directly to a physical (technical) or informational actor. These interrelations mark the direction of analysis. In Step 2 the goal is to ‘interview’ the actors. This is accomplished through a relational mapping of the influences across both human and non-human actors. The aim of this step is to see how these actors relate to each other and the associations they create – to identify how they interact, how they negotiate, and how they form alliances and networks with each other. The relational mapping described resonates with the propositional networks described in detail in Stanton et al. (2009).

Complemented by a thematic analysis (Boyatzis, 1998), a relational mapping was conducted within the context of the Combat Identification (CID) process of detect, classify, recognize, identify (described in detail in chapter 4). Translation and inscription processes were recognized within the relational mapping from which insights into the dynamics of the accident aetiology were explored. Distributed simulation exercises were conducted to provide a validation and to generate additional insights into matters pertaining to fratricide. Additionally, the application of system dynamic modeling and Anticipatory Failure Determination (AFD) further validated and informed the ANT analysis. This will be discussed in section 3.4.

ANT was selected as the ‘lens of investigation’ with a focus on the socio-technical system treating both humans and non-humans symmetrically as actors. The ‘relational’ nature of ANT created an unbiased, ‘level playing field’ to examine the complex dynamics, interactions, interrelationships and space of possibilities. The actor network theory approach to analysis thereby examines the inherent relationality that permeates the network, giving rise to a topological mapping of the problem space. The ‘systemic’ focus that stems from this approach brings to light the dynamics and nonlinearity that characterizes accident aetiology.

3.4 RESEARCH DESIGN

Research Framework

To begin a discussion of the research design for this thesis requires understanding and articulation of the framework that is the foundation of this work. Four basic elements, Table 3.1, form the framework for this study (Crotty, 2005:3).

Table 3.1 Research Framework Elements

Epistemology	The theory of knowledge embedded in the theoretical perspective and thereby in the methodology.
Theoretical perspective	The philosophical stance informing the methodology and thus providing a context for the process and grounding its logic and criteria.
Methodology	The strategy, plan of action, process or design lying behind the choice and use of particular methods and linking the choice and use of methods to the desired outcomes.
Methods	The techniques or procedures used to gather and analyse data related to some research question or hypothesis.

The epistemology describes the way of understanding and explaining what we know (Crotty, 2005). Such foundations give research projects a guiding compatible framework for design and methodology choice. The systemic epistemology enacted in this thesis ‘...provokes thinking about the world in a completely different manner than other forms of thinking (Gharajedaghi, 2006)...seeks to derive knowledge from a strategic vantage point (Haynes, 2001) and make sense of causality from various perhaps conflicting perspectives’ (Houghton, 2009:100). The theoretical perspective supports the methodology by providing an approach to understanding the ‘world’ and grounds a set of assumptions supporting the methodology selected. Within a particular methodology are a myriad of assumptions that reflect the theoretical perspective. Crotty (2005:66) remarks that ‘Different ways of viewing the world shape different ways of researching the world’. The theoretical perspectives that form the foundation of this work are inherently complementary in that they facilitate greater explanatory rigour and enrich the theoretical development of the concepts that emerge. These theoretical perspectives include: Systems Thinking, Actor Network Theory and Complexity Theory. They describe a set of assumptions (described in chapter 2) that support the methodology developed for this work. The methodology associated with Latour (2005) ‘follow the actor’ used in this work was chosen as it is sensitive to emergent behaviour that so characterizes complex systems. Thus as noted in van der Duin (2005:90):

The methodological result of this perspective is that no a priori assumptions will be made about who will act in any particular set of circumstances. Action will be the result of network construction, and networks are constructed out of

all kinds of bits and pieces, some of which we might label ‘social’, or ‘natural’ or ‘technical’, and so on.

The case study characterizes the method supporting this study.

Research process

The challenge associated with opening the ‘black box’ is, as argued by Williams-Jones and Graham (2003:272) ‘...to ‘unpack’ and better understand the underlying processes and components of actors and networks that may not be readily apparent’. To start following actor interactions, it is necessary to develop a preliminary sketch of the network. Combining the central tenets of ANT, the researcher follows the actors analyzing the inscription and translation processes thereby tracing and revealing the inherent interconnectivity and complexity resident within the network construct. Mind mapping (Buzan and Buzan, 2006) proved to be a valuable tool to facilitate the visualization of the interrelationships and connections within the network space thereby giving rise to the emergence of insights from the coding and thematic analysis processes. These insights were further analysed to support the argumentation and presented using causal loop diagrams (Sterman, 2000) and explored using Anticipatory Failure Determination (AFD) described in detail in Appendix B.

The spiral development approach facilitated the ANT methodology in that it allowed a process whereby increments of collecting, coding, and analysis facilitated a conceptual convergence regarding pilot error and fratricide. The phases of thematic analysis: data familiarization; generating initial codes; searching for themes; defining and naming

themes; and producing a report were integrated within the spiral development approach in figure 3.1.

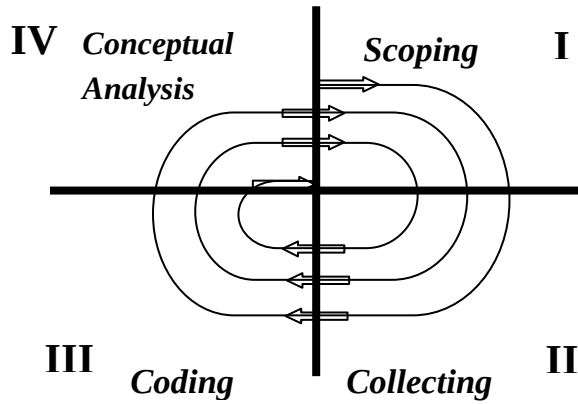


Figure 3.1a - Top view of spiral research framework

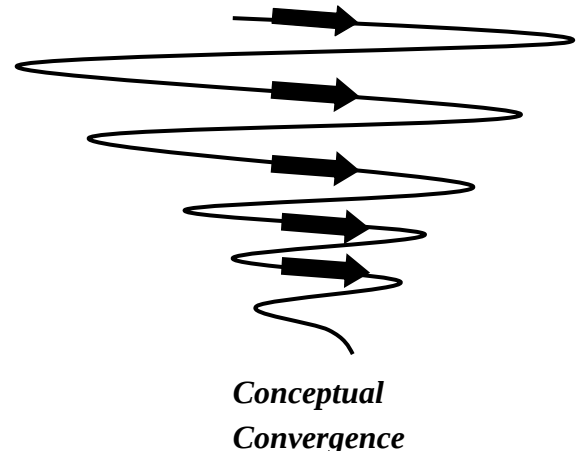


Figure 3.1b - Side view of spiral research framework illustrating conceptual convergence

Framing the Research

The boundaries of the case study were set wide (and open –ended) thereby allowing the ANT approach ‘follow the actor’ to work within an open system. A number of information sources were identified to generate knowledge in relation to aviation accident aetiology and friendly fire. These included case studies of incidents, statistics, official government reports and the literature regarding accident aetiology from the domains of engineering, physical sciences, cognitive science and social sciences. In addition the case study analysis was complemented by results from two distributed simulations.

Literature review. A comprehensive literature study was carried out to gain knowledge regarding accident aetiology involving complex socio-technical systems

and specifically aviation accidents and fratricide. Sources of literature included military and academic books and journal articles, media reports, official government reports, transcripts, video and audio recordings. There was no shortage of relevant case studies to draw upon for this work. As some incidents were classified, only unclassified incidents were used during the course of the research. Of particular use were the US, UK and CA government reports.

Experimental data. As noted by Garson (2009:267) ‘...After years at the periphery of the social sciences, simulation is now emerging as an important and widely used tool for understanding social phenomena. Through simulation, researchers can identify causal effects, specify critical parameter estimates, and clarify the state of the art with respect to what is understood about how processes evolve over time’. Simulation facilitates exploration of assumptions that shape our models and understanding of complex systems. To inform the concepts of sensemaking and situation awareness and to facilitate understanding regarding the ANT processes of inscription and translation, insights were drawn from distributed simulations JSMARTS II and the MALO Project.

JSMARTS II (Appendix C) was a limited scope experiment conducted to examine the JSMARTS principle of a Modeling and Simulation ‘pick-up game’ within the context of a dirty bomb in Ottawa. The distributed simulation, utilizing a High Level Architecture (HLA) facilitated the problem space for the scenario. The MALO Project developed and demonstrated a limited synthetic environment (SE) of the Maritime Air Littoral Operational Environment required for a Maritime Air platform to operate as

part of a task force. The SE was developed and executed based on HLA distributed Federation Technology. The Project demonstrations focused on two specific applications in the context of littoral/C4ISR task force operations: namely multi platform, multi sensor, Anti Submarine Warfare (ASW) and Anti-Surface Warfare Task Group support operations; and the application of airborne sensors to coastal and overland surveillance and targeting.

To facilitate within-case and cross-case analysis, a number of fratricide case studies (primary case and secondary case) were conducted. Primary case studies, identified in chapter 4, constituted the detailed within-case and cross-case studies that revealed the ‘emergent social’. Secondary case studies provided a vehicle for ‘validation’ and ‘sensitivity analysis’ of the research results.

Application

Actor Network Theory stems from ethnographic and case study methodologies and as such does not have specific methods associated with it, although Callon (1986, 1991) and Latour (1996) do provide the guidance ‘to follow the actor’ and ‘....let them set the framework and limits of the study themselves’ (Tatnall and Burgess, 2002:184). As argued by Law and Callon (1988:285) ‘...we are concerned to map the way in which they [actors] define and distribute roles, and mobilize or invent others to play these roles’. The term black box was originally used in information science to reduce the complexity of the objects to inputs and outputs. In technology studies, the black box represents a technical artefact that appears self evident. The application of ANT to

open the black box ‘... leads the way to an investigation of the ways in which a variety of social aspects and technical elements are associated and come together as a durable whole, or black box’ (Cressman, 2009:6).

Following the actors was conducted within a spiral development process thereby giving rise and facilitating an iterative process within a data collection methodology. Following an approach much like that articulated within Tatnall (2000:85) required one:

To search continually for new actors and to investigate how these actors formed alliances to create or strengthen their networks. It involved continually asking questions like: ‘which networks now exist?’, ‘to what extent are these networks durable?’, are they in contention with other networks?’ As questions are asked more questions are suggested by the answers, and the process goes on. Once the first actors are identified and interviewed, networks and new actors emerged. It was then necessary to ‘loop back’ to interview these new actors and to analyse the networks and alliances that had formed. Sometimes this analysis uncovered additional new actors that had to be interviewed, and the process looped again.

By following the actors we begin to reveal the fundamental importance of ‘objects’ within the context of fratricide and pilot error and hence learn from the actors ‘...without imposing on them an a priori definition of their world-building capacities’ (Dolwick, 2009:38). Essentially ANT is likened to ethnography extended to non-humans. As suggested by Latour (2005:97-120) the ANT research entails five sources

of uncertainty, connecting the nature of: groups, actions, objects, facts, and how to write research accounts.

1. The nature of 'Groups' concerns identifying what actors were assembled together. This was accomplished through examination of the sources of evidence described in section 3.4. In each of the case studies, the relations between the actors were mapped and coded for common themes that were identified in the data (written reports, video, and audio).
2. The nature of 'Actions' concerned the examination of agency within the actor network. This was accomplished by tracing the actor network and analyzing the inscription and translation processes.
3. The nature of 'Objects' concerned recognizing the participation of non-humans in the course of action associated with fratricide. We examined which objects were being enrolled, mobilized or dispatched? Were these objects making a difference in the course of action?
4. The nature of 'Facts' concerned, within the context of fratricide, '...which facts were being disputed and made matters of concern? Which ones were being challenged, and which ones were standing up to and surviving those challenges?
5. What characterizes an ANT analysis is the way of accounting for the social. As Latour (2005:131) argues here, social is not a special ingredient, or domain of reality, implying humans only. Instead, it refers to associations of radically heterogeneous actors.

Due to the arising complexity of the network analysis, it was necessary to identify key moments within the context of the case study and trace the relations from these points. These were derived from the linear event based descriptions of the accident aetiology contained in the case study material drawing upon the lessons learned from Tatnall (2000) and applications of ANT such as Callon (1986a, 1986b), Law (1987), Law and Callon (1988), Latour (1993), the work contained in Aanestad and Hanseth (2000), Aanestad (2003), Czarniawska and Hernes (2005). Key events within the case study were starting points for the analysis. It provided an entry point whereby the incident (black box) was opened revealing a network of relations. The relational analysis was informed through analysis of all case study material including supporting analysis using Why Because Analysis (WBA) (Ladkin and Stuphorn, 2004), Systemic Theoretic Accident Mapping Process (STAMP) (Leveson, 2002; Leveson, Allen and Story, 2002) and Snook (2000).

Within the framework of 'follow the actor', thematic analysis of the data was conducted. As described by Boyatzis (2006:6) 'thematic analysis is regularly used by scholars and researchers in literature, psychology, sociology, cultural anthropology, history, art, political science, economics, mathematics, chemistry, physics, biology, astronomy and many other fields'. Thematic analysis (Boyatzis, 1998) is a search for themes that emerge as being important to the description of the phenomenon (Daly, Kellehear, and Gliksman, 1997). The process involves the identification of themes through 'careful reading and re-reading of the data' (Rice and Ezzy, 1999:258). It is a form of pattern recognition within the data, where emerging themes become the

categories for analysis. Braun and Clarke (2006:78) argue that ‘through its theoretical freedom, thematic analysis provides a flexible and useful research tool, which can potentially provide a rich and detailed, yet complex, account of data’. Braun and Clarke (2006:82) present the theme as ‘...something important about the data in relation to the research question, and represents some level of patterned response or meaning within the data set’. Rather than ‘voluminous description’, the research methodology sought to provide insights into accident aetiology and generate a conceptual model ‘construct’ to facilitate understanding regarding the ‘social’.

The follow the actor approach of ANT was framed within a case study analysis methodology (Yin, 1994). Each case study was analysed using within-case analysis methods, thereby examining each event, mapping out what occurred over the event timeline and what factors appeared to influence the behaviors of those involved. The purpose of this stage was to allow the unique patterns of each case to emerge before generalizing across cases. Following the within-case analysis, cross-case analysis was conducted to search for cross-case patterns. These patterns were derived from iterative constant comparative methods, crossing between the data and emerging concepts thereby defining and refining the insights that emerged. Thematic analysis (Boyatzis, 1998; Braun and Clarke, 2006) was therefore integrated into the process of following the actors. The application of thematic analysis was not linear but rather required an iterative approach which was inductive and data-driven (Boyatzis, 1998: 29). As an inductive approach, the themes were strongly linked to the data themselves (Braun and Clarke, 2006:83). The results of ‘following the actors’ and thematic

analysis were subsequently explored within AFD. AFD is based upon inventive problem solving, described in appendix B. The 9 steps included:

1. Formulation of the original problem.
 - a. Identify the system function and the failure under study.
2. Formulation of the inverted problem.
 - a. Transform the problem identifying the system with the failure as the intended consequence.
3. Amplification of the inverted problem.
 - a. Expand upon the new frame of reference, exploring the actors involved in the creation of the failure.
4. Search for apparent solutions to the inverted problem.
 - a. Examine cases in which the same phenomenon is created as a solution.
5. Identification and utilisation of resources.
 - a. Examine the relational network for leverage points to realize a solution.
6. Search for the needed effect.
 - a. Look for mechanisms that would activate the leverage points within the relational actor network.
7. Search for new solutions.
 - a. Explore where the solution space resides.
8. Formulation of hypotheses and tasks for their verification.
 - a. Create opportunities to verify the solution.
9. Development of means to prevent failures.

The AFD modeling environment also facilitated the relational mapping of the space of possibilities combining both the results from the thematic analysis and following the actors.

Data Considerations

Addressing the rigor in research attests to the credibility of the research findings.

Padgett (1998) describes six strategies that help to ensure rigor: Prolonged engagement; Triangulation; Peer debriefing and support; Member checking; Negative Case analysis; and Auditing. To address the credibility of the findings these six strategies were employed during the course of this research. Within the qualitative domain the positivistic criteria of internal and external validity, reliability and objectivity are translated in terms that provide insights into establishing trustworthiness of the research: credibility, transferability, dependability and conformability (Denzin and Lincoln, 1994). Credibility refers to the confidence that one has with the findings. To establish credibility the methods of triangulation, member checking, peer debriefing and support and negative case analysis were employed. As noted by Yin (1994) converging lines of evidence is one methodology that contributes to validity. This can be achieved via triangulation. Yin (1994) and Maxwell (2004) emphasize the importance and benefits of triangulation in qualitative research design, ethnography, and case study research (Bickman and Rog, 1998:xvii). Triangulation was engrained as a research design element in order to address issues pertaining to validity and reliability. Patton (2001) argues for the use of triangulation to strengthen the study by combining methods or data sources.

Using diverse arrays of evidence such as documentation, archival records, and participant observation supports a convergence of facts associated with the case study and thereby adheres to as noted by Yin (1994) as ‘multiple sources of evidence’.

The use of multiple (cross-case) analysis in place of negative case analysis further enhanced the theoretical depth of analysis as it provided an opportunity to compare and contrast the inherent properties associated with the case studies and thereby look for emergent themes that characterize fratricide. Member checking and peer debriefing were completed in a public forum through the publishing and presentation of papers stemming from this research in peer-reviewed venues (Appendix A).

As the goal of this research was to obtain insights into the phenomenon of fratricide, the case studies were purposefully selected to ensure sufficient data (information rich) existed to maximize understanding of the underlying phenomenon. The size of the sample was informed primarily by the research objective, research question(s), and, subsequently the research design.

Limitations

With respect to the document reviews that formed one of my data collection methods, it is noted that the case study material (data) used during the course of the analysis varied in depth and breadth. As such, methodological strategies such as triangulation, and with-in case analysis were employed drawing upon various mediums of data such as print, video and audio. Only data pertaining to fratricide involving US, UK and Canada were available for analysis and therefore constitute the focus of this research.

3.5 CONCLUSION

The research approach for this work reflects the comments of King, Keohane and Verba (1994:12):

Social science research at its best is a creative process of insight and discovery taking place within a well-established structure of scientific inquiry. The first rate social scientist does not regard a research design as a blueprint for a mechanical process of data-gathering and evaluation. To the contrary, the scholar must have the flexibility of mind to overturn old ways of looking at the world, to ask new questions, to revise research designs appropriately, and then to collect more data of a different type than originally intended.

ANT facilitated an interpretive portrayal of the problem space, not an exact rendering of it. It therefore provides insight into issues regarding accident aetiology associated with complex socio-technical systems, improves our understanding regarding the complexity of fratricide and thereby complements investigative analysis of accident aetiology. Through complexity theory, we recognize that systems are comprised of interdependencies and interactions among the elements that create the whole. Thus, complexity theory suggests that ‘...studying the interdependencies and interactions among the elements, as well as the unity of the system itself ...will provide critical insights for understanding system properties’ (Anderson et al., 2005:673). The paradigm associated with complexity thinking extended traditional ideas about the execution of case studies (Yin, 1994). Much like the experience reported by Anderson et al. (2005:673), the complexity paradigm as an integrating element of the analysis facilitated the creation of a powerful tool for increasing our understandings regarding the specific context of the case study. Allowing the insights to emerge from the actors (data) and opening the black box and revealing the ‘silenced, deleted’ voices of the

actor network ensured that a priori specifications of concepts, modes of analysis, and preconceived notions of human and non-human actors would not impede discovery of important phenomena and insights, thereby weakening achievement of the research goals (Mittman, 2001:3). The methodology described in chapter 3 is applied to the case studies described in detail in chapter 4.

Chapter 4

Research Data

Defining the Problem Space

4.1 INTRODUCTION

On 4 September 2006, a USAF A-10A Warthog providing close air support during Operation Medusa in the Panjwayi District opened fire on a Canadian Camp, mistaking their small garbage fire for a recently bombed enemy target. The investigation concluded that the incident was preventable. The pilot lost situational awareness and failed to confirm the target with his targeting displays before engaging. Military fratricide incident reports show that losses from fratricide are indeed significant. For example, in Operation GRANBY (1991), the UK forces suffered nearly 80% of their combat losses from fratricide (Dean and Handley, 2006:4). Although there have been technological advancements deployed to support combat identification, fratricide continues to occur at alarming rates (Wilson, Salas and Priest, 2007:243)

Through the application of Actor Network Theory, Complexity Theory, and Systems thinking, we seek to generate insights from a ‘systemic’ perspective regarding accident aetiology, thereby revealing properties of the problem space that help to garner a better appreciation and understanding regarding such accident attributions as ‘pilot error’. Drawing upon case studies stemming from incidents of fratricide, we examine the accident aetiology that so often looks to ‘pilot error’ as the start and end point of investigations. Using a combination of within-case and cross-case analysis, as

discussed in chapter 3, we garner insights from an examination of three primary fratricide case studies supported by an additional three secondary case studies and informed through distributed simulation experiments.

This chapter presents the research data used in defining the problem space for this thesis. In so doing it draws upon the underlying theoretical foundations discussed in chapter 2 and the qualitative analysis methodology (case study) discussed in chapter 3. Section 4.2 begins with a discussion exploring the frequency of occurrence, causes of fratricide and its evolution within the process of Combat Identification (CID). Section 4.3 introduces the primary/secondary fratricide case studies outlined in tables 4.1 and 4.2. Section 4.4 presents concluding remarks regarding the case studies.

Table 4.1 Primary Fratricide Case Studies

Date	Incident	Nations involved
17 Feb 1991	Apache Helicopter/Bradley fighting vehicle	US/US
17 Apr 2002	F-16/ Canadian soldiers	US/Canada
14 Apr 1994	F-15/Black Hawk helicopter	US/US (multinational)

Table 4.2 Secondary Fratricide Case Studies

Date	Incident	Nations involved
5 Dec 2001	B-52/ US soldiers	US/US (multinational)
22 Mar 2003	Patriot missile battery/RAF Tornado	US/UK
28 Mar 2003	A-10/ armoured vehicles	US/UK

4.2 FRATRICIDE OVERVIEW

Fratricide is often cited as an unavoidable feature of war, stemming from what is commonly termed 'fog of war' (Ministry of Defence, 2002:9). With this in mind, we are reminded from Normal Accident Theory that serious accidents are a "normal" result or an integral characteristic of the system. Reason (1997) argues that serious accidents in organizations responsible for the management of hazardous technologies may be rare, but they are inevitable over time. With the advent of satellite communications and the constant presence of the media at the war front, the realities of warfare have reached the living rooms of the general public. The Ministry of Defence (2002:12) reports that, 'Public opinion is less tolerant of any casualties, especially those incurred through fratricide, where the overall aim is questionable'. This reluctance of the public to accept casualties particularly resulting from human error has most certainly shed light on the issue of fratricide.

Definition

The term 'fratricide', 'amicicide', 'amicide', 'friendly fire', 'blue on blue' are all terms denoting the action of an accidental death of ones own forces. There are numerous definitions of fratricide in the literature representing national and organizational views. The US Joint Publication 1-02 (2001:222) defines friendly fire as '...a casualty circumstance applicable to persons killed in action or wounded in action mistakenly or accidentally by friendly forces actively engaged with the enemy, who are directing fire at a hostile force or what is thought to be a hostile force'.

The UK Joint Doctrine Publication 0-01.1 (2006: F10) defines fratricide as ‘the accidental death or injury which occurs when friendly forces engage their own forces believing either them, or their location, to be an enemy target’.

Analysis conducted by The Technical Cooperation Programme (TTCP) under the auspices of Action Group (AG) 13 has made significant contributions to the literature on fratricide. The AG 13 defines friendly fire as ‘...a friendly fire event is the deliberate engagement of non-enemy entities by friendly forces in the belief that the entities are enemy. Entities include both personnel and material’ (Caseley, Dean, Gadsden and Houghton, 2007: 544). Common themes that cross the various definitions include: mistakes, accident and belief regarding target identification.

The statistics on fratricide provide a quantitative measure thereby highlighting the significance of the issue. The traditional widely used method of representing fratricide statistics as described in Outteridge, Catchpole, Henderson and Shanaha (2003:15) presents it in terms of a simple ratio between two groups of friendly casualties (equation 4.1).

$$\frac{\text{Number of friendly casualties by friendly fire}}{\text{Total number of friendly casualties}} \quad (4.1)$$

As described in Syms and Salt (2004), a number of studies have provided insight into the issue of fratricide such as Shrader (1982), Brown (1990), Bickers (1994), Regan (1995), Kemp (1995), Waterman (1996), Bowden (1999), Snook (2000). Shrader’s (1982) historical study of fratricide containing a review of existing literature on World

War I, World War II, Korean War and the Vietnam War identified 269 cases of friendly fire involving US ground forces. Shrader (1982) concluded that amicide accounts for something less than 2 percent of casualties in battle. Outteridge et al. (2003) reported that based on the study of Steinweg (1994) that examined historical evidence of the 20th century, that fratricide rates are at least five to eight times the generally accepted two percent figure. Steinweg (1994:29) concluded that 'Fratricide rates have been, and are, conservatively 10-15 percent of our casualties'. This is supported by the results of the United States Office of Technology Assessment (OTA-ISC-537:1993) in that the official fratricide rate for Desert Storm was 24 percent and hence stated that the past fratricide rates to be underdetermined. A comprehensive study conducted by Syms and Salt (2004) examined accounts of fratricide uncovering 1318 separate incidents of which 1238 were post 1900. The study spans a period dating back to 480 BC to present day. Their analysis shows that recent fratricide rates far exceed the 2% reported by Shrader (1982). Among the environments (Air, Land, Sea), the occurrence of fratricide is not symmetrical. The data compiled by Syms and Salt (2004) show that air to ground fratricide accounted for 40% of the total for the 20th century as a whole. Table 4.3 presents fratricide statistics cited in Outteridge et al. (2003:18).

Table 4.3 Fratricide Statistics (1914-1991) (derived from Outteridge et al. (2003:18))

Conflict	Source of data	Fratricide rate
World War I (1914-1918)	Besecker Diary (Europe)	10% Wounded in Action
World War II (1939-1945)	Bougainville Study	12% Wounded in Action 16% Killed in Action
Korea (1950-1953)	25 th Infantry Division	7% Casualties
Vietnam (1961-1970)	WDEMT (autopsy) WDEMT (autopsy) WDEMT Hawkins	14% Killed in Action (rifle) 11% Killed in Action (frag) 11% Casualties 14% Casualties
Grenada (1983)	TRADOC	17% Casualties
Just Cause (1989)	US Department of Defense	5-12% Wounded in Action 13% Killed in Action
Desert Storm (1990-1991)	US Department of Defense	15% Wounded in Action 24% Killed in Action

Further to the above statistics, the extent of fratricide incidents and near misses is acknowledged with the report that during the period February 2004 to February 2005, 32 attacks on British and other coalition vehicles in southern Iraq were classified as ‘friendly fire incidents’ (CBC News Online, 2007).

Fratricide causes/insights

Fratricide has been regarded as a matter of misperception of a decision-maker regarding reality or ‘ground truth’ (Syms and Salt, 2004). Decision-making, within the context of a cognitive process situates the blame on the pilot for any outcomes resulting from his/her decision: a decision based on imperfect knowledge and uncertainty. Hence we are presented with the findings of pilot error as the root cause in the accident aetiology.

Loss of Situation Awareness (SA) has been cited by US sources, (FM-1-114, 2000: I-0, 1), as a primary cause of fratricide characterized by: Target identification errors; Navigation errors; Communications errors; and Weapon errors. The most common cause of fratricide, as reported by Ministry of Defence (2002:7) is a ‘...lack of Situational Awareness through poor identification and co-ordination of forces, and failures in communication together with inadequate procedures’. Loss of situation awareness appears to be an underlying theme across fratricide cases of which air-to-ground incidents are the most prevalent. Maintaining awareness of the flying environment is a primary task for any aviator. As described by Endsley (1999), SA describes a cognitive mental model comprised of 3 phases: Perception, Understanding and Projection (figure 2.5) and as such is contextual with spatial and temporal dimensions. The degradation of SA has been linked to attention management and perception challenges arising from a variety of variables that negatively impact judgment and decision-making.

An analysis of fratricide incidents conducted by Gadsden and Outteridge (2006:8-9) details 12 high-level causal categories of failure that characterizes fratricide (Table 4.4).

Table 4.4: Causal categories of failure regarding Fratricide

12 High Level Causal Categories
• Command and control
• Procedures
• Equipment/technology
• Situational awareness
• Misidentification
• Physical/physiological factors
• Pre-deployment preparation
• Team work
• Environmental factors
• Communications/information
• Platform configuration
• Cognitive factors

Of these the most prevalent categories of causes of fratricide, as identified by this particular analysis are: Communications/ Information, Command and Control, Procedures, Misidentification, and Cognitive Factors. Situational Awareness is highlighted as a major contributory factor as well. As discussed in chapter 2, complexity thinking recognizes the condition of multifinality and multiple causation. As noted in Gadsden and Outteridge (2006:7) ‘...incidents rarely (if ever) have single cause. There are often complex interrelationships between contributing factors, which can occur at different levels (strategic, operational, and tactical) and with different levels of impact’.

Combat Identification

Within the context of military aviation and fratricide, combat identification has been cited as a means by which military units distinguish friend from foe during operations. Ministry of Defence (2002:19) defines combat identification as ‘...System of systems which aim to provide commanders with rapid, secure, positive identification of platforms, equipment and people in or approaching the Joint operations area’.

As detailed in Dean and Handley (2006:9), Ministry of Defence (2002:1) describes Combat Identification (CID) in terms of three components:

1. Tactics, Techniques and Procedures (TTPs) – Technology has to be operated within an overall military process. TTPs define that process, and should be designed to supplement the characteristics of the personnel and technology deployed in the battle space.
2. Target Identification (TID) – The process that allows the immediate determination of a contact’s identity by friendly, discrete platforms or individuals. TID also refers to specific types of system, which can either be co-operative (exemplified by IFF transceiver systems) or non co-operative (exemplified by submarine passive sonar and Electronic Support Measure (ESM) systems).
3. Situational Awareness (SA) – The aim of SA is the provision of a timely, high fidelity, operating picture to enable commanders to understand their operational environment. SA concerns the understanding derived by an observer about their situation; Situational Information (SI) is used to represent

the information available to them through aids such as a tactical picture and other reference information derived from reports, databases etc.

The three components of CID are integrated and reflected within the four distinct CID processes: Detect, Classify, Recognize and Identify. Famewo et al. (2007b:8) defines them accordingly:

1. Detect. A vehicle, person or structure of possible military interest is noticed. The military observer takes action to search for further information.
2. Classify. The object is distinguished by class, such as wheeled or tracked vehicle, animal or human.
3. Recognize. The object is distinguished by category, such as tank or personnel carrier in the tracked vehicle class. If the object is human, elements of the person, such as lack or presence of equipment, head-gear, or posture are used to determine if the person is of military interest.
4. Identify. The object is distinguished by model (e.g., 4 door sedan if a vehicle) and the force allegiance (friend, foe, etc) is determined (but not confirmed). If the object is human, elements of the person, such as

clothing, equipment, posture and/or gender are used to determine if the person is armed or potentially combatant.

The impact of poor combat identification described in National Audit Office (NAO, 2006:2) include: friendly troops killed/wounded in action, neutral personnel killed or wounded, restrictive operating procedures, civilian casualties, strain on coalition operations, reduced force morale, enemies not engaged because wrongly identified as friends, temporary reduction in tempo of operations following friendly fire incident, loss of equipment and damage to civilian property and infrastructure.

The analysis conducted by Famewo et al. (2007a) reveals the inherent complexity of the CID process highlighting the factors affecting decision making from pre-incident to post incident. Famewo et al. (2007a:21) argues that the CID process:

...is not a simple stimulus-response task, but involves continuous decisions (implicit or explicit) that serve to build one's situation awareness and create expectations about the environment and people, assess the threat level of a contact, and also evaluate actions taken.

What underlies the CID process is the requirement to combine information. Famewo et al. (2007b:7) argues that '...not only must data-driven information (e.g., visual cues, sensors and communication) be aggregated, but it must also be combined with cognitively driven elements of information (e.g., expectations, beliefs, knowledge from previous experiences)'. Figure 4.1 captures the salient process and information

flow associated with combat identification as presented in Dean, Vincent, Mistry, Hynd and Syms (2005:22). It highlights the development of SA (influenced and constructed) with relevant knowledge and expectations from memory and retrieved information.

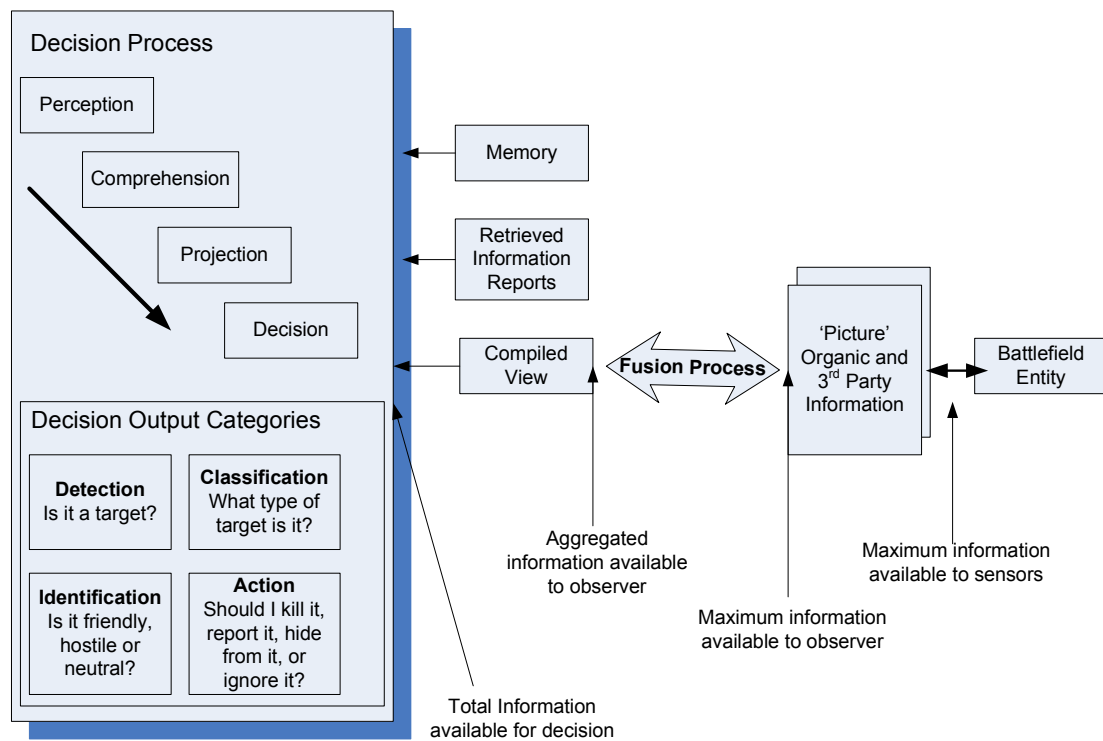


Figure 4.1- Information Flow during a CID (Dean et al., 2005:22)

The decision making process associated with CID is most closely aligned with Recognition Prime Decision making (Klein, 1997) characterized by situation assessment, pattern matching and mental simulation (figure 2.7). As described in Famewo et al. (2007b:17) 'It involves sizing up the situation, forming expectancies about what will happen next, determining which cues are most relevant, recognizing the goals reasonable to pursue and recognizing a reaction to apply in the situation so

that it can be implemented (Klein, 1997)’. It is apparent from the discussion and figure 4.1 that one of the underlying elements of the decision making process is the requirement for information aggregation which involves both the weighing and combining information that is relevant to the CID. This process becomes apparent in the case study description in chapter 5 examined through the lens of ANT.

4.3 CASE STUDIES

PRIMARY FRATRICIDE CASE STUDIES

Three case studies bound the primary examination of the problem space: Apache helicopter/ M113 fratricide (1991); F-15/Black hawk helicopter fratricide (1994); Tarnak farms F-16/ Canadian ground troops fratricide (2002).

CASE STUDY: Operation Desert Storm: Apache helicopter Fratricide incident: 17 Feb 1991

An excerpt from the GAO/OSI (93-4) report describes the fratricide incident.

‘On February 17, 1991, at approximately 1:00 a.m. (Persian Gulf Time), a US Bradley Fighting Vehicle (Bradley) and an M113 Armored Personnel Carrier (M113) were destroyed by two hellfire missiles fired from an Apache helicopter. Two US soldiers were killed and six others were wounded in the incident. The incident occurred after US ground forces, which were deployed along an east-west line 5 kilometers north of the Saudi-Iraqi border, reported several enemy sightings north of their positions. In response, a ground commander called for Apache reconnaissance of the area. A team of three Apaches subsequently found two vehicles, which appeared to be those described by ground forces. These vehicles were, in fact, a Bradley and an M113’.

The investigation into the Fratricide incident of 17 Feb 1991 involving Apache helicopters and Bradley Fighting Vehicle and M113 Armored Personnel carrier, revealed human error to be the primary cause. The Event Causal Factor analysis derived from the case study material reveals that the Apache Battalion Commander, who led the team of three Apaches, read the wrong grid coordinate on his navigation system while flying as copilot/gunner. As a result, he misidentified the target vehicles' location as being north of the line of friendly vehicles and in the exact location of one of the reported enemy sightings. Relying on this erroneous information, the Ground Commander authorized the Apaches to engage the targets.

It is relevant to this discussion to note that two friendly fire incidents preceded this accident. As briefly described in GAO/OSI-93-4 (1993:12), the February 1 incident exposed problems with the Apaches' AN/APR-39A (V) 1 Radar Warning Receivers, revealing how friendly emissions would be characterized as enemy signals. This is important since such information is integrated into the ROE as a source and trigger for a response. The February 15 incident highlighted the need for special control procedures to avoid fratricide in the desert's featureless terrain. In this particular incident, an Apache copilot/gunner visually misidentified a Bradley as an enemy vehicle and fired a Hellfire missile at it. The vehicle was not struck, apparently because the copilot/gunner had observed the target through the Target Acquisition and Designation System (TADS) but had mistakenly selected an alternate tracking choice, the Integrated Helmet and Display Sight System that used a sighting mechanism in his

helmet for the laser-guided missile to follow. As a result, the missile followed an inaccurate line of sight (GAO/OSI-93-4, 1993:17).

As described in the case study material, the precipitating event that led to the fratricide incident of 17 Feb 1991 stemmed from the sighting of movements of suspected enemy vehicles north of where the task force's line of advance had halted. Reported sightings by the gunners using thermal sights, positioned the targets in excess of 5 kilometers away. The resolution of these imagers resulted in only a blip of light and the systems could not distinguish shape outline. Using Ground Laser Locator Designator, targets were detected at 3 kilometers and appeared to be separating into smaller groups and hiding in the folds of the terrain. The track of suspected enemy movements was considered consistent with what the US forces expected (GAO/OSI-93-4, 1993:28). Believing that all TF-41 vehicles were positioned south of berm, the task force Commander requested assistance from the Apaches in relocating the targets. At 1142 16 February 1991, a launch order was received by 1-1 AVN from the Brigade Commander to destroy the targets. The 1-1 AVN Commander was concerned with the mission because of the adverse weather conditions which included winds in excess of 30 knots and blowing sand. In spite of the misgivings regarding the mission, the Brigade Commander ordered the 1-1 AVN Commander to launch the aircraft. The conditions were such that the Commander and his pilot had difficulty locating their aircraft in the blowing sand and lack of moonlight. One of the three Apaches almost crashed on takeoff because of the high winds.

Due to the short notice launch ordered by the Brigade Commander, the Apache crews launched with only a basic knowledge of the enemy vehicles' reported position and had to develop the mission plan based on those reports. Generally however, crews receive detailed permission briefings regarding their assignments which include such topics as intelligence summaries, weather, battle plan and status of radios.

The primary target grid position was manually entered into their respective Fire Control computers of the Apache helicopters. Approaching the operations area, the Apaches observed friendly vehicles facing north, deployed along an east-west line, which they identified as the screen line. Approaching the search area on a north east line vice north line perpendicular to the front, the Apaches received authorization from the task force commander that they could shoot anything north of 25 grid line. While conducting the screen, the Apaches reported two targets about 6000 meters off the nose, which he estimated to be on the 29 east-west grid. As noted in the report, 'apparently , none of those listening to the radio traffic realized the Apache's miscalculation, namely that if the Apaches were positioned on the 9123 grid lines at 068 degree compass heading, targets positioned 6000 meters directly in front of them would be approximately the 25 east-west grid- not the 29 east-west grid' (GAO/OSI-93-4, 1993:36).

Working with these targets, the Apache lead helicopter using the TADS, lased and stored the coordinates of the targets in the Fire Control Computer. Gunfighter 6 (firing unit) gun tape recorded the first three grid coordinates in the system. Gunfighter 6 observed the following readout:

0 38R NT 96592446 A+ MO4

138R NT 91602700 A+1024

2 38R NT 91302910 A+1101

Gunfighter 6 thought he was reading the grid coordinates for the vehicles he was seeing 6,000 meters away on the 070 heading, which were stored in position 0. Instead, he read the search coordinates given to him at the beginning of the mission, which he had manually input and stored in position 1. The ground commander, Iron Deuce six, confirmed that the coordinates were ‘exactly where we shot the last vehicle. Looks like we killed one of them. Those are the enemy. Go ahead and take them out’ (GAO/OSI-93-4, 1993:38). This comment was made under the assumption that the Apache was relaying the correct position.

The vehicles at that location were beside each other whereby the Apache remarked: ‘915270. Looks like one vehicle pulled up to another one there. They may be transloading people’. This was consistent with the scenario as understood.

Although correct position information was relayed by the other apache helicopter, it was not acknowledged by Gunfighter six. During the course of the event, the Apache misread the coordinates 3 times. Upon firing a Hellfire missile, the Apache reported that the first target was completely destroyed.

Following the incidents of 1 and 15 February, and the recognized problems encountered in the stark desert terrain, the need for special control procedures to avoid fratricide was discussed. This SOP required aircraft to fly on a heading of south to

north, perpendicular to the screen line, whenever approaching their targets. Following the incident, the Brigade Commander had the impression that the 1-1 AVN commander had failed to brief the soldiers under his command about this new procedure since it was not adhered to the evening of the fratricide.

As detailed in the report (GAO/OSI-93-4, 1993:48), the engagement priorities for the Apache helicopters were: (1) immediate threat to self, (2) immediate threat to team members, (3) immediate threat to ground forces, and (4) other targets in priority. The rules of engagement state:

Criteria for determining clearance to fire will be disseminated through the chain of command. In situations where air crews are uncertain as to the identification of the target, or doubt exists that the target is hostile, the following criteria will be used: a. if the target commits a hostile act, it will be immediately engaged. b. If the target cannot be visually identified as hostile, it will not be engaged until confirmed as hostile by at least one report from US or Allied Forces in relation to the target's position and orientation on the battlefield (GAO/OSI-93-4, 1993:48).

The Apache gun tapes clearly show that no hostile action had been taken by the target vehicles during the course of their CID. Although the AN/APR39A (V) I Radar Warning Receiver (Voice Warning) repeatedly warned of possible enemy presence, the immediate nature of the threat is arguable. Since the target could not be visually identified as hostile and was not committing hostile acts, the 1-1 AVN Commander's decision to confirm the target coordinate with ground commanders was consistent with

the SOPs. Unfortunately, however, ‘the 1-1 AVN Commander provided incorrect information to the ground commanders, who were dependent upon him for information regarding the target’s position’ (GAO/OSI-93-4, 1993:48).

The training conducted by 1-1 AVN prior to deployment concentrated on attack missions that involved clearly identified targets behind enemy lines. This fratricide incident involved a reconnaissance mission in close proximity to friendly forces. Supporting this was the commander’s insistence prior to the incident that the Apache was not designed for reconnaissance missions. He explained ‘...that the target-viewing screen used by the copilot/gunner is only 3.6 inches wide, limiting the copilot/gunner’s ability to distinguish between friendly and enemy vehicles’ (GAO/OSI-93-4, 1993:48). Coupled with this are the technical ‘misalignment’ of system threat warning systems. The AN/APR-39A (V) 1 Radar Warning Receiver (Voice Warning) had been installed on the Apaches a few weeks before the aircraft were deployed to the Persian Gulf. The new system used an electronic voice, instead of a tone, to warn crew members of enemy radar and gun tracking of their aircraft. Only after the Apaches were deployed on missions in the Persian Gulf War was it learned that the AN/APR-39A (V) 1 misinterpreted signals from U.S. Army Ground Surveillance Radars as enemy signals.

The incident can be summarized within the context of the CID process. The four distinct processes of CID (Detect, Classify, Recognize, and Identify) were compromised resulting from deficiencies in the CID components (TTPs, TID, SA) revealing a disconnect between ‘...data-driven information (e.g., visual cues, sensors

and communication) and cognitively driven elements of information (e.g., expectations, beliefs, knowledge from previous experiences)’ (Famewo et al., 2007b:7).

CASE STUDY: Operation Provide Comfort: Black Hawk fratricide incident: 14 April 1994

On April 14, 1994, two U.S. Army Black Hawk helicopters and their crews assigned to Operation Provide Comfort were transporting U.S., United Kingdom, French, and Turkish military officers; Kurdish representatives; and a U.S. political advisor in northern Iraq. Concurrently, a U.S. Air Force Airborne Warning and Control Systems (AWACS) aircraft was flying over Turkey to provide airborne threat warning and control for Operation Provide Comfort aircraft, including the Black Hawk helicopters. The pilots of two U.S. F-15 fighters patrolling the area misidentified the Black Hawks as Iraqi Hind helicopters and shot them down, killing all 26 individuals aboard (GAO/OSI-98-4:2). There were three key players in this incident: a US Air force E-3B AWACS, a 2 ship flight of US Army UH-60 Black Hawks helicopters and a 2 ship flight of US Air Force F-15 C Eagle fighters. The context of this incident is shaped by the fact that this fratricide was preceded by 50,000 hours of incident free flight operations executed during Operation Provide Comfort.

Daily flight operations were referred to as “mission packages”. The AWACS mission package involved the following: (1) control aircraft enroute to and from the tactical area of responsibility (TAOR), or no-fly zone; (2) coordinate air refueling; (3) provide airborne threat warning and control in the TAOR; and (4) provide surveillance,

detection, and identification of all unknown aircraft (figure 4.2). F-15 fighters, as the first aircraft in the TAOR, were to search—“sanitize”—the area with radar and electronic measures to ensure that it was clear of hostile aircraft and then fly orbit to provide air cover for the rest of the package. The Army’s Black Hawk helicopters flew supply and transport missions for the Military Coordination Center. They also provided transport into the TAOR to visit Kurdish villages and maintain a visual presence (GAO/OSI-98-4:3).

On 14 April, the AWACS took off from Incirlik Air Base Turkey. The mission was to provide ‘airborne threat warning and air control for all operation Provide Comfort aircraft’ (Snook, 2000:4). The specific AWACS crew was on its first mission in theatre, having arrived in country just three days before. Shortly after, two UH-60 Army Blackhawk helicopters took off from Diyarbakir, Turkey enroute to the Military Coordination Centre (MCC) headquarters in Zakhu. The Black Hawks reported their entry into the no fly zone to the AWACS enroute controller and landed 6 minutes later. There they picked up 16 members of the UN Coalition. Subsequently the Black Hawks reported to the AWACS enroute controller that they were departing Zakhu enroute to the towns of Irbil and Salah ad Din Iraq for meetings.

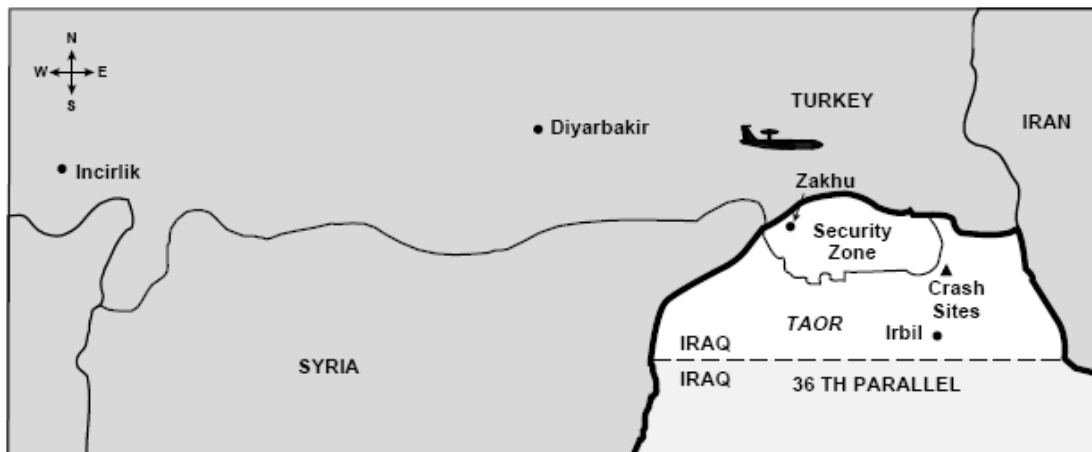


Figure 4.2- Operation Provide Comfort Operations area (GAO/OSI-98-4:15)

The AWACS surveillance officer labeled the flight on the radarscope track. When the helicopters landed at Zakhu, their radar and IFF returns on the AWACS radarscopes faded. The Black Hawk radioed the AWACS and gave their destinations on the enroute radio frequency. Although directives stated that all aircraft inside the Tactical Area of Responsibility (TAOR) should be on the area of responsibility (AOR) frequency, they did not switch frequency. Despite the contrary directive, helicopters typically stayed on enroute frequency, and no one on board the AWACS directed them to change. Because the helicopters remained on the enroute frequency, they were not able to hear subsequent transmission on the AOR frequency between the F-15 fighters and the AWACS. Additionally the Black Hawks did not reset their IFF mode I transmission on takeoff from Zakhu. Helicopters had a specified mode I for operations in Turkey but all coalition aircraft were supposed to change to a single, designated mode I while flying in the TAOR. The AWACS was supposed to check the mode IV of all aircraft as they entered Iraq, but many AWACS crewmembers did not believe that requirement applied to helicopters. As noted in the report (AAIB, 1994:5)

‘AWACS personnel did not routinely monitor the Black Hawk helicopter flights or pass information on those flights to other OPC aircraft. The result was that there was no effective coordination of OPC fixed-wing and helicopter operations within the TAOR’. This represents a lack of operational integration and cohesion within the command and control system of this operation.

Two F-15s were tasked that day to be the first aircraft in the No Fly Zone (NFZ) and to ‘sanitize’ it (check for hostile aircraft) before other coalition aircraft entered the area. Tiger 1 was lead, with Tiger 2 as his wingman. They received standard pre-mission briefings including the current situation at operation Provide Comfort, intelligence, weather and the day’s Air Tasking Order (ATO). The F-15s reached their final checkpoint before entering the NFZ approximately an hour after the helicopters had entered. According to their directives, when they performed this ‘sanitizing sweep’ they were supposed to be the first coalition aircraft into the TAOR (Eflein, 1998:48). They turned on all combat systems, switched the IFF Mode I code from 42 to 52, and switched to the NFZ radio frequency. They reported their entry into the NFZ to the AWACS. At this point within the AWACS command and control suite, the Black Hawks’ radar and IFF contacts faded as the helicopters entered mountainous terrain. The computer continued to move the helicopter tracks on the radar display at the last known speed and direction, but the identifying *H* symbol (for helicopter) on the track was no longer displayed. Two minutes after entering the NFZ, the lead F-15 picked up hits on its instruments indicating that it was getting radar returns from a low and slow-flying aircraft. The flight lead reported a radar contact of a low, slow moving

aircraft and subsequently gave the AWACS TAOR controller the coordinates of the contact. The TAOR controller unaware that the Black Hawks earlier transmissions on the enroute frequency, responded with 'clean there', meaning that he had nothing in his radarscope at those coordinates (Eflein, 1998:50-51). As noted by Eflein (1998:51), there exists evidence that indicates that he may actually have had IFF returns at that spot on his scope, and 'the appropriate response would have been 'paints there'. The proper call should have indicated to the F-15s that the AWACS was getting a friendly IFF return from the unknown aircraft' (Eflein, 1998:51).

The lead F-15 pilot alerted his wingman and then locked onto the contact and used the F-15's air-to-air interrogator to query the target's IFF code. In accordance with SOPs and ATOs, all coalition aircraft should have been squawking Mode I, code 52. The scope showed it was not. The lead F-15 pilot then switched the interrogation to a second IFF mode (Mode IV) that all coalition aircraft should be squawking. For the first second, it showed the right symbol but for the rest of the interrogation (4 to 5 seconds) it said the target was not squawking Mode IV. The lead F-15 pilot then made a second contact call over the main radio, repeating the location, altitude, and heading of his target. The wing F-15 pilot replied that his equipment showed the target. This time the AWACS enroute controller responded that he had radar returns on this scope at the spot but did not indicate that this might be a friendly aircraft. This is significant since we begin to see the emergence of expectations within the CID process (whereby all aircraft should be squawking the appropriate IFF code).

After making a second check of Modes I and IV and again receiving no response, the F-15 executed a visual identification pass to confirm that the target was hostile. He saw what he thought was an Iraqi helicopter. He pulled out his aide memorie with aircraft pictures in it, checked the silhouettes, and identified the helicopters as Hinds, a type of Russian helicopter flown by the Iraqis. The F-15 wing pilot also reported seeing two helicopters, but never confirmed that he had identified them as Iraqi aircraft. According to the wingman testimony, ‘...Lead initially called them ‘Hinds, no Hip, confirm Hind.’ I was looking down. I did not go as low as he did on that initial pass. I was looking at shadows. It appeared to be a Hind to me. As I pulled off he confirmed they were Hinds’ (Younger, 1999:88). The F-15 visually misidentified the lead Black Hawk as an Iraqi Hind helicopter. Although he requested confirmation he was positive that he saw Iraqi Hinds. This identification was based on their location within the TAOR, lack of electronic response despite repeated queries, their camouflage paint scheme, and their silhouettes. The wingman believed that they were Iraqi Hinds; he saw nothing to make him doubt the flight lead’s visual identification. He reported tally two, to indicate that he had seen two helicopters, at about the same time, the AWACS TAOR controller radioed ‘copy Hinds’ to indicate that he had heard flight leads transmission. The flight lead took the wingman’s response as confirmation, not only of the number, but also of the type of helicopters. The F-15 lead pilot called the AWACS and said they were preparing to engage enemy aircraft, cleared his wingman to shoot, and armed his missiles. He then did one final Mode I check, received a negative response, and pressed the button that released the missiles. The wingman fired at the other helicopter and both were destroyed.

The ROE governing Operation Provide Comfort were promulgated in OPLAN 91-7. For the 3 years subsequent to the issue of OPLAN 91-7, the mission continued to evolve as the political situation continued to change. Unfortunately, neither the ROE nor the OPLAN were updated again until after-and because of the fratricide of 14 April 1994. ROE guidance for the TAOR were as follows (Eflein, 1998:61-62):

- a. Any unidentified airborne object in or approaching airspace within a US air defense area of responsibility will be identified by any means available, including visual recognition, flight plan correlation, electronic interrogation, and track analysis.
- b. When feasible, airborne objects in or approaching the airspace within a US area of responsibility that have not been satisfactorily identified by communications, electronics or any other means will be intercepted for visual identification purposes'.

Any aircraft identified as Iraqi military found north of the 36th parallel could be destroyed. It clearly demonstrated that the ROE were status based; in other words, Iraqi aircraft whether rotary or fixed wing, could be destroyed based on hostile identification alone (Eflein, 1998:62).

The wingman testified that under the ROE, four indicators could be used for unidentified aircraft to 'come up friendly'; three methods were electronic identification, AWACS confirmation, and visual identification (Eflein, 1998:64).

Status based ROE in a joint and combined operation are inherently dangerous given the limitations and difficulties with regards to interoperability and communication (Eflein, 1998:65). 'The ATO contained the order of flying activity within the TAOR, detailing radio frequencies and IFF data for each aircraft. The fighter squadrons used the ATO as the definitive guide for the activity within the TAOR. The army helicopters were not adequately reflected on the ATO' (Eflein, 1998:55). The flow sheets were derived from the ATO. Since the ATO was incomplete with respect to helicopters, so too was the flow sheet. Thus the F-15 pilots could not interrogate the Black Hawk mode II despite the ATO stating that mode II and IV were to be the primary means of identification (Eflein, 1998:56). Testimony established that army helicopters customarily did not change their mode I squawk while inside the TAOR. Eflein (1998:57) reports that the noncompliance of the helicopters with regards to the IFF settings was not a one-time occurrence, but a custom.

The Airspace Control Order (ACO) the ROE and the special instructions, are required reading for all aircrew members. The ACO was dated 12 Dec 1993 and was largely based on OPLAN 91-7. It was therefore outdated (Eflein, 1998:57). The ACO was not written to include army Black Hawks. Although the ACO specified a common TAOR radio frequency, the command never ensured that the army followed the directive (Eflein, 1998:59). The Aircraft Accident Investigation Board Report Volume 1 (AAIB, 1994:4) stated that there existed '...a breakdown of clear guidance from the Combined Task Force to its component organizations' additionally '...personnel did not receive consistent, comprehensive training to ensure they had a thorough

understanding of the USEUCOM-directed ROE. As a result, some aircrews' understanding of how the approved ROE should be applied became over-simplified'.

Following the incident, the fighter pilots engaged in self-blame: 'We misidentified the helicopters; we engaged them; and we destroyed them. It was a tragic and fatal mistake' (Flach, Dekker and Stappers, 2008:132). The pilots viewed their decision making process in terms of linear series of errors without acknowledging or recognizing the ambiguity, risk, uncertainty and pressure of the situation.

The accident aetiology was characterized, in the opinion of the Investigation Board President, as 'a chain of events' beginning with the Combined Task force's failure to provide clear guidance to its component organizations, the components' misunderstanding of their responsibilities, Operation Provide Comfort's failure to integrate Army helicopter and Air Force operations, AWACS crew mistakes, and ending with the F-15 lead pilots misidentification of the helicopters and the wingman's failure to notify the lead pilot helicopters (GAO/T-OSI-98-13). The case study highlights disconnects between ROE, procedures and information derived from systems thereby revealing a lack of cohesion and alignment within the system of system construct. As shown in the first case study as well, expectations shaped perception, decision making and action.

CASE STUDY: Tarnak farms 17 April 2002

In the evening of 17/18 April 2002, a section from “A” Company, 3rd Battalion, Princess Patricia’s Canadian Light Infantry BG (3 PPCLI BG) were conducting a live-fire exercise in the vicinity of Kandahar, Afghanistan, when they were mistakenly engaged by two American F-16 fighter aircraft.

As described in the Tarnak Report (2002), on 17 April 2002, Coffee 51 Flight took off from an undisclosed location, tasked to conduct an on-call interdiction mission in the northeastern section of Afghanistan. In this role, Coffee 51 Flight was to transit to the assigned area, loiter for an undisclosed amount of time, and then return to its home base. SOPs mandate that aircraft switch from tactical Strike frequency to Tanker Control to facilitate air-to-air refueling. This is significant because it marks a transition from the combat phase to the transit phase of the mission, both physically in terms of communications used, and psychologically in terms of the pilots’ expectation of the nature of activity they would be facing. At around 21:21Z, based on the testimony, Coffee 51 Flight made an unrecorded radio call stating that they had observed some form of ground fire. The aircraft commander of the AWACS, listening on the same frequency, stated in his personal written account that Coffee 51 Flight had reported that they saw tracer fire, and that they asked if they should turn back and mark the position. As confirmed by the testimony of the AWACS Mission Crew Commander’s (MCC) in charge of the mission aboard, the marking of the position was acknowledged and duly authorized. During that same time period, Coffee 51 also reported that they had ordnance available to drop. By 21:22:38Z, the time at which

the recording equipment was turned on in both F-16's, the two aircraft had already turned toward the north and evasively split themselves.

The origin of the 'ground fire' was from the Tarnak Farm Multi-Purpose Range Complex attracted their attention. This site, formerly one of the main Al-Qaeda training installations, had been partially converted into a multi-purpose firing range. In this regard, it was used regularly by local coalition forces to conduct training day and night. As part of the planned night exercise, "A" Company personnel were conducting a variety of firing drills, encompassing a range of weapons from personal side arms up to and including shoulder-fired anti-tank munitions. Though visible from the air, the armament being employed was of no threat to the aircraft at their transit altitude. Nevertheless, one of the F-16s invoked the right of self-defence and released a Mark 82 500-lb Guided Bomb Unit (GBU-12) Laser-Guided Bomb (LGB) on the soldiers' firing position. The resulting blast killed four soldiers and injured eight others, one very seriously. Following their attack, the aircraft recovered at their home base without further incident.

From an air operations point of view, however, the F-16 pilots involved were not aware of the Tarnak Farm Op Area, or the planned live-fire exercise. Lacking this critical information, it is apparent that the F-16 pilots mistakenly interpreted the live fire as a threat to their formation, and engaged upon a decision-making process that led to the declaration of self-defence and the release of a weapon on friendly troops. Accordingly, it is the overall conclusion of the Board that the proximate fault for the

outcome of the attack lies with the two F-16 pilots of Coffee 51 Flight. Furthermore, there are a number of secondary deficiencies that, if corrected, may have prevented the accident. These are largely but not limited to systemic shortcomings in air coordination and control procedures, as well as mission planning practices by the tactical flying units. The effects of these shortcomings are compounded by expectancy on the part of both ground and air authorities that all Airspace Control Measures would be understood and applied.

The board concluded that the fratricide was due to the failure of the pilot to exercise appropriate flight discipline. A key factor in reaching this conclusion was analyzing the pilot's actions in relations to the special instructions (SPINS) and the linking of the ROE to their actions. Whereas the pilots' claim that they took appropriate actions in self-defense in accordance with the standing rules of engagement (SROE); the CIB concluded noncompliance with OEF ROE by determining the pilots failed to leave the immediate threat area as mandated by the OEF SPINS. As described in Jeter (2004: 382) during military operations involving air assets the JFACC has the authority through SPINS to further restrict ROE as promulgated by the JFC. SPINS are a primary measure by which the JFACC controls air operations through campaign strategy, operational constraints and tactical procedures. SPINS have several sections which provide in detail how ROE will be applied in mission execution. They therefore are just as binding on the pilots as ROE issued by operations orders (OPORD) from the combatant commander; and for a pilot to use force appropriately, he must comply with the SPINS and ROE (Jeter, 2004:382).

Understanding the interrelations of the ROE to the actual fratricide event requires an understanding of how the ROE are 'inscribed' into the operations. As detailed in Jeter (2004: 406) the OEF ROE state that: 'Aircraft always have the right of self-defense against AAA.' The OEF ROE also state that: '...aircraft should NOT deliberately descend into the AAA range to engage and destroy AAA units which fire well below their altitude'. The OEF ROE details were provided in OEF SPINS. The OEF SPINS provide some insight and clarity representing specific mission planning information such as minimum altitude levels and potential AAA locations thereby detailing limitations within the operations. The OEF SPINS were comprised of various articles detailing how ROE was to be applied. Special Instructions (SPINS) - Commanders Guidance: This section details CFACC's guidance to all aircrew participating in OEF. Such guidance addresses operational objectives, commander's intent and mission tasks and priorities. Special Instructions (SPINS) - Section 3 Communication Article 8.6.2: This article explains the Surface-to-air Fire (SAFIRE) reporting requirements... Special Instructions (SPINS)- Section 4 Airspace Article 4.3: Defines and provides the details on where information on[undisclosed] will be published....Special Instructions (SPINS) - Section 5 ROE Article 5.2.2: This article describes the concept of self defen[s]e and how it will be applied in theatre... Special Instructions (SPINS) - Section 5 ROE Article 9: This article provides the details on how ROE will be applied for defen[s]e against SAM's and AAA threats... Special Instructions (SPINS) - Section 5 ROE Article 10: This article provides the details on how ROE will be applied in the case of Air to Ground Attacks. It includes details on

the right to Self Defen[s]e... Special Instructions (SPINS) - Section 6 Operations Article 2.6 (Jeter, 2004:406). It is important to emphasize that the OEF SPINS stated clearly that it was critical for coalition air forces to do everything they can to minimize the potential for self-defense situations.

These SPINS represent current binding limitations on the operational aircrews and reflect the modifications to the SROE. As described in Jeter (2004:406) of note are the limitation set by the CFACC and promulgated in the SPINS that aircraft were directed to fly no lower than [undisclosed] feet [above ground level] AGL for normal flying operations and no lower [undisclosed] feet for situations in which they planned to employ ordnance. Of note was that COFFEE 52 set his altitude warning for [undisclosed]. As he approached the perceived SAFIRE location, he descended below [undisclosed] feet [mean sea level] MSL and the altitude warning sounded. Jeter (2004:406) reports that 'OEF ROE directed that aircraft should not descend into the lethal range of a AAA system firing well below them in order to attack in self-defense'. Testimony from Coffee 51 and 52 state that they believed that the ground fire was burning out around 10,000 feet AGL, well below their initial transit altitude. What is significant is that there existed a disconnect between the OEF SPINS and the actions of the pilots. The authority to use force in self-defense in accordance with the SROE is limited to lawful orders of superiors, rules within the SROE and other ROE that were promulgated for the mission (CJCSI-3121.01A, 2000). As described in Jeter (2004:407) this would include the SPINS which are considered a lawful order by the CFACC which proscribed in detail how to handle AAA. 'When the pilot perceived the

AAA threat and descended toward the site, placing himself in harms way along with transitioning below the restricted altitude, he violated the SPINS. By violating the SPINS to mark the SAFIRE he lost his ability to justify his use of force in self-defense under the OEF ROE' (Jeter, 2004:407).

The board identified a chain of events and circumstances that precipitated the accident. As reported in the Coalition Investigation Board (2002) the 17 April 2002 Tarnak Farms Range incident was a direct and proximate result of actions taken by the two F-16 pilots involved. Based on the evidence presented, given the pilots expectations when he encountered what he believed to be SAFIRE, he misperceived the caliber, trajectory, and distance traveled of the munitions. Although ground fire reports indicate that minimal munitions were fired, all parallel to the ground, he reported that he perceived elevated fire that he characterized as burning out at 10,000 feet with projectiles that were likely to continue to travel once the initial visual incendiary material dissipated. The misperception was likely exacerbated by the environmental conditions. Although pilots are trained in NVG limitations, their use can contribute to potential misperceptions.

The investigation revealed that the behavior of the F-16 pilot in flight suggests a perceptual set or mind set regarding the threat associated with surface-to-air fire. It was stated during the course of the investigation that 'when perceptual sets are established, individuals tend to scan the environment for confirmatory cues. Information that would negate what is already believed generally receives minimal to

no allocation of attention. Only information that is overwhelmingly contradictory may be sufficient to lead an individual to question current beliefs or hypotheses or to change their overall cognitive assessment of a situation' (CIB, 2002:52).

It was concluded that the lack of situational awareness exhibited by the F-16 pilot follows from poor planning and preparation combined with problems associated with attention, misperception, and fatigue. The pilot channelized attention and missed important information that could have redirected his course of action. The misperceptions held by the pilot were exacerbated by his discipline failure in managing his crew duty day. Added to this were the known challenges of the night-flying environment and limitations associated with NVGs. The Coalition Investigation Board found by clear and convincing evidence that the cause of the friendly fire incident on 17 April 2002 was the failure of [Major Harry Schmidt], the 170th Expeditionary Fighter Squadron Weapons Officer and the incident flight wingman, to exercise appropriate flight discipline. This resulted in a violation of the rules of engagement and the inappropriate use of lethal force. Under the circumstances, Major [Harry Schmidt] acted with reckless disregard for, the foreseeable consequences of his actions, thereby endangering friendly forces in the Kandahar area (Jeter, 2004:379).

Of particular note in these primary case studies are the issues pertaining to expectations and trust that permeated not only the human to human relations but also the human to physical and informational elements and how they had an impact on the evolution of the accident aetiology in terms of sensemaking, decision making and action. Within the CID process the accident can be seen to be an entanglement of these

issues whereby the relations between them become the focus of the study. In that sense, ANT provides the appropriate perspective and methodology to understand fratricide and the attribution of human/ pilot error. Although the case studies differ in time, location and specific circumstances, what emerges as a common thread that guided action are the ROE and their relational ‘shaping’ of the socio-technical system through processes of inscription and translation. It is these issues that precipitated the requirement to conduct simulation studies within a synthetic environment to better understand and explore the nature of SA and the actor network processes of inscription and translation. This will be discussed in detail in chapter 5

SECONDARY CASE STUDIES

The secondary case studies are introduced as supporting material to provide further insight into the problem space associated with fratricide. These case studies are comprised of B-52 JDAM Incident (2001); US Patriot Missile/ UK Tornado (2003); and US Air Force A-10/ UK soldiers (2003).

CASE STUDY: B-52 JDAM Incident 05 December 2001

On 5 Dec. 2001, a U.S. Air Force B-52 dropped a GPS guided Joint Direct Attack Munitions (JDAM) on a friendly position near Sayd Alim Kalay, Afghanistan, killing three U.S. Service members and five Afghan soldiers, as well as injuring numerous US and Afghan soldiers. Central to this fratricide incident was the use of a hand-held GPS receiver. Investigators of the incident determined that the ground forward air controller was using a hand-held GPS receiver to send enemy coordinates to the B-52 so that the aircrew could then program their payloads, (JDAM bomb), to hit the

precise coordinates given to them by the ground controller. In this case, the procedures were correct except that the coordinates given to the B-52 were not the enemy's position, but rather the friendly position of the U.S. and Afghan fighters (Musselman, 2008). The investigation also discovered that the GPS receiver's batteries had been replaced just prior to the passing of the coordinates. What is of significance to this sequence of events is that when the batteries on this specific GPS receiver are replaced, the GPS, upon powering up, displays its current location. The ground controller had mistakenly thought that the GPS receiver would display the last known coordinates prior to being shut down for battery placement, which was the coordinates of the enemy position. In addition to the replacement of the batteries, another item of doctrinal interest occurred that contributed to this mishap: the sending of friendly coordinates in the improper format. In accordance with JCAS doctrine, an enemy position is sent as a 10-digit coordinate and a friendly position is sent as a 6-digit coordinate. Sending the enemy position as a 10-digit coordinate improves the accuracy of the weapon system. Conversely, the coordinates of a friendly position is passed as a 6-digit coordinate to decrease the accuracy of any enemy weapon system that might be employed against them if the enemy has signal interception capability. In this incident, both friendly and enemy coordinates were passed utilizing the 10-digit format. This highlights that an additional doctrinal misapplication occurred in concert with the wrong coordinates being transmitted to the B-52.

The accident highlights the inherent danger of armed conflict and the potential for fratricide on the battlefield and in particular the conduct of close air support and

training. What is important to recognize is that the controller in this incident had completed the requisite training prescribed by the USAF for the conduct of close air support but the training did not include the use of a GPS receiver and the intricacies surrounding its use. What is important to note is that none of the services has a curriculum requirement to train their ground controllers in the use of a GPS receiver, even though the GPS is integrated as part of their normal operating procedures. Most, if not all, of this type of training is accomplished in the context of on-the-job training (OJT).

One unique ability of the GPS receiver is that it can take information derived from a laser designator or range finder, process that information and compute a location based on slant range from the laser source. In this fashion, the location of an enemy position can be determined to within just a few meters. The benefits of this technology is evident given that traditional methods involving the use of map estimation is limited in accuracy to hundreds of meters. As described in Binney (2003:25-290) the question arises then why is the GPS not the preferred method of instruction at the service schools? Had the training of this Air Force ground controller included the use of a GPS receiver, he may not have made this type of mistake on the battlefield.

What this particular case brings to light is the reliance on technology given its inscribed accuracy and reliability. The apparent lack of doctrinal and HCI training suggests how the simplicity of use associated with standard GPS systems has made it second nature to the operator, almost an appendage of the human. The over reliance on

this technology is well articulated and explored in Johnson, Shea and Holloway (2008:1) who note that ‘...National Oceanic & Atmospheric Administration (NOAA) released a warning in 2002 about some of the systemic effects of GPS on navigation behaviour. In particular, they observed that some mariners were more willing to follow higher risk routes closer to known hazards because they felt confident in the use of GPS technology to accurately identify the position of those hazards’. Emerging from this case study are issues pertaining to expectation of accuracy and reliability trust, technology and the system.

CASE STUDY: US Patriot Missile 22 March 2003

Royal Air Force Tornado GR4A ZG710 was returning to Ali Al Salem Air Base in Kuwait on 22 Mar 03 when it was destroyed by a US Army Patriot Surface-to-Air-Missile after being mistakenly identified as an Iraqi Anti-Radiation Missile. The aircraft was the second of a pair of Tornados, flying as part of a package of Coalition aircraft, operating during the early part of the war in Iraq. Both members of the crew were killed instantly when the missile hit their aircraft.

The Tornado had been operating as part of the RAF Combat Air Wing based at Ali Al Salem in Kuwait. All flight preparations including briefings, start up, take off and the operational phase of the sortie were all completed as planned. As part of the preflight checks, the Identification Friend or Foe (IFF) system was checked by the ground crew and confirmed to be working correctly. The Tornado was returning to Kuwait airspace

after their mission over Iraq and had just begun a descent towards Ali Al Salem. At an altitude of 17938 ft during its transit back it was struck by the Patriot missile.

During this time the Patriot Battery crew were monitoring for Iraqi Tactical Ballistic Missiles when the Tornado was tracked by their system. The Patriot system indicated that an Anti-Radiation Missile was coming directly towards them. The track (Tornado) was interrogated for IFF but there was no response. Having met all classification criteria, the Patriot crew launched the missile, and the Tornado, mistaken for an “Anti-Radiation Missile”, was engaged in self-defence. The Patriot crew had complied with extant self defence Rules of Engagement for dealing with Anti-Radiation Missiles (MOD: 2004:2)

It is clear that the immediate cause of the accident was that a Patriot missile destroyed the Tornado. The Board concluded that the following were contributory factors:

Patriot Anti-Radiation Missile classification criteria; Patriot Anti-Radiation Missile Rules Of Engagement; Patriot firing doctrine and crew training; Autonomous Patriot battery operation; Patriot IFF procedures; ZG710’s IFF serviceability; aircraft routing and airspace control measures, and Orders and Instructions. A variety of other factors were considered and discounted once the evidence had been analysed.

The development and fielding of the Patriot air defense missile system in the early 1980s represented a significant improvement in operational capability that allowed the US to wage a computer-aided air battle by incorporating decision-making logic into

the weapon system itself—as opposed to a separate C2 system. This capability through its decentralized engagement logic, permitted operators to handle a larger number of threats and speeds engagement by automating portions of the decision-making process. The systems received accolades resulting from its operational success demonstrated countering the Iraqi tactical ballistic missile (TBM) threat during Operation Desert Storm and most recently during Operation Iraqi Freedom (OIF). In both Gulf wars, TBMs were successfully engaged by Patriot employed in a fully automatic, operator-monitored mode however these successes were mired by an unacceptable number of fratricidal engagements attributable to track misclassification problems, particularly during OIF (Hawley, Mares and Giamannco, 2005:2).

The CID process inherent within the Patriot system identifies hostile missiles through their flight profile and other characteristics, including the lack of an IFF response. The criteria programmed into the Patriot computer were based on the many different Anti-Radiation Missiles available worldwide, and were therefore very broad. In this particular incident the flight profile of the Tornado met these criteria as it commenced its descent into Ali Al Salem. The results of the investigation noted that the criteria used to identify hostile missiles should have been better managed, based on the known threat from Iraq, and concluded that the generic Anti- Radiation Missile classification criteria programmed into the Patriot computer were a contributory factor in the accident. The Board concluded that the ROE associated with Patriot System was not robust enough to prevent a friendly aircraft being classified as an Anti-Radiation Missile and then engaged in self-defence.

As described in Hawley et al. (2005), Patriot crews are trained to react quickly, engage early and to trust the Patriot system. In hindsight had the crew delayed firing, the Tornado would probably have been reclassified as its flight path changed. The crew had about one minute to decide whether to engage. The crew was fully trained, but their training had focused on recognising generic threats rather than on those that were specific to Iraq or on identifying false alarms. The Board concluded that both Patriot firing doctrine and training were contributory factors in the accident.

The Patriot crew was operating autonomously, with a primary role of protecting ground troops from missile attack, but the Rules of Engagement allowed the Battery to fire in self-defence. A critical component of its capability lies with its communications suite which was apparently still in transit from the US, therefore contact with the Battalion HQ and other units was through a radio relay with a nearby Battery, which was equipped with voice and data links to and from the Battalion HQ. The lack of communications equipment meant that the Patriot crew did not have access to the widest possible “picture” of the airspace around them to build situational awareness. The Board considered it likely that a better understanding of the wider operational picture would have helped the Patriot crew, who would then have been more likely to identify the Tornado as a friendly track, albeit one without a working IFF. The Board concluded that the autonomous operation of the Patriot battery was a contributory factor.

As described in Hawley et al. (2005), IFF is a system designed to identify automatically whether or not a particular asset, such as an aircraft, is a “friend or foe”; civilian Air Traffic Control also use it to identify and track aircraft. The system works as a challenge and reply whereby a signal is sent from the ground or air to the aircraft, which then replies with the appropriate code thereby providing identification. There are five different modes of IFF, which can work in parallel or alone. These include Mode I (an unencrypted code, which was used in Iraq by all the Coalition aircraft) and Mode IV (an encrypted form of IFF). Investigation showed that the Patriot Battery’s IFF interrogator for Mode IV was working throughout the engagement period, but that Mode I codes were not loaded. The Board believed that autonomous operations without voice and data connections to and from Battalion HQ might have contributed to the difficulty the Battery had in receiving the Mode I IFF codes. The Board concluded that the lack of IFF Mode I codes increased the probability of the accident, and was therefore a contributory factor.

The Board considered IFF serviceability, potential IFF failures, and aircrew actions relating to the IFF. Following initial investigation, it became apparent that certain power failures associated with the IFF may not be displayed to the crew. The most likely explanation for the absence of an IFF response was that there had been a power supply failure. The Board recommended that further work be conducted to research the failure modes, reliability and serviceability of the Tornado IFF system.

As described in Hawley, Mares and Giamannco (2005:25) ‘...the Boards of Inquiry examining the root causes of Patriot fratricide incidents during Operation Iraqi Freedom concluded that the training provided to van crews was a contributing factor’. The training practices of the air defence community were criticized for their emphasis rote drills rather than high-level judgment. ‘What this means is that much pre-OIF Patriot training was reduced to a stimulus-response exercise with little intervening thought or judgment: If you see X...Then do Y. A rote, crew-drill approach to training might be appropriate for many aspects of air defense operations (e.g., march order, emplacement, system set-up, etc.), but it is not suitable for air battle operations or management. These require a focus on adaptive decision making within a complex and dynamic tactical setting (Hawley et al., 2005:25).

The Patriot System Performance Report (2005:2) noted that the combat identification capability embodied in the Mode IV IFF system performed very poorly which has not only been demonstrated operationally but also during many training exercises. Of particular note arising from the investigation was why this deficiency was never resolved. Given the number of coalition aircraft flights in OIF (41,000) and the large number of Patriot deployment (60) and the issues regarding the IFF deficiencies the possible Patriot-friendly aircraft observations were in the millions (Patriot System Performance Report, 2005:2).

A second shortfall, according to the Patriot System Performance Report (2005:2) ‘...was the lack of significant situational awareness in the combined air defense

system, which involved major systems such as Patriot, AWACS, and AEGIS. It is assumed that data are routinely communicated from one system to the other, that targets are correlated, and target information is shared and assimilated by all'. The assumption is a long way from reality. In fact '...the communication links, the ability to correlate target tracks by disparate sensors, and the overall information architecture are simply not there' (Patriot System Performance Report, 2005:2).

The third shortfall was the Patriot system operating philosophy, protocols, displays, and software, which seemed to be a poor match to the conditions of OIF. The operating protocol was largely automatic, and the operators were trained to trust the system's software; a design that would be needed for heavy missile attacks. The 30 days of OIF involved nine engagements of tactical ballistic missiles which were immersed in an environment of some 41,000 coalition aircraft sorties; a 4,000-to-1 friendly-to-enemy ratio (Patriot System Performance Report:2005:2). It is important to note that the Patriot crew had complied with the appropriate Rules of Engagement.

The RAF Board of Inquiry was carried out in parallel with a US investigation. The Board of Inquiry report concluded that the contributory factors were complex, many and various, and has made a series of recommendations which are currently being implemented (NAO, 2006). Major General Vane (president of the board of inquiry) was convinced that human performance issues were part of the problem associated with the fratricide incident. As noted in the Hawley and Mares (2007:1) 'he was particularly concerned by what he termed a "lack of vigilance" on the part of the

Patriot operators along with an apparent “lack of cognizance” of what was being presented to them on situation displays with a resulting “absolute trust in automation’.

This case study brings to the forefront how technology is not an external part of the human system but is actually integrated into the SA and decision making process.

Issues of trust and expectations thread through this case from ROE through the software and hardware and training and doctrine. It reflects the entangled complexity of the accident aetiology associated socio-technical systems.

CASE STUDY: US Air Force A10 28 March 2003

During Operation TELIC, Close Air Support was provided to the United Kingdom’s 16 Air Assault Brigade by a US Reserve unit, 3rd Anglico. On 28 March 2003 a recce patrol of the Brigade was advancing North East from the Ramaylah Oilfields. A flight of two US A10 aircraft from the 3rd Anglico had been tasked with missions against Iraqi forces in the area. One of the A10s attacked the two lead combat vehicles in the United Kingdom patrol, believing them to be Iraqi rockets. The attack resulted in the death of a Lance Corporal and serious injuries to four crew members of the Combat Vehicles, and damage to a Spartan light armoured vehicle nearby.

Following the 1991 Gulf War and in response to the Iraqi use of military force to repress ethnic and religious minorities, no fly zones were established in northern and southern Iraq. The flight operations in support of ensuring these no fly zones were code named Operation Northern Watch and Operation Southern Watch. These missions were persistent until 19 March 2003 when the US and coalition partners

launched Operation Iraqi Freedom with the designated mission to ‘locate and destroy Iraqi weapons of mass destruction and liberate the Iraqi people from Saddam Hussein’s regime’ (FFIB Report-ad_dayr12_24, 2003:4).

To facilitate operational employment of air assets during deployed operations, the US Air Force creates temporary or provisional units called expeditionary wings, groups and squadrons. Forces are then temporarily assigned to these expeditionary units for a normal period of 90 days. Supporting the operations the 190th Fighter Squadron (190 FS), 124th Fighter Wing (124 FW), Idaho Air National Guard were deployed in support of the 190 Expeditionary FS. Ground Operations were conducted by the 16th Air Assault Brigade (16 AA Bde) composed of a UK Army brigade task force and various units from the UK Army and USMC.

Understanding the decision making in this incident requires an understanding of the threat environment, which was assessed as significant to coalition aircraft operating in the area of responsibility. It was assessed that ‘Iraqi forces possessed extensive stores of surface-to-air threat systems...in addition to small arms carried by Iraqi ground troops, ...radar SAM systems, infra-red SAM systems, optical AAA, and radar aimed AAA’ (FFIB Report-ad_dayr12_24, 2003:4).

Command and Control was conducted through a Coalition Air Operations under the responsibility of the Coalition Force Air Component Commander (CFACC) and executed through the Coalition Air Operations Center (CAOC). As detailed in the

FFIB Report, the CAOC was responsible for planning and tasking of air operations over Iraq and perform near real-time monitoring of all air missions flown in support of OIF. The tasks associated with the coordination of air operations included: development of air strategy and plans, task and execution of day-to-day air operations, dissemination of all-source intelligence, issues pertaining to airspace control procedures, and continually assessing overall mission effectiveness of air operations. The CFACC distributes guidance, objectives and unit taskings primarily through the Roles of Engagement (ROE), Air Tasking order (ATO), Special Instructions (SPINS), and Airspace Control Order (ACO), all of which are produced by the CAOC staff (FFIB Report-ad_dayr12_24, 2003:7).

In support of OIF Close Air Support (CAS) Concept of Operations (CONOPS) were derived from guidance contained in: 1) Joint Publications 3-09.3, Joint Tactics, Techniques and Procedures for Close Air Support (CAS), Final Coordination 28 August 2002; 2) USCENTCOM Concept of Operations for Joint Fires, 10 November 1999; and 3) USCENAF CAS CAO SOP, 12 July 2001. Derived from these sources, three different CAS control are available:

Type 1 Control requires the Joint Terminal Attack Controller to visually acquire the attacking aircraft and the target under attack.

Type 2 Control occurs when either visual acquisition of the attacking aircraft of the target at weapons release is not possible.

Type 3 Control is used when the tactical risk assessment indicates that CAS attacks impose low risk of fratricide. ...grant a “blanket” weapons release

clearance to an aircraft or flight attacking a target' (FFIB Report-ad_dayr12_24, 2003:8).

It was noted in the reports that Type 3 Control, '...prior to the incident the coordination and success of CAS within 16 AA Bde had been very effective' (FFIB Report-ad_dayr12_24, 2003:9).

The incident took place late afternoon 28 March 2003. During this time a reconnaissance patrol of United Kingdom (UK) Combat Vehicle Reconnaissance (Tracked) (CVR(T)) Scimitar light tanks and CVR (T) Spartan armored engineer vehicles assigned to the 16th Air Assault Brigade (16 AA Bde) were proceeding north in Iraq toward a small village about 30 miles northwest of Basrah' (FFIB Report-ad_dayr1_11, 2003:2). In support of the operations a flight of two A-10 aircraft (call signs POPOFF 35 and 36) were engaging Iraqi military vehicles in the same area. The aircraft were operating under Type 3 CAS through the Ground Forward Air Controller (GFAC), call sign MANILA HOTEL. The Iraqis were employing a "shoot and scoot" mode of operation thereby contributing to a dynamic and complex operating environment. During the sortie involving the 2 A-10s, POPOFF 35, the flight lead, was both directing the air support attack operations as well as assisting friendly artillery fire accuracy. It was during this time that POPOFF 36 visually acquired the UK reconnaissance patrol ('...which he believed to be a convoy of enemy vehicles') (FFIB Report-ad_dayr1_11, 2003:2). The location of the UK patrol was approximately 2000 meters west of where POPOFF 35 had observed friendly fire impacts. POPOFF

36 requested from POPOFF 35 who requested from MANILA HOTEL about possible friendly forces in the area, ‘...as they had been given no previous information about any friendly forces in the immediate vicinity’ (FFIB Report-ad_dayr1_11, 2003:2). Responding to a number of queries regarding disposition of friendly forces, MANILA HOTEL consistently confirmed that friendly forces were well clear of POPOFF 35 flight position (but the A-10s did not relay the coordinates of the vehicles). With the aid of image stabilizing binoculars and descending to altitude between 5000 and 10000 ft, POPOFF 35 identified the orange panels on the vehicles as being something in an angled position with vertical development, which led them to conclude that they were either orange rockets or launchers (FFIB Report-ad_dayr1_11, 2003:2). Following the CID process and the determination of a classification of hostile, POPOFF 35 directed POPOFF 36 to fire upon the convoy.

After the second strafing attack on the convoy by POPOFF 36, MANILA 34 (another USMC GFAC) who was on the same UHF frequency as MANILA HOTEL and POPOFF 35 flight, informed the flight that there were friendly forces in the area. The pilots immediately broke off the attack, and subsequently received confirmation of the blue-on-blue engagement. During the course of the sortie that resulted in the fratricide event, POPOFF 35 was re-tasked to operate in a different location than assigned by the ATO with the mission to ‘find and destroy concealed Al-Hussein missiles (FFIB Report-ad_dayr12_24, 2003:13).

As noted earlier, the threat environment was considered significant stemming from the recognized air threat in the area of operations as small arms, AAA and both mobile and shoulder fired SAM systems. It was noted in the report that ‘...A SAM threat warning received by POPOFF 36 in the area reinforced the knowledge that threat systems were active in Iraq thereby acting as a factor that drove POPOFF 35 flight to remain at medium altitude while identifying targets. During the incident, the Sun elevation, combined with a haze layer at low altitude, decreased the visibility in the target area and accentuated shape and shadows of vehicles’ (FFIB Report-ad_dayr32_37, 2003:25).

The communications environment in the time leading up to and including the incident was considered as high volume resulting on occasions of ‘stepped on’ transmissions. ‘These communications problems caused an overall decrease in situational awareness resulting from missing information’ (FFIB Report-ad_dayr32_37, 2003:25). As described in detail in the accident report, the GFAC and pilots exhibited poor communications omitting several key pieces of information during exchanges. As well although the pilots discussed location of the suspect targets on an inter-flight frequency, they failed to communicate this information to GFAC. The apparent assumptions regarding locations and ambiguous terminology ‘well clear’ exhibited by GFAC contributed to the accident. As noted in (FFIB Report-ad_dayr32_37, 2003:26): ‘random informal questioning of A-10 pilots resulted in definitions of ‘well clear’ ranging from a spectrum of 1 to 5 kilometers range between a target and friendly forces, to simply that friendly forces are not a factor in the target area’. Contributing to

the communications difficulties was POPOFF 36 management of his flight's internal communication characterized as poor throughout the mission which served to interrupt communications with the GFAC and added to the task saturation of POPOFF 35 effecting communications to support target identification.

The command and control associated with this incident in terms of the Type 3 CAS defined as "low risk of fratricide" served to reinforce the pilots' perception that '...friendly forces were not a factor in the target area...employs a "blanket" weapon release clearance, which served to create a perception of an enemy-only environment' (FFIB Report-ad_dayr32_37, 2003:26). As noted 'the tactics expected from the enemy artillery vehicles (shoot and scoot), coupled with the perception of the distance from the previous artillery engagement and the question of orange panels ultimately resulted in misidentifying the friendly vehicles as enemy forces'. Response Set (Expectancy) defined as 'factor in which the individual has a cognitive or mental framework of expectations that predispose them to a certain course of action regardless of environmental cues' was identified as a contributory factor. As noted in the report (FFIB Report-ad_dayr32_37, 2003:27):

The cognitive framework of hostile vehicles was established by the presence of valid military vehicular, artillery and rocket targets in the vicinity. The incident forward air controller, MANILA HOTEL, had cleared POPOFF 35 flight for Type 3 CAS. Type 3 Control is defined as "used when the tactical risk assessment indications that CAS attacks impose low risk of fratricide. When commander's authorize type 3 control, JTACs grant "blanket" weapons release

clearance to an aircraft or flight attacking a target or targets which meet prescribed restrictions set by the JTAC’.

The incident scenario is characterized as complex. Prior to the incident, POPOFF 35 had just completed a successful strafe run against valid military vehicular and artillery targets and subsequently attempting to shift/correct UK artillery fire on an additional valid target. It was during this time that POPOFF 36 visually acquires the incident vehicles. As well during the sortie, POPOFF 35 received a Radar Warning indicating a possible surface-to-air threat.

The Board found that in an attempt to increase the CVR(T) Scimitar’s visibility from the air, the crews of the HCR had fitted additional day-glow panels to the tops of their vehicle turrets. This additional measure was noted by the Fitting Advisory Team and thought to be an enhancement. The Board further found that whilst all of the individuals concerned were acting in the very best of interests, that this ‘enhancement’ contributed to the misidentification of the “orange panels” as “orange rockets”. It was noted in the report (Board of Inquiry, 2004:5-3) that the pilots had very ‘...little or no UK/Coalition AFV training and were unlikely to have been familiar with the non-standard TIPs fitting for the CVR(T) Scimitar’.

Separate inquiries were carried out into the incident in the US and the UK. As the incident was similar to the incidents of fratricide in the first Iraq conflict, Operation Granby, involving US A10 aircraft, in which nine UK personnel died, the inquiry was

tasked with reviewing the lessons learned following these incidents. Soldiers in the convoy, realising they were the target of a US aircraft, took action to prevent a further attack, including releasing red smoke to indicate they suspected friendly fire. The US Forward Air Controller then instructed the A10 pilot to call off the attack. The Board concluded that the cause of the incident was that the A10 had engaged the UK patrol believing it to be hostile, without the required authorisation from the United States of America Liaison team. Contributory factors to the incident included:

1. 'the employment of the least restrictive Rules of Engagement for Close Air Support without providing sufficient control or situational awareness (in particular data on the position of friendly forces);
2. human factors given the pilot's expectations about the absence of friendly forces in the area (based on information and briefings provided on the nature of the enemy forces), and task saturation of the pilots had contributed to the misidentification of orange panels as orange rockets;
3. although the patrol vehicles had been fitted with thermal identification panels (the orange panels), adaptation of those panels (with day glow side panels) had contributed to the vehicle's misidentification;
4. the pilots had received minimal recognition training on allied fighting vehicles, making it impossible for them to positively identify the combat vehicles; and had to rely on binoculars to identify the vehicles from a height of 5,000 to 6,000 feet;
5. poor communication during the sortie had led to confusion and lack of situational awareness (for example, the pilots had not passed any details of

their intended target (the UK patrol) or sighting of the orange panels to the US Liaison Team)' (NAO, 2006:19-20).

One of the survivors criticised of the attack the US pilot for showing 'no regard for human life' and accused him of being 'a cowboy' who had 'gone out on a jolly' (Barkham, 2003). 'Lance Corporal Gerrard said: "All this kit has been provided by the Americans. They've said if you put this kit on you won't get shot....You've got an A-10 with advanced technology and he can't use a thermal sight to identify whether a tank is a friend or foe. It's ridiculous' (Barkham, 2003).

This case study highlights the expectations and trust that emerges within the socio-technical system. It is reflected in the ground troops and their 'modification' of the panels to prevent a fratricide, and the information and communications that shaped the SA of both the pilots and controllers. The three secondary case studies highlight how a lack of cohesion and alignment of the socio-technical system in terms of technical integration of systems with human and informational domains created conditions that precipitated the fratricide.

Understanding ROE

What is implicated in all fratricide incidents and ties them together are the Rules of Engagement (ROE) and their relationship to the CID process. It follows that a detailed understanding of ROE is required as it emerges from the ANT process of following the actors. ROE represents the intersection of the political, military and legal domains facilitating a framework that encompasses national policy goals, mission requirements

and the rule of law. In particular it performs three functions: ‘(1) Provide guidance from the President and Secretary of Defense to deployed units on the use of force; (2) Act as a control mechanism for the transition from peacetime to combat operations (war); and (3) Provide a mechanism to facilitate planning’ (Eflein, 1998: 36). As such ROE (CJCSI 3121.01A, 2000) provide the guidance regarding actions to be taken in response to some hostile action. As a tool, ROE regulate the use of force.

As described in the Operational Law Handbook (2007) and detailed in Jeter (2004: 384-385), ROE satisfy three purposes:

Political Purposes: ROE ensure that national policy and objectives are reflected in the action of commanders in the field, particularly under circumstances in which communication with higher authority is not possible. For example, in reflecting national political and diplomatic purposes, the ROE may restrict the engagement of certain targets, or the use of particular weapons systems, out of a desire not to antagonize the enemy, tilt world opinion in a particular direction, or as a positive limit on the escalation of hostilities. Falling within the array of political concerns are such issues as the influence of international public opinion, particularly how it is affected by media coverage of a specific operation, the effect of host country law, and the status of forces agreements with the United States.

Military Purposes: ROE provide parameters within which the commander must operate in order to accomplish his assigned mission: (1) ROE provide a ceiling on operations and ensure that U.S. actions do not trigger undesired escalation, i.e., forcing a potential opponent into a “self-defense” response. (2) ROE may

regulate a commander's capability to influence a military action by granting or withholding the authority to use particular weapons systems by granting or restricting authority to use certain types of weapons or tactics. (3) ROE may also reemphasize the scope of a mission. Units deployed overseas for training exercises may be limited to use of force only in self-defense, reinforcing the training rather than combat nature of the mission.

Legal Purposes: ROE provide restraints on a commander's action consistent with both domestic and international law and may, under certain circumstances; impose greater restrictions on action than those required by the law. ... Commanders must therefore be intimately familiar with the legal bases for their mission. The commander may issue ROE to reinforce principles of the law of war, such as prohibitions on the destruction of religious or cultural property, and minimization of injury to civilians and civilian property (Jeter, 2004:384-385).

What becomes apparent are the many factors that affect the development and implementation of ROE. ROE are characterized as providing clear and tailored guidance regarding actions to be taken. As articulated by Jeter (2004:386) '...ROE delineate what can be attacked, how it can be attacked, and whose permission you need to attack it. For example the Standing Rules of Engagement (SROE) have been termed '...the tether between the NCA and the soldier, whereby the SROE represent real-time guidance from our national leaders to the military member' (Jeter, 2004:386).

Peaceful, Wartime, Standing ROE

PROE are premised on the right of self-defense. The applications of legitimate force in these circumstances are necessity and proportionality. As noted in Eflein (1998:40) 'Necessity is the requirement that force be used in response to a hostile act or in situations in which the hostile intent is evident. Additionally, 'necessity also must relate to the requirement to use force because other measures are unavailable or obviously would be futile. Proportionality means that the amount of force used in response to a threat must be of reasonable intensity, duration, and magnitude to counter the threat'. Wartime ROE (WROE) are governed by the laws of war (or the laws of armed conflict) are employed with respect to the use of force for offensive purposes, such as to achieve an objective for mission accomplishment (Eflein, 1998: 40).

Standing ROE (SROE) '...provides implementation guidance on the inherent right of self-defense and the application of force for mission accomplishment' within the bounds of the United Nations charter and international law' (Eflein, 1998:41-42). As such the SROE represent the doctrinal merge of WROE and PROE. Given this characteristic of the SROE, it provides a '...variable mechanism that changes as the operations position on the continuum changes. For operations that are inherently peaceful, the SROE allows the use of force for defensive purposes and only in reaction to a hostile act or clear indication of hostile intent' (Eflein, 1998:41-42). What is particularly relevant with regards to SROE in the case studies is that '...once a force has been declared hostile by appropriate authority, US units need not observe a hostile

act or a demonstration of hostile intent before engaging that force' (Eflein, 1998:42).

Thus once a force has been declared hostile, it is the enemy and the basis for engagement is status alone.

ROE and Air Operations

Within the aviation domain, ROE and plans developed at the operational level are transmitted to operators at the tactical level who execute the campaign. The Joint Air Operation Center (JAOC) for aerospace operations is the focal point for mission planning and execution' (Jeter, 2004:388). With regards to aerospace operations, the JAOC represents the focal point for planning and execution for the joint task force (JTF) is where centralized planning, direction, control, and coordination of aerospace operations occur. Operational and tactical command and control are exercised through the JAOC responsible for transmitting the strategy, operational constraints and tactical procedures through the Air Tasking Order (ATO), Airspace Control Order (ACO) and Special Instructions (SPINS) (Jeter, 2004:391).

As described in Jeter (2004:392-393), SPINS represent a primary document which articulate the ROE for the overall air campaign. They also provide instructions on other operational procedures and tactics. Once complete, SPINS are jointly transmitted with the ATO and ACO to assist operational aircrews in planning for execution of the mission. The purpose of SPINS is to provide clear instructions based on authoritative guidance. SPINS reflect the strategy and objectives that were issued from the President and Secretary of Defense and sent through the respective chain of command. For example, the ROE will be published first in the Operation Orders then

subsequently in the SPINS to the ATO. Since SPINS are an integral part of the ATO and disseminated by the JAOC they represent an inherent authority. SPINS provide details to the tactical operators on how to adhere to the current ROE as they plan for mission tasking, coordination and execution. As such SPINS have the power of a direct order based on the command authority of the JFACC to accomplish the mission which is derived from the JFC. Additionally, SPINS provide detailed guidance on other operational aspects like communications and air refueling procedures. Since SPINS are intended to provide clear and detailed guidance on how to comply with ROE, they are constantly reviewed by an ROE Cell to ensure they are properly amplifying the ROE thereby contributing to their validation and authority (Jeter, 2004:393).

During operations, such as those described in the case studies, aircrew are required to comply with the SPINS, which amplify the current air operation ROE. Since SPINS elaborate in detail on how to comply with the current air operation ROE measures, they facilitate clear guidance and are considered ‘...binding and take precedence over SROE. This is especially significant when the perceived conflict involves the right of self-defense’ (Jeter, 2004:395). One of the purposes of ROE is to lay out the - parameters of self-defense and what triggers a right to use force in self-defense. As reported in Jeter (2004:395)

The fundamental US policy on self-defense is repeatedly restated throughout the SROE: These rules do not limit a commander's inherent authority and obligation to use all necessary means available and to take all appropriate

actions in self-defense of the commander's unit and other US forces in the vicinity. The commander has the authority to exercise this right of self-defense when faced with a hostile act or a demonstration of hostile intent.

The US fundamental policy on self-defense is 'These rules do not limit a commander's inherent authority and obligation to use all necessary means available and to take all appropriate actions in self-defense of the commander's unit and other U.S. forces in the vicinity'. The SPINS specify operational constraints which are binding on the pilots as ROE. Thus, for the pilot to use force appropriately in self-defense he must comply with the SPINS (Jeter, 2004:397).

4.4 CONCLUSION

'Public opinion is less tolerant of any casualties, especially those incurred through fratricide, where the overall aim is questionable' (Ministry of Defence, 2002:12). The effects of a fratricide incident have significant impacts. For example following the 1991 A10 incident, the 'overnight tempo within UK units dropped, drastically lowering operational effectiveness. Trust between UK and US forces was severely diminished. Politically, a strain was placed on the coalition' (Dean and Handley, 2006:5).

The ROE represent the explication regarding the lawful use of force, including the parameters of the right to use force in self defence, eliminates uncertainty, thereby helping the troops on their mission (Eflein, 1998:37). The ROE reflect the national policy as determined by civilian and military leaders. The United States follows

courses of action designed to further political goals, and the ROE must be tailored to prevent unnecessary escalation (Eflein, 1998:36). Militarily, ROE may actually restrict the manner in which a commander can carry out his mission. They form the outer boundaries that the commander and his troops must stay within while trying to accomplish the mission (Eflein, 1998:37). The law is the foundation of the ROE; when the ROE are overlaid onto the operational continuum (Eflein, 1998:38).

Collectively the case studies reveal emergent themes that are derived from the systems perspective recognizing the complex socio-technical domain. These themes that cross all case studies include expectations, beliefs, decision making and situation awareness emerge within the deficiencies of the CID components and reveal a disconnect between data-driven information and cognitive driven elements (Famewo et al., 2007b:7).

These case study descriptions form the backdrop from which we will ‘follow the actors’ to explore in detail the black box of pilot error. In the following chapter, we draw upon the theoretical perspectives discussed in chapter 2 (Systems Theory, Actor Network Theory, Complexity Theory) and through the case study methodology reveal another perspective that reflects the emergent power and politics that permeate the network space thereby suggesting a de-centered aetiology and challenging the linearity that so characterizes current accident models.

Chapter 5

Discussion: Opening the black box

5.1 INTRODUCTION

Urry (2002:59), in his discussion of complexity and systems, remarks that there exists a ‘...profound disproportionality of ‘causes and effects’. Such systems possess a history that irreversibly evolves and in which past events are never ‘forgotten’. His statement resonates with the analysis discussed in this chapter. Through the lens of ANT what emerges from the analysis is a network characterized by actors that are neither purely technical nor purely social, but rather what Callon and Law (1995) terms ‘a hybrid collectif’. This actor network comprised of ‘heterogeneous’ elements/relations erases the dichotomy that traditionally exists between the human and non-human, and thereby challenges the attribution of blame associated with ‘pilot error’. Senge (1990:13) succinctly put it, ‘our actions create the problems we experience’. In other words our history, our previous intra-actions are entangled within and shape our current experience. Informed by complexity thinking, ANT suggests that the keys to understanding the network (system) are contained in the patterns of relationships and interactions among the system’s agents as described by Capra (1996), Lee (1997), and Anderson et al. (2005). The black box associated with pilot/human error obscures the fact that it is dependent on the network of heterogeneous elements and alliances of which it is a part. Within the black box are the silenced, deleted voices associated with the accident aetiology. We therefore must suspend our traditional conceptualization of causality and rethink its nature in terms of conditions of possibilities. The traditional methodology associated with decomposition and tree structures that has shaped

accident investigation processes, results and accident models is further expanded within the network space of ANT. Through ANT it is recognized that

...technology is no longer simply a means to an end, nor is it to be treated as separated from the social, or the corporate body. Technology can transform ends and become politics by different means, an integral part of the social or the body politic. Hence, technology may also perform a role; become an actor (Tryggestad, 2005:39).

Through this analysis it thereby becomes evident that causal processes in complex systems cannot be accessed by simple analysis. As Byrne (2005:105) remarks: 'History will matter.... Context will matter. Agency will matter'.

This chapter integrates the theoretical foundations discussed in chapter 2 and applies them to the case studies described in chapter 4 through the methodological approach described in chapter 3. Section 5.2 introduces the concept of the black box and the process by which it is opened. Section 5.3 presents the accident aetiology described in the case studies in terms of an actor network. It is argued that the network of heterogeneous elements that comprise the actor network can be conceptualized as the hybrid collectif, existing at the nexus of the human, physical and information domains. The distributed simulations are used to explore the characteristics of the actor network and the hybrid collectif. From these simulations we gain greater understanding regarding the processes of translation and inscription. Section 5.4 introduces the concept of illusions of certainty from which an argument is presented showing, through the lens of ANT how translation and inscription processes shape expectations,

sensemaking, trust and decision making thereby shaping the accident aetiology. Section 5.5 presents an argument for the notion of a distributed SA that emerges from the network of heterogeneous elements. Finally, based on the argument presented, section 5.6 argues for the notion of fratricide as de-centered. Arguments presented draw upon evidence from the case studies through ‘follow the actor’ methodology of ANT complemented by thematic analysis and supported by insights from distributed simulations. System dynamics modelling is used as an explanatory tool to depict the processes involved in the recurrence of fratricide. Anticipatory Failure Determination and the TRIZ methodology are used as an analysis tool for validation and to garner additional insights into the problem space of fratricide and pilot error.

5.2 OPENING THE BLACK BOX

The concept of the ‘black box’ is not new. In information science, the black box was used ‘...to make opaque the veneer complexity of technologies in order to reduce complex technology to its inputs and outputs.....Adapted for technology studies, a black box is a technical artifact that appears self evident and obvious to the observer’ (Cressman, 2009:6). In actor network terms the black box is regarded as that which is taken for granted, that no longer needs an explanation. A network therefore appears to be a series of black boxes within which lie inherent assumptions. It is by opening the black box that we begin to see the interconnectedness of the social and the technical and recognize that the dichotomy between the two is a simplification of a complex entity. What is important to realize is that ANT analysis does not provide a narrative of the accident aetiology nor produce an exact rendering of the problem space but

rather facilitates an interpretive examination that reveals insights into the accident aetiology.

As described in chapter 4, the first series of case studies point to pilot or crew error as a contributing cause of the fratricide incident. These three cases are presented together in this analysis in order to show common themes that emerge from the process of ‘following the actor’ and facilitated through thematic analysis. The three case studies are separated in time (1991, 1994, and 2002) and place (Southern Iraq, Northern Iraq and Afghanistan). Taken together they facilitate a cross-case analysis that supports the emergent concepts and themes that evolve as described in chapter 3. The second series of fratricide case studies are used as a validation exercise of the emergent themes and to garner additional insights from the accident aetiology. Informing the analysis are observations and insights from two distributed simulations: JSMARTS II and MALO TDP. These two distributed simulation experiments reflect the relational network construct of ANT recognizing the High Level Architecture (HLA) that defines the physical network of the simulation and the actor networks that reside within each of the federated distributed simulations. It is through the simulation experiments that we garner insights into the nature of inscription, translation and emergent behaviour within an actor network. The following analysis and discussion focuses primarily on the first series, however salient examples will be referred to from the other case studies where applicable.

Multi-event sequencing and Event Causal Factors diagramming, as described in the case study event timelines, provides the starting point for the analysis in which ANT then provides a 'relational' view of the problem space. This is consistent with other methodologies of accident investigation and is supported by Blackett (2005:88) who argues that '...no single analysis technique can cover all necessary aspects of an analysis. Therefore, a hybrid approach should be adopted which combines the best features of the various techniques available'. From an event based analysis of the case studies that identify the sequence of events, we map the four distinct processes that characterize combat identification (CID): detect, classify, recognize and identify and view them within the context of the three strands that define CID: Tactic, techniques and procedures; Target identification; and Situational Awareness.

As described in Johnson (2003) causal analysis is not only concerned with what happened, but that it looks beyond the facts to identify the reasons why the accident occurred. From this analysis the actors emerge and their relational connectivity is explored. A tracing of the relations and actors results in a 'complex' actor network construct. Figure 5.1 shows a mapping of the network space (using RiskOutlook™) providing a visualization of the problem space and inherent relational properties and complexity.

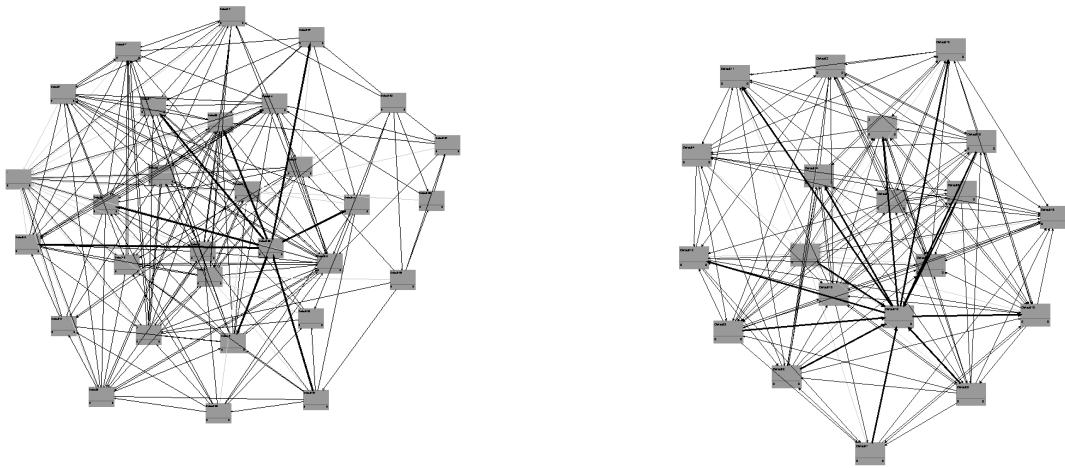


Figure 5.1- Actor Network tracing (visualization)

5.3 DEFINING THE ACTOR NETWORK

Here we define and detail the actor network representation of the accident aetiology associated with fratricide that emerges from the ANT and complexity lens of analysis.

We argue that within the context of this thesis emerges what has been termed in the literature as hybrid collectifs (Callon and Law, 1995). A fundamental tenet of this analysis is the symmetrical treatment of humans and non-humans (Callon, 1999) to challenge the dichotomy that resides in traditional sociological approaches. To insist on symmetry as argued by Law (1994: 9-10) ‘...is to assert that everything, more particularly, that everything you seek to explain or describe should be approached in the same way’.

As described in chapter 3, beginning with the linear event based views of the case study incidents; the ANT methodology of ‘follow the actor’ facilitates the relational tracing revealing a network space. Through an iterative process of coding both within

case and cross-case analysis, as well as input from the simulation exercises, emergent themes were captured via the process of thematic analysis in which the themes become refined through an iterative process thereby resulting in overarching concepts.

Through the application of Anticipatory Failure Determination (AFD) described in Appendix B, the emergent themes were explored and validated. Figure 5.2 shows a high level view of the problem space derived from the AFD analysis. AFD, through a structured methodology rooted in the Theory of Inventive Problem Solving (TRIZ), facilitates an examination of the problem space through failure analysis and failure prediction and thereby provides a more explicit and detailed exploration of the actor network, relations and processes of translation and inscription. This methodology provides a unique analysis tool to examine matters pertaining to accidents. In following the actor, AFD allowed the results to be contextualized in a structured manner and provided a link to the CID process. From following the actor, facilitated by thematic analysis and AFD modeling, we saw four very general types of actors emerge: human beings, with the skills and knowledge that they generate and reproduce; artifacts, which include all the nonhuman entities that facilitate performance of a task; texts and inscriptions, which include everything that is written or recorded (such as SOPs, ATOs, ROE) , as well as the channels through which they circulate (such as command and control processes); and institutional authority, which is embedded in regulations and power relationships (Gherardi and Nicolini, 2000: 16).

From these general actors, three relational domains become apparent that describes the actors within the actor network: Physical, Human and Informational (figure 5.3).

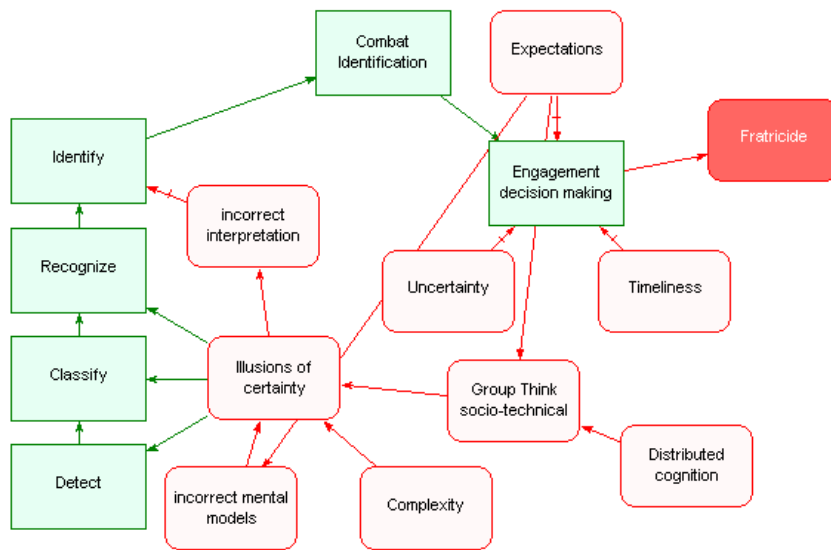


Figure 5.2- Thematic view of Problem Space

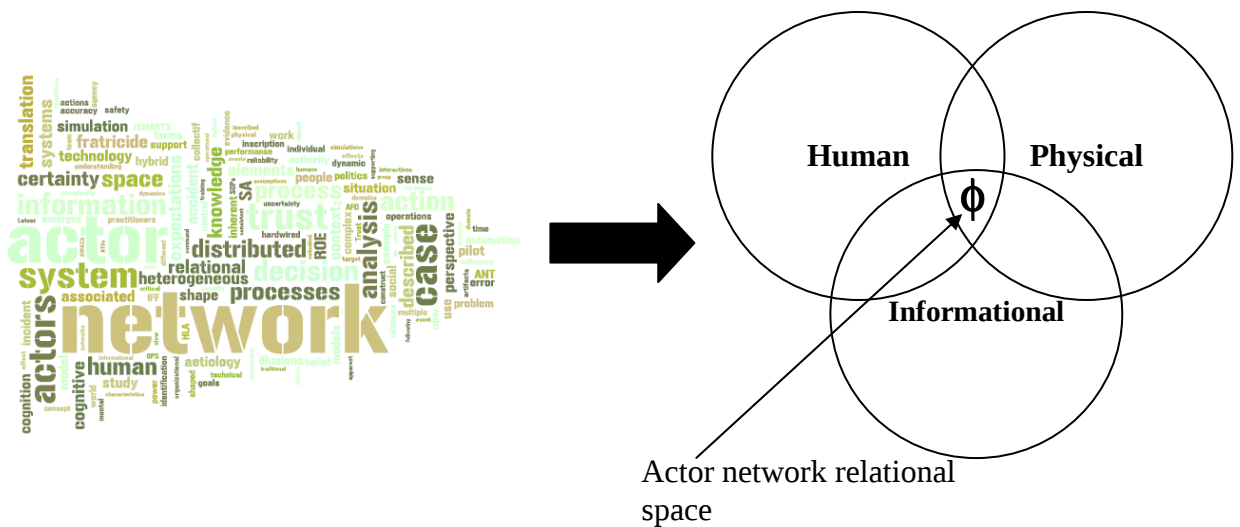


Figure 5.3- Thematic Analysis to Relational Domains

Actor Network Theory does not focus on these domain areas in the analysis a priori but rather focuses on the intersection of the **Physical**, **Human**, and **Informational**

(represented by the symbol ϕ), which is interpreted and represents the actor network relational space. This space represents what we term the 'hybrid collectif' within which the dichotomy associated with the human and the technological is dissolved. As argued in van der Duin (2005:88), '...It does not make sense to ignore materials and to treat them separately, as though they were different in kind: the characterization of materials is just another relational effect'.

As we begin to conceptualize ϕ , we recognize, as Urry (2002:58) writes, the '...relationality is brought about through a wide array of networked or circulating relationships implicated within different overlapping and increasingly convergent mobile, material worlds'. From complexity theory we recognize that the relational interactions are complex, rich and non-linear involving multiple negative and positive feedback loops (Urry, 2002:59). The Actor Network perspective draws our attention to the system interaction over multiple time-spaces exhibiting a disproportionality of 'causes and effects' and hence influences the attribution of pilot error and human error as captured in figure 5.3. What is important to recognize in defining the actor network is that history matters and context matters. These two attributes are embedded within the actor network and affects the relational characteristics and dynamics of the network (Urry, 2002:59).

In defining the actor network, technology, as an actor within the socio-technical system is not regarded as an object in itself but rather as a relational entity. Michael (2003:130) argues that '...technologies work as they do because they are composed of

complex heterogeneous distribution- of assemblages- of humans and non-humans'. This was explored through the AFD analysis which further illustrates that the pilot is essentially '...an effect generated by a network of heterogeneous, interacting, materials' (Law, 1992:3) depicted in figure 5.4. In defining the actor network, the pilot therefore becomes this entangled network of heterogeneous elements, a hybrid collectif. Law (1992:3) argues that:

...what counts as a person is an effect generated by a network of heterogeneous, interacting, materials. ... But converted into a claim about humans it says that people are who they are because they are a patterned network of heterogeneous materials. If you took away my computer, my colleagues, my office, my books, my desk, my telephone I wouldn't be a sociologist writing papers, delivering lectures, and producing "knowledge". I'd be something quite other -- and the same is true for all of us.

Similar to the thought experiment described in Callon and Law (1997:171) describing 'Andrew the strategist', from the AFD modeling we selectively begin removing actors within the actor network describing the accident aetiology thereby conducting a sensitivity analysis of the accident aetiology by exploring the space of possibilities. The pilot ceases to exist with the removal of the sensor systems, navigation systems, communication systems, the elements necessary to complete the Combat Identification process. What we discover is the pilot and essentially 'pilot error' is a heterogeneous network: 'person' + aircraft + supporting crew and technicians + orders, SOPs, ROE + avionics + sensors + virtual team members + communications + training + doctrine + air force culture + work of engineers + legal council + politicians. It is this very

relational network of actors that creates the possibility for action. In defining the actor network, the pilot emerges as this entangled network of heterogeneous elements, a hybrid collectif. What this reveals is that action, as seen in the case studies, takes place in a 'hybrid collectif' that is comprised of entangled human actors as well as non-human actors in multiple ways. Viewed from this perspective, tools (such as the hardware and software) that are embedded in the actor network are as Callon and Caliskan, (2005:18) remark not just things that are used to achieve certain ends: 'They contribute to the making of the universe of possibilities that make action itself'.

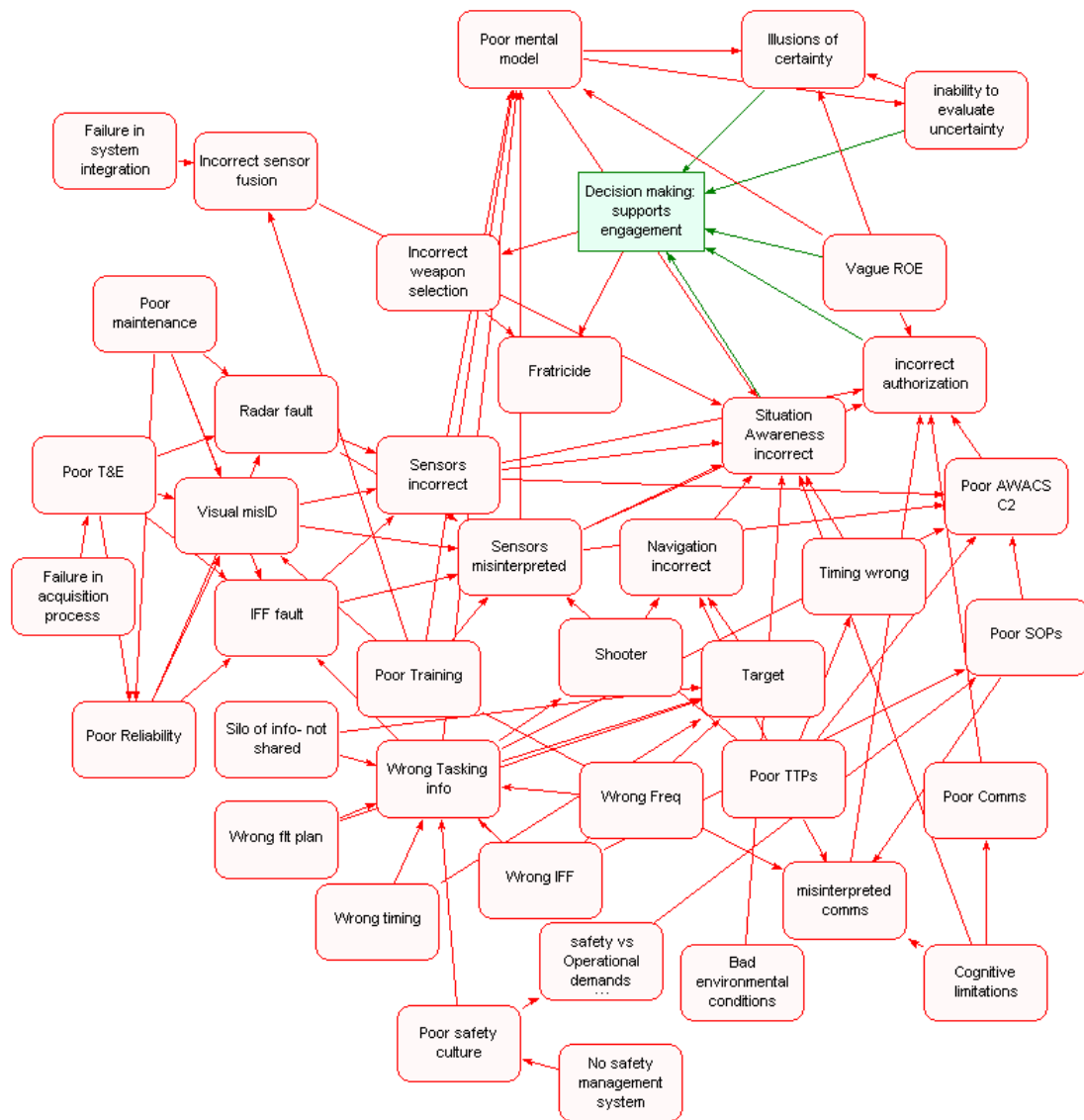


Figure 5.4 - Hybrid Collectif

The application of AFD in the analysis facilitated ‘following the actors’ in presenting a space of possibilities and predictive failure modes (Appendix B). As such, within our case studies the actors (humans and non-humans) emerge as entangled phenomena, relational beings.

The relational theoretical perspective makes visible agency as a network attribute transcending the human/non-human dichotomy and opens the possibilities for distributed agency and a de-centered aetiology. As entities are relationally defined so action arises from the distributed set of competencies resident within the actor-network in which humans and non-humans are both full participants. The AFD reveals through its predictive mapping that in principle then, non-humans have the potential to act, a potential which arises from the network relations in which they are enmeshed. Callon and Law (1997:166) argue that ‘...there is no difference between the person and the network of entities on which it acts. Or (the real point) between the person and the network of entities which acts through the person. Network and person: they are co-extensive’. This is a critical element in understanding accident aetiology from this Actor Network perspective. It sets the stage for our argument for a de-centered causality, thereby challenging the attribution of blame associated with pilot error. In defining the actor network as described, what emerges from the analysis are complex webs and networks composed of non-linear heterogeneous associations that give rise to insights into how time and space are bound into the networks.

Recognizing the complexity of the problem space associated with fratricide from the ANT perspective, we use system dynamics modeling as an exploratory and explanatory tool. The field of system dynamics was created at MIT in the 1950s by Jay Forrester. It is designed to help decision makers learn about the structure and dynamics of complex systems, to identify high leverage points for sustained improvement and to catalyze successful implementation and change. System dynamics

provides a framework for dealing with dynamic complexity, where cause and effect are not obviously related (Dulac, 2007:58). Complex dynamic systems are defined in the systems dynamics field as systems that: (1) are extremely complex, consisting of multiple interdependent components; (2) are highly dynamic; (3) involve multiple feedback processes; (4) involve non-linear relationships; and (5) involve both hard and soft data (Dulac, 2007:63). System behavior in system dynamics is modeled by using feedback (causal) loops created by interactions among system components. Drawing upon system dynamics (Sterman, 2000:11), figure 5.5 illustrates the inherent complexity in the CID process that arises from defining the actor network.

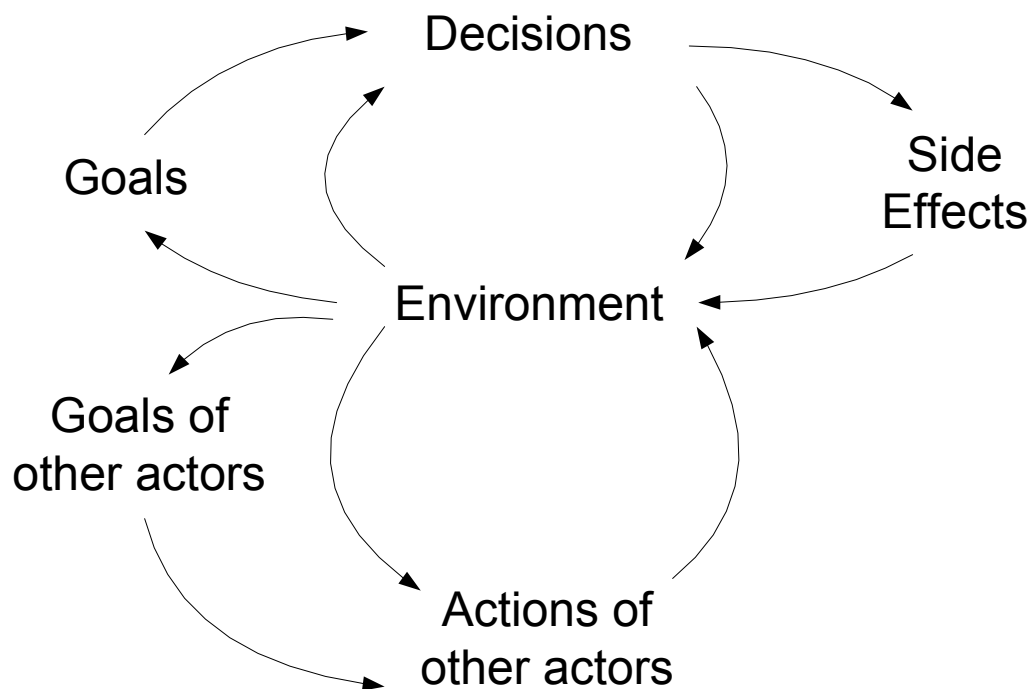


Figure 5.5- ANT view of the problem space

What we see within the causal loop diagram shown in figure 5.5 are the unanticipated ‘side effects’ of the decision making process that arises from the actor network of

heterogeneous elements transcending the linear cause and effect to show how elements distant in time and space are resident within the decision making process. The results of our actions, based upon our perceptions, define the situation and hence will shape our goals and decisions. Of particular note is how actors, with inscribed goals and agendas influence actions of other actors, through the process of translation thereby shaping decision making. Within the case studies, the ROE becomes ‘threaded’ throughout the actor network aligning the human, physical and informational domains thereby shaping SA, decision making and actions. Expectations, beliefs and trust thereby emerge from the actor network facilitating insights into the accident aetiology. For example the Standing Rules of Engagement (SROE) have been termed ‘...the tether between the NCA and the soldier, whereby the SROE represent real-time guidance from our national leaders to the military member’ (Jeter, 2004:386). The ROE, as described in chapter 4, are integrated into the ATO and SPINS. The SPINS thereby represent an inherent authority that provides details to the tactical operators on how to adhere to the current ROE as they plan for mission tasking, coordination and execution (Jeter, 2004:392-93). This relational interdependency between the ROE and decision making and sensemaking represents an inscription and translation within the actor network which resonates through the human, physical and informational domains. The distributed simulations reflect this very nature whereby inscribed rules (HLA rules) align the actors participating in the simulation. When alignment is not adhered to, the functionality of the simulation is detrimentally affected such that misrepresentation may occur. Hence as will be described later, the misrepresentation may not be noticed until such time as an accident or incident occurs. The causal loop

diagram is supported by the result of AFD analysis that highlights the inherent connectivity resident within the actor network. Implied by the causal loop are the translation and inscription processes of ANT (within the goals of other actors) shaping action and inaction. Sterman (2000:11) remarks that ‘...the effects we didn’t anticipate...the effects which harmed the system – these are the ones we claim to be side effects. Side effects are not a feature of reality but a sign that our understanding of the system is narrow and flawed’.

As we define the actor network, it must be emphasized that the manner in which non-human actors interact and shape the actor network has significant impacts on the ‘social’ (Latour, 2005). The entangled state that characterizes the actor network highlights that in defining pilot error and agency, the role of the non-human actors must be considered and developed along with the human actors. Although the introduction of a new process, new technical fix, new ROE (as discussed in the 1991 case study) is pertinent to the prevention of fratricide, it becomes part of the dynamics associated with the actor networks. Through the AFD mapping, barriers (Hollnagel, 1999) are recognized and mapped with their inherent inscribed expectation of reliability and performance revealing a deviation from the ‘ground truth’. These barriers become ‘fixes’ to fratricide that enable the conduct of operations to satisfy the ROE. As described in chapters 2 and 4, barriers include Material: Weapon Arming mechanisms; Functional: Positive identification required; Symbolic: IFF, IR panels; and Immaterial: SOPs, ROE.

The ANT analysis and validated through AFD shows how these barriers were linked to the fratricide event. For example the 1994 case study we see how symbolic (IFF), functional (identification requirements) and Immaterial (SOPs, ROE) relationally were implicated in the fratricide. Each barrier can be seen to perpetuate a belief and trust in the ‘safety system’ shaping a mindset traced through the CID process that resulted in the fratricide. Although each barrier was intended to act as a fix to prevent a fratricide incident, collectively due to inscription and translation processes actually became implicated in them. Figure 5.6 depicts a system dynamics model that captures the salient points with regards to fratricide and barriers that is applicable to the case studies.

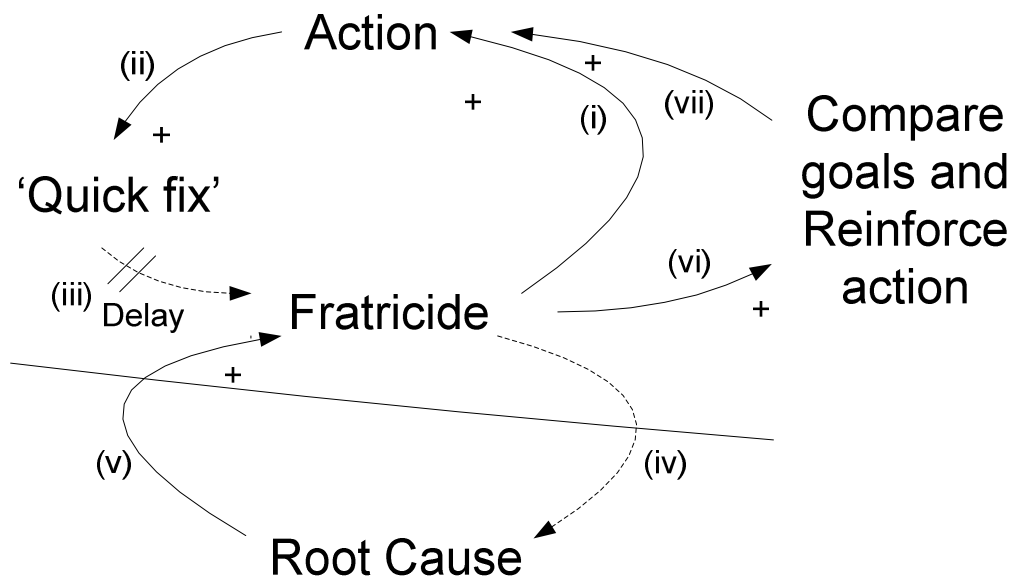


Figure 5.6- Fratricide system dynamic model

To interpret this model, we begin with arrow (i). The ‘+’ sign indicates that an increase in the occurrence of a fratricide event causes an increase in ‘Action’ to

address it. Arrow (ii) with a '+' sign indicates that an increase in 'Action' to address the fratricide introduces a 'quick fix' that I interpret as the response to traditional reductionist understanding of the problem space. The dotted arrow (iii) indicates that an increase in the use of the quick fix slightly contributes to reducing fratricide. The diagram shows the 'root cause' outside the system boundary and thereby unaffected by the dotted arrow (iv). Arrow (v) shows a positive contribution to the fratricide event. An increase in 'fratricide occurrence' increases the compare goal and reinforces action and thereby increases 'Action'. The delay between the quick fix and fratricide represents the period of invulnerability (such as 50,000 hours of accident free missions) thereby contributing to the expectations and beliefs regarding 'certainty' that resides within the system. As noted in Musselman (2008:21) solutions to fratricide '...are linked by way of 'Band-Aid' fixes providing short term solutions'. This false sense of safety and certainty fails to recognize the nature of the interconnectivity of the actor network. This model shows why the actions taken (such as barriers) tend to not reduce fratricide. The solutions stem from a reductionist paradigm introducing such fixes as 'reflector tape' in the Tarnak case study, the presence of legacy processes as described in the 1994 Blackhawk incident or the addition of panels to the vehicles in the A-10 incident. In all cases these 'solutions' miss the more 'systemic issues' and complex interconnectivity. The sensitivity of a system resulting from dynamic interdependency is well known in the domain of Systems Dynamics. What the actor network represents is an entanglement of performances and mediation folded into the materiality of things.

The actor network description associated with the accident aetiology parallels and is supported by the work of Callon (1986a) in his discussion of automobiles. Callon (1986a) describes how the user of the automobile is endowed with the capacity to decide where they want to go. Similarly, the pilot is endowed with decision making capability that is enabled by the network of heterogeneous elements that are aligned such as air traffic control infrastructure, refueling, pilot training, operational training, military indoctrination, flight rules and orders, military and international law, ROE, navigation and avionics systems. This illustrates how the pilot is part of a web of relations linking heterogeneous elements (of human and non human entities). This is not unlike the representation of Pasteur as a network of heterogeneous elements (Latour, 1988). Similarly, Law and Callon (1988) describe how the TSR 2 long range tactical strike and reconnaissance aircraft was a network of heterogeneous relationships. Callon and Law (1997:167) argue that ‘Technicians, politicians, industrialists, different kinds of metal, metal fatigue, the production capacities of companies, wind-tunnels and budget restrictions, all of these were built into the TSR2 network and helped to give it shape’. All this supports the notion that the role of the pilot and subsequent ‘pilot error’ emerge as ‘... effects once associations have been stitched together. That is, as entities become enrolled, combined and disciplined within networks, they gain shape and function. Action and agency, and their shapes and forms, therefore emerge from association rather than from human agents’ (Van der Duin, 2005: 92).

The Causal Map associated with the 1994 Black Hawk incident, as concluded by General Andrus, President of the Investigation Board, resulted from a chain of events (Snook, 2000:65), whereas under the rubrics of an ANT perspective reveals a relational and de-centered view of the incident that is characterized by the actor network. As noted by Snook (2000:73), the standard attribution of ‘pilot error’ was made noting that ‘...the F-15 pilots ‘erred’ when they misidentified the helicopters’ thereby reflecting as Perrow (1984:67) remarks as an oversimplification. The relational actor network as shown in figure 5.4 reveals the complexity, interconnectivity, heterogeneity and dynamics that reside within the network of elements that include: IFF, SOPs, recce training, AWACS system from which emerged an expectation and trust. This hybrid collectif thereby represents the black box associated with pilot error containing the silenced and deleted voices of the heterogeneous actors.

Actor Network Processes (Mediation, Inscription and Translation)-Hardwired Politics

Inscriptions make action at a distance possible by stabilising work in such a way that it can travel across space and time and be combined with other work. This is recognized within the ROE that comprise the political, military and legal frameworks to support armed conflict. The relational analysis reveals that the ROEs are connected to the IFF, communications, SOPs, SPINS, ATOS all of which collectively are derived to support the engagement. The ROE can be seen to have translated and aligned its goals in congruence with the capabilities of the systems that comprise the actor network. For example the ROE are explicit in terms of the identification criteria required for target

engagement described in chapter 4. Callon and Law (1997:167) emphasize that ‘people are networks, devices are networks. But so too, are texts’. The text such as the ROEs, SOPs, SPINS, ATOs are central to the process of gaining credibility and authority within the actor network. Examination of ROEs and ATOs reveal a hierarchical authority of political, legal and military entities that characterize the web of connections. As Callon and Law (1997:170) argue the texts ‘...reflect, are produced by, and help to create, a teeming world of entities’. They rely on a network of ‘technical’ entities such as IFF, radar, sensors aligned to satisfy the criteria inscribed within the ROE and translated operationally within the ATO and SPINS. Following the actor reveals this in the case study material and identifies how dysfunctional command and control supported by these ‘texts’ were implicated in the fratricide. This is demonstrated in the Tarnak case as described in chapter 4. For example as noted in Jeter (2004:409) ‘...the SROE principle for self-defense by the pilot was applicable, but the CFACC's superior lawful orders through the OEF SPINS were the controlling mandate. To support the use of force appropriately, the pilot must comply with the SPINS and ROE. Therefore, in the Tarnak Farms case the claim by the pilots that they took appropriate action in self-defense is-not supportable because they violated OEF SPINS’. However, significant command and control issues that support the ROE and SPINS, as detailed in chapter 4, reflects a disconnect between the articulation of the ROE to the operationalization of it (Jeter, 2004:380-381). In the case of an invocation of self-defense, the involved aircraft commander accepts authority’ (Jeter, 2004:402).

Arising from the Command and Control deficiencies that support the operationalization of ROE, a perceptual mindset was established that precipitated the fratricide incident (CIB, 2002: 52).

As specific actors (such as technological elements) are included or excluded from the network, informational and human actors were affected. For example in the 1994 case study the inclusion of secure voice (Have Quick II) system on the F-15, shaped the type of information that could be communicated as well as with whom the communications could be with. It is of note that this upgrade to the air force communication suite was not introduced into the army (Black Hawk) communication suite and contributed to issues pertaining to interoperability. Using the modelling approach of AFD, the potential flaws within the socio-technical system defining the actor network space are viewed from a perspective that allows for full exploitation of the system's weaknesses revealing within the network of heterogeneous elements problems associated with actor cohesion and alignment stemming from translation and inscription processes. From the thematic analysis and contextualizing the fratricide incident in terms of CID process, the AFD model (figure 5.7) reveals how ROE are enabled through the hybrid collectif: a product of heterogeneous engineering and reveals through the translation process how trust emerges as a product of actor networking. What becomes evident is that ROE requires alignment of the CID process in a supporting actor network architecture that is comprised of heterogeneous elements as SOPs, communication, authority, trust, IFF, radar, skills, mental models, decision making. Callon and Latour (1981:40) state, 'By translation we understand all the

negotiations, intrigues, calculations, acts of persuasion and violence thanks to which an actor or force takes or causes to be conferred on itself authority to speak or act on behalf of another actor or force. “Our interests are the same”, “do what I want”, “you cannot succeed without going through me”’. The informational level of the problem space, the authoritative (reliability) inscribed into the ATOs and ROEs, system functions, (FLIR, GPS, IFF) shape the sensemaking, mental models and decision making. They serve as mediators that shape action. Their relational influences impact and is realized within the sensemaking and mental model construct. Take for example the 1994 case study in which the status-based ROE with its inherent authority that relationally connects legal, political inscriptions converged with the informational domain and physical domain. The CID process is translated by the ROE seeking to align the TTPs and SOPs. The requirement for IFF represents the physical manifestation that enables the ROEs. Similarly within the informational domain, the SPINS and ATOs reinforce the ROEs and connect all domains (PHI) setting up expectations: expectations that all aircraft will use the appropriate IFF code; expectations that the aircraft sortie information is contained in the ATOs and no aircraft will enter the TAOR prior to sanitization; expectation that all aircraft will utilize the appropriate frequencies; and expectations that the AWACS will provide the command and control as advertised by its capability that is ‘hardwired’ into its actor network. Figure 5.7 shows a conceptual model that highlights how ROE, as an actor with inscribed goals, translates and permeates throughout the actor network thereby shaping action and decision making.

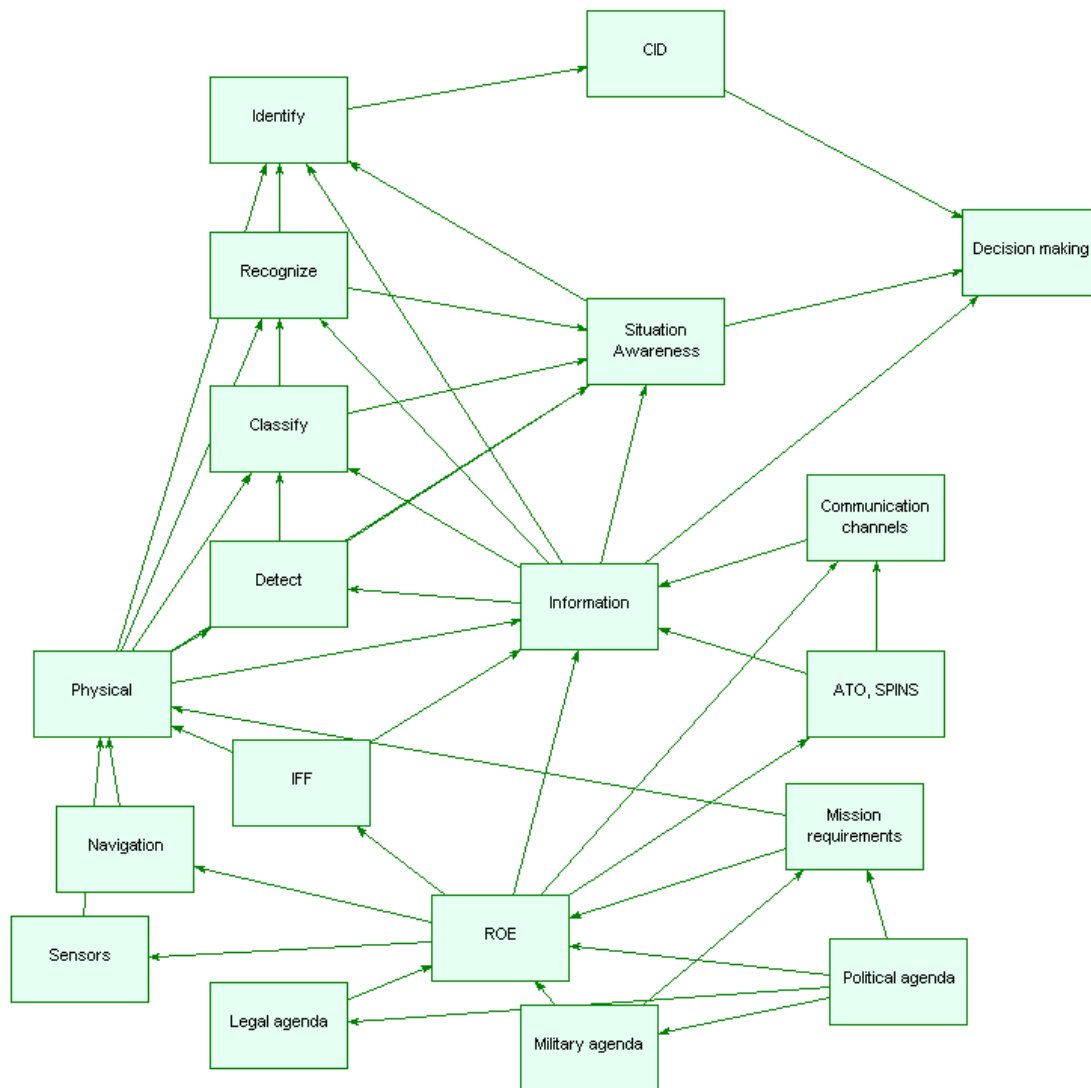


Figure 5.7- ROE translation permeates the network space

Through the application of the inventive approach within AFD, future failures were invented, and created thereby devising the paths for catastrophic accident (fratricide) revealing as argued by Latour (1999a:183) ‘...action is a property of the whole association, not only of those actants called humans’.

Translation and mediation comprise what Latour (1999a:186) refers to as ‘programs of action’. The actors within the network merge into a hybrid, which can only be understood by taking both the human and non-human aspects together. Latour (1994:35) argues that ‘Action is simply not a property of humans but an association of actants’. This is a key point. Fratricide thereby is viewed not from a human-centric perspective but rather recognizes that fratricide is derived from a network of actors and relations. In the case of the Patriot system incident, translation processes can be seen to emerge from the analysis associated with the automation and Human Computer Interface (HCI) that shapes action and inaction, the ‘presumed’ accuracy associated with the navigational systems, the authority and assumed capabilities associated with the command and control infrastructure such as that of the AWACS, ATO, and SOPs. The case studies reflect how actors, such as these have an inherent accuracy, certainty and authority that translates (forces) the actor (as part of the hybrid collectif) to act in a certain manner. These actors through translation shape action and decision making (figure 5.6). This is a critical concept in our analysis of pilot error. The black box of pilot error is now open as a result of the actor network analysis. Rather than the question, ‘how could they not have known’ with its hindsight bias, we approach the problem space with the insightful question what actor network dynamics, translation and inscription processes precipitated and contributed to the accident.

As argued by Verbeek (2005:130), the concept of delegation indicates that programs of action can be ‘inscribed’ into artefacts.’ Within the context of the case studies, technical mediation expands our notions of action and experience. Actors within the

network, such as a technical artefact, co-shapes the human world relations by giving shape not only to people's actions but also to people's experiences. The experience of the pilots within the first case studies series was mediated by their participation within this hybrid of human and non-human actors that relationally transcend linear temporal and spatial conceptualizations. In the first case (1991) the systems such as the navigation system, weapons system, the RWR that provided erroneous cues and alarms mediated the action of the pilots in addition to their experience of the event or more specifically the SA. It co-shapes the ways in which humans can be present in their world and the ways in which reality can be present to humans. Johnson (2004) analysis reveals how the NVG has been implicated in aviation accidents. This resonates with the analysis of the Tarnak case study whereby it was noted that NVG are '...famous for the way they distort images' (Friscolanti, 2005:257) which made it 'impossible to accurately estimate the height of munitions firing on the ground below' (Friscolanti, 2005:257). The 'system dynamic effects' of this technology in the way that human are presented in the world and the world presented to the humans interrelated with SOPs, ATOs, tactics, techniques and procedures is reflected in figures 5.6 and 5.7.

Supporting the translation and inscription within the actor network are the contractor and government making claims of reliability and inscribing that 'credibility' onto the actor. When we consider the concept of hardwired politics, GAO/NSIAD-97-134 (1997:1) explicitly illustrates how '...the long-standing DOD and manufacturer claims about weapon performance can now be contrasted with some of our findings. For

example it was noted that: ‘the F-117 bomb hit rate ranged between 41 and 60 percent—which is considered to be highly effective, but is still less than the 80-percent hit rate reported after the war by DOD, the Air Force, and the primary contractor; DOD’s initially reported 98-percent success rate for Tomahawk land attack missile launches did not accurately reflect the system’s effectiveness; the claim by DOD and contractors of a one-target, one-bomb capability for laser-guided munitions was not demonstrated in the air campaign where, on average, 11 tons of guided and 44 tons of unguided munitions were delivered on each successfully destroyed target (with averages ranging from 0.8 to 43.9 tons of guided and 6.7 to 152.6 tons of unguided munitions delivered across the 12 target categories; and the all-weather and adverse-weather sensors designed to identify targets and guide weapons were either less capable than DOD reported or incapable when employed at increasing altitudes or in the presence of clouds, smoke, dust, or high humidity’. This highlights issues pertaining to the very test and evaluation that weapon systems undergo prior to deployment (GAO/NSAID-00-119-2000) and resonates with issues pertaining to interoperability such as the RWR in the Apache case study, the Have Quick II radios in the Black Hawk case study, the system models in the Patriot case and the SOPs described in the Apache, Black Hawk, Tarnak and Patriot case studies that were insufficiently validated and employed.

Compounding the issue, the combination of SOPs, TTPs, technical capability inscribed and translated is reflected in GAO/NSIAD-97-134 (1997:21) in which:

While higher altitude deliveries clearly reduced aircraft casualties, they also caused target location and identification problems for guided munitions and exposed unguided bombs to uncontrollable factors such as wind. Medium- and high-altitude tactics also increased the exposure of aircraft to clouds, haze, smoke, and high humidity, thereby impeding IR and electro-optical (EO) sensors and laser designators for LGBs. These higher altitude tactics also reduced target sensor resolution and the ability of pilots to discern the precise nature of some of the targets they were attacking.

...Radar systems were less affected by weather, but the poor resolution of some radars made it impossible to identify targets except by recognizing nearby large-scale landmarks or by navigating to where the target was presumed to be. Radar systems specifically designed for target discrimination and identification suffered reduced resolution at the higher altitudes (and greater standoff distances) where they were operating.

Table 5.1 from GAO/NSIAD-97-134 (1997:26) highlights some of the discrepancies between claimed performance and actual performance. Training, tactics and procedures are based on the expectations of the equipment (actors). What does this mean in terms of our analysis? What emerges from the ANT ‘follow the actors’ analysis is that the relational impact of these actors results in the creation of expectations that links the ROE to the systems supporting identification and decision making resulting in ‘illusions of certainty’ thereby shaping actions, sensemaking and decision-making.

Table 5.1 Technical Performance Claims (cited in GAO/NSAID-97-134)

Table 1: Manufacturers' Statements About Product Performance Compared to our Findings		
Manufacturer	Their Statement	Our Finding
General Dynamics	'No matter what the [F-16] mission, air-to-air, air-to-ground. No matter what the weather, day or night'.	The F-16's delivery of guided munitions, such as Maverick, was impaired and sometimes made impossible by clouds, haze, humidity, smoke, and dust. Only less accurate unguided munitions could be employed in adverse weather using radar
Grumman	'A-6s...[were] detecting, identifying, tracking and destroying targets in any weather, day or night'.	The A-6E FLIR's ability to detect and identify targets was limited by clouds, haze, humidity, smoke, and dust; the laser designator's ability to track targets was similarly limited. Only less accurate unguided munitions could be employed in adverse weather using radar Only less accurate unguided
Lockheed	'During the first night, 30 F-117s struck 37 high value targets, inflicting damage that collapsed Saddam Hussein's air defense system and all but eliminated Iraq's ability to wage coordinated war'.	On the first night, 21 of the 37 targets to which F-117s were tasked were reported hit; of these, the F-117s missed 40 percent of their air defense targets. BDA on 11 of the F-117 strategic air defense targets confirmed only 2 complete kills. Numerous aircraft, other than the F-117 were involved in suppressing the Iraqi IADS, which did not show a marked falloff in aircraft kills until day five
Martin Marietta	'Aircraft with LANTIRN can 'locate and attack targets at night and under other conditions of poor visibility using low-level high speed tactics'.	The LANTIRN can be employed below clouds and weather; however, its ability to find and designate targets through clouds, haze, smoke, dust, and humidity ranged from limited to no capability at all.
McDonnell Douglas	TLAMs 'can be launched...In any weather'.	The TLAM's weather limitation occurs not so much at the launch point but in the target area where the optical [Deleted].
Northrop	The ALQ-135 'proved itself by jamming enemy threat radars, and was able to function in virtually any hostile environment.	[DELETED]
Texas Instruments	TI Paveway III: one target, one bomb.	Of a selected sample of 20 targets attacked by F-117s and F-111Fs with GBU-24s and GBU-27s, no single aim point was struck by only 1 LGB- the average was 4, the maximum 10.

Similarly, issues pertaining to dedicated anti-fratricide kit reflect issues pertaining to reliability. As reported in the Audit Report (2001:i):

The Battlefield Combat Identification System (BCIS) did not have an up-to-date and comprehensive test and evaluation master plan. Further, the Army lacked funding to test 19 operational requirements and did not plan to operationally test a production prototype of the system in cold, fog, snow, or rain. Without an updated test and evaluation master plan that accurately shows

user requirements, testers will not fully evaluate the effectiveness of the BCIS in reducing fratricide. As a result, the Army has increased the risk of producing a system that will not meet the full needs of the user.

We begin to see how the relationality inherent within the actor network permeates the socio-technical system and de-centers the blamism associated with pilot error. Winner (1980) argues that some technologies are ‘inherently political’ in that they have specific political consequences that will manifest themselves in any setting. The capabilities resident within the technology such as IFF, sensor systems and in particular the AWACS support the political, military and legal dimensions of the ROE. These very actors and the successes they have ensured (reflected in 50000 hours of accident free operations) justifies the status quo statement ‘Our operational flying missions in support of UN peacekeeping have not required special training programs...Pre-mission briefings are sufficient’ (Air Force Secretary Sheila Widnall in Fall of 1993) (Eflein, 1998:33). In the Tarnak case study, the systems and processes (ATO, SPINS, ROE) supported the pilot in the assignment of authority to act in self-defense. In fact across all incidents, the relational analysis and AFD modelling show that the ROEs shaped the SA, action and decision making of the pilots through processes of translation and inscription within the actor network. It is recognized through the analysis that there exists ‘...the challenge to balance competing interests in the formation of ROE. ROE that are too constrained will prevent the warfighter from getting the job done. ROE that are too broad could allow military operations which may be inconsistent with national objectives or may allow

room for fratricide' (Jeter, 2004:388). The implications for ROE therefore requires the alignment of the actor network to achieve the political objective. This requires that the ROE have supporting actors (with an inscribed capability and reliability) to achieve its goals. For example navigational accuracy, IFF capability supported by TTP and SOPs must be aligned to enable the ROE. A perceived 50% reliability and accuracy with regards to the IFF would inhibit the ROE by virtue of the perceived inability to 'positively' identify a target. Therefore the ROE permeates the network space to align the actors with its objective, through the process of translation.

Within the Tarnak 20002 incident, the failure in translation of ROE to the operational level (via ATO, SPINS, training, culture, physical system enablers) resulted in the misalignment of goals within the hybrid collectif comprised of the human, physical and informational domains and is reflected in: the failed effort to establish clear standards or provide mission planning support thereby contributing to the lack of situational awareness; the lack of uniform training and standards for squadron personnel; failure in the command and control processes and flow of information; failure in the promulgation, display and use of the Airspace Coordination Order (ACO), reflecting significant inconsistencies; and the lack of representation of ground forces at the Air Expeditionary Group Level (Jeter, 2004:380-381). These failure to align (successfully translate) the ROE to the operational level represent a lack of systems perspective on the operational level and hence within the ANT vocabulary, a failure in heterogeneous engineering. This failure in the translation was validated using AFD and the inventive problem solving methodology. In creating the pathways

to fratricide, these elements emerged from the tracing. What is important to recognize is that the actors take form and attributes as a function of their relation with other entities (Law, 1999). The ROE take their form through alignment with the actors such as IFF, SOP, ATO, SPINS and training.

In exploring the actor network characterized by a relational connection of heterogeneous elements, we turn to the ‘synthetic environments’ where the virtual world is comprised of a distributed network architecture. These distributed simulations are an instantiation of the actor network. The distributed simulations embrace HLA design principles that manifest as federations of simulations composed from modular components with well-defined functionality and interfaces and is therefore likened to heterogeneous engineering. As described in Buss and Jackson (1998:820-821), there are three main components to the HLA: the HLA rules, the HLA interface specification, and HLA object model template (OMT). The first component of the HLA definition is the HLA Rules that describe the responsibilities of simulations with respect to the RTI in an HLA compliant federation. There are five federation rules and five federate rules (Table 5.1a, 5.1b) (US Department of Defense, 1996, 1998):

Table 5.2a- Federation Rules

Federation Rules
(1) Federations shall have a FOM in OMT format.
(2) All representation of objects shall be in the federates and not the RTI.
(3) During federation execution, all exchange of FOM data shall be via the RTI.
(4) During federation execution, all federates shall interact with the RTI in accordance with the interface specification.
(5) During federation execution, an attribute of an instance of an object may be owned by only one federate at a given time.

Table 5.2b- Federate Rules

Federate Rules	
(6)	Federates shall have a SOM in OMT format.
(7)	Federates shall be able to update/reflect attributes and send/receive data in accordance with their SOM.
(8)	Federates shall be able to transfer/accept attribute ownership in accordance with their SOM.
(9)	Federates shall be able to vary the conditions under which they provide attribute updates in accordance with their SOM.
(10)	Federates shall be able to manage local time in a way which will allow them to coordinate data exchange with other members of the federation.

The second component of the HLA definition is the interface specification, a standard for federates to interact with the RTI. It defines how RTI services are accessed. The third component of the HLA definition is the Object Model Template (OMT), a common method for prescribing the information contained in the HLA object model for each federation and simulation. OMT is the interface language for HLA. Object models describe the set of shared objects in a simulation or federation, the attributes and interactions of these objects, and the level of detail at which the objects represent the real world including their spatial and temporal resolution. The HLA OMT provides a common representational framework for object model documentation. The OMT fosters simulation interoperability and the reuse of simulations. There are two types of object models in HLA, Federation Object Models (FOMs) and Simulation Object Model (SOMs), documented using the OMT. The FOM contains all shared information (objects, attributes, interactions and parameters) essential for a particular federation. The SOM contains all federate information (objects, attributes, interactions and parameters) which is visible to other federates in a federation and all information from other federates that may be reflected in the federate. HLA's approach to interoperability is through the ability to publish and

subscribe to attributes and interactions. These are discovered through the federation's FOM. Local object interaction is substantially different from remote interaction, since the latter is possible only by the receipt of the change in a subscribed attribute.

The HLA paradigm thereby represents a suitable analogy for the actor network. Like the actor network, the federates are relationally interrelated within the simulation. The federates have inherent inscriptions that shape the interactions within the distributed simulation and result in an emergent behaviour. As noted in the Australian DSTO-GD-0255 (Clark, Ryan and Zalcman, 2000:1):

The US DoD has mandated the High Level Architecture (HLA) which has technical advantages over the previous standard, Distributed Interactive Simulation (DIS). HLA provides greater flexibility compared to the rigid requirements to achieve DIS compliance. However this flexibility can also be a disadvantage since all participating simulations must agree on which information to interchange. This limits those players wanting to interoperate to agree before hand on such specifications, and may compromise the open interoperability that is a key feature of DIS.

From the ANT lens, this feature of HLA represents the translation process whereby an inherent 'power' inscribed into the use of HLA as an industry and NATO standard translates other models and nations to comply with the rules associated with that architecture. Failure to comply with the rules and specifications results in a dysfunctional simulation and invalid results. The HLA architecture has managed to align industry, nations, and technical standards in a distributed socio-technical system.

What emerges from a study of these simulations is how federates, representing black boxes in a network establish expectations based on the apparent simulation fidelity that shape sensemaking, action and decision making. For example in the JSMARTS II, the radiation dispersion model was inscribed with capabilities and limitations that shaped the course of the simulation exercise (figure 5.8). The fidelity associated with the 3-D models, translated and established expectations regarding the fidelity of the radiation models thereby establishing a belief that the radiation models take into consideration the complex material and structural nature of the city buildings in terms of radiation attenuation. Similarly in the MALO simulation, the federates such as the ocean model was based upon an inscription resident within a ray path tracing model and in situ data. This very choice of a federate capability actually sets inherent parameters within the simulation that affects the tactical employment of underwater sound in the prosecution of a terrorist subsurface threat. The operator using the simulation thereby approaches the exercise with expectations that have been inscribed into him through a process of translation (training both experiential and text based).

What emerges from this exercise is the realization that technology mediates and shapes the human experience and relations to their world. Taking these observations from the M&S world and applying them to the fratricide case studies reveals how actors such as the ROEs, ATO, SPINS and supporting physical actors (GPS, IFF) all shape the actions that emerge from the actor network. Mediation can therefore be considered the mixing of humans and non-humans in this actor network. It is through this mediation (mixing) that voices become deleted, the visible become hidden, a

black box is created. The process of black boxing (intentionally or unintentionally) makes the actors and their relations opaque (Latour 1994:36) as represented in the simulations whereby the federation (consisting of federates) represents a black box.

Mediation, translation and inscription processes lie at the kernel of the actor network. It is through these processes that we begin to understand how action, inaction, sensemaking, decision making are shaped by the actor network and thereby de-centers our perspective from the human to the network of heterogeneous elements that comprise the actor network. We recognize that the actors are not passive entities but participate in the creation of possibilities. To paraphrase Baygeldi and Smithson (2004:118), technology can be used as an instrument of influence and hence embody micro politics of power. The actors, through the distributed nature of agency within the network, ‘vary in the extent to which they influence or resist the influence of other entities’ (Somerville, 1999: 10). What is important to emphasize as reported by Somerville (1999:10):

Not only are humans and non-humans to be seen within the same (conceptual and terminological) framework, but micro-actors (individuals, computers, etc) and macro-actors (institutions, corporations, governmental organizations, etc) are to be seen in this way as well.

Sommerville (1999:10) argues that ‘Such interaction means, for instance, that computers as “non-humans” have now become such an intrinsic part of organizational life that any “failure” on the part of computers to play their allocated “role” will be no less catastrophic to an organization than a human failing’.

Within the domain of M&S, the illusions of certainty are best captured by the adage ‘Garbage in, Hollywood out’ (Roman, 2005:1). It represents how inscribed dysfunctionality within models can be ‘represented’ as having greater fidelity and certainty than it actually has. It represents an emergent behaviour that is realized within an actor network that includes both human and nonhumans.

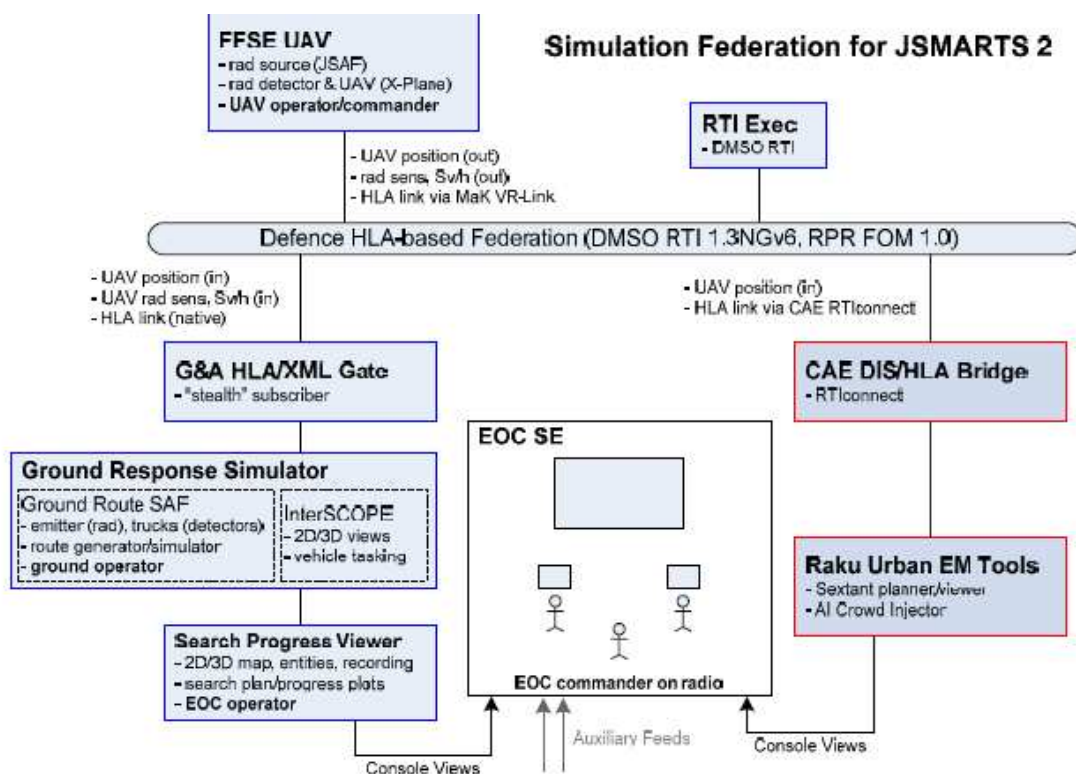


Figure 5.8- JSMARTS II Simulation Federation

The fratricide case studies are powerful reminders of how the decision to rely on automation, processes and integrated system of systems can be one of the most important decisions a human operator can make, particularly in time critical situations. Matters of trust emerge from this analysis and as described in Riley (1989) are

complex. As reported in Parasuraman and Riley (1997:234) ‘...operator attitudes toward automation might influence automation usage’. The seduction of technology often obscures the fact that new computerized and automated devices also create new burdens and complexities for the individuals and teams of practitioners responsible for operating, troubleshooting, and managing high-consequence systems (Woods et al., 1994). Law (2000a: 9) argues that ‘Adding complexity to the relations which make up a system in order to strengthen those relations may actually dissolve those relations in practice’. Failures to understand the reverberations of technological or process change on the operational system and the socio-political framework behind them hinder the understanding of important issues surrounding the evolution of human error within a system and how breakdowns occur. An artefact’s capacity for influence (whether physical or informational (ROE)) is thus dynamic and not static (Aanestad, 2003). The installation of new secure voice communications on the F-15 that was not compatible with the Black hawk operations; the complacency of successful operations thereby supporting the adoption of legacy processes; the misalignment of IFF and communications protocols associated with the Black Hawk are just a few examples.

The emerging issue from this analysis reveals how human, informational and physical domains intersect (at the hybrid collectif) and as such Command and Control becomes a relationally defined ‘entity’ that exists as a function of the three domains. The relational construct becomes politically charged enabling and constricting action and inaction. The ROE (rooted in politics) to bring about some strategic outcome, requires the cooperation (translation) of other actors to enable it. As such the network

represents ‘hardwired’ politics. Just as Law (1987) describes the politics inherent within the actor network of the Portuguese ship, so to the political agenda are transcribed and enacted by the hybrid collectif thereby enabling pilot error (black box) to become politically charged and hardwired.

We understand from ANT how tools shape use, misuse and action. They are as much of the command and control schema as the organization itself, thus command and control cannot be realized without the tools. They are therefore implicated in the accident aetiology through the inherent complex relationality. Much of the issues that stem from poor command and control and failure to align processes between SOPs, ROE and training as per the case of the Black hawk incident, the Tarnak incident and Apache incident can be traced to dysfunctional knowledge management (collection/creation, access and sharing) and the inability of the actor network to systemically learn.

As suggested by Hernes (2005:113), one way of analyzing decision-making processes is to ‘...work from the ways in which actors present themselves as spokespersons for institutions that exist beyond the organizational space, utilizing institutions as indisputable source of authority or knowledge.’ In the context of the fratricide incidents, the ‘devices’ such as NVG and image enhancers present themselves with an ‘authoritative capability’ that has been integrated into the system to “fix” problems associated with SA and hence through the process of translation shapes decision making and action. This is characterized as a stage whereby certain actors position

themselves as indispensable resources in the solution of problems that they have defined. Within the context of the case studies we view this in terms of the technical hegemony that permeates the solution space of fratricide. These actors within the network (such as GPS, reflector tapes, IFF, NVG, LGB) all impose their definition of a problem and their suggested solution on other actors. Hardwired politics not only define the problems and solutions but also establish roles and identities for other actors in the network. It is the realization of power that becomes apparent in the analysis whereby black boxed actors (or macro actors) have authority to act and speak on behalf of the whole network. This is an exercise in power through the process of translation.

The emergence of power as micro-politics are seen within the context of disciplinary technologies within a dynamic network construct. The system dynamic influence diagram (figure 5.6) captures this phenomenon. A new technology (a new actor) creates new dynamic and new capabilities, affecting the network space and relations. The relational interdependence and entanglement facilitates our understanding of how power relations within the actor network contribute to a distributed networked agency. Gephart (2004:22) argues that 'Power is the ability to have ones account of reality become the reality perceived by others in the face of alternative claims through the use of sense-making practices'. Power lies at the foundation of the process of translation. Urry (2002:60) argues that '...through complexity, power is conceptualized not as a thing or possession or structure, rather, power flows or runs, increasingly detached from specific territory or space'. Power emerges from the actor network, circulates

and flows aligning actors in the hybrid collectif. The interdependencies that permeate the network space through relations reflect differential power relations that result from a complex interweaving of interests and agendas. What takes place then is the black boxing of causality (Morrell and Hartley, 2006:496).

Design can be construed as a process where various interests (from various parties within the process) are translated into technological solutions such as the panels of the A-10 incident. In addition, the design encompasses organizational arrangements and procedures that must be followed to make the technology work properly (or as envisioned by the design team). Within this process, existing and legacy technology will be reinterpreted and translated into new ways of using it. To make the technology work, all these elements must be aligned, i.e. cooperating toward a common goal (Aanestad and Hanseth, 2000). This failure of the goals to align and cooperate is implicated in each of the case studies. The inscribed patterns of use may not succeed because the actual use deviates from it such as the 1994 case associated with the Black Hawk organizational SOP resulting in conflicting IFF and frequency management within the TAOR; such as the 1991 case in which the failure to comply with SOPs regarding the perpendicular approach along the friendly line of defence that shaped expectations. Rather than following its assigned program of action, a user may use the system in an unanticipated way; he/she may follow an anti-program (Latour, 1991; Monteiro, 2000). As noted in Thrift (1999:34):

From the interaction of the individual components [of a system] ...emerges some kind of property...something you couldn't have predicted from what you

know of the component parts...And the global property, this emergent behaviour, feeds back to influence the behaviour...of the individuals that produced it.

The influence diagram (figure 5.6) illustrates this behavior.

Agency

As described in Rose and Jones (2005:23) 'agency...is intimately connected with power, in fact this is one of its defining characteristics, since the loss of the capacity to make a difference is also powerlessness'. When we speak of the socio-technical systems, the social as described by Latour (1999b:17), can be viewed as (contrary to traditional thinking) not being made of agency or structure at all, but rather of being a circulating entity'. This has a profound effect on how we view the problem space associated with the case studies. We approach the case study without any preconceived (a priori) notion of agency and thereby address ourselves to the emergence of the 'social' as a relational attribute of the network space. Traditional accident models differentiate between the human and non-human and thereby make an assumption regarding the attribution of agency to humans. The material agency that we argue for is not an inherent structure or possession of neither some actor nor an attribute but rather is an emergent effect inherent within the relationality of the actor network (Callon and Law, 1995). Lanzara et al. (2005:67) argues for a '... complex web (network) of artifacts, actors and relations as essential in our understanding of collective or systemic task accomplishment coordination and agency processes'. In fact, '...agency effects depend on the extension of the network as a whole. If it looks

like the agency is stacked with the humans, this is only a peculiarity of the local topology of the network' (Middelton and Brown, 2005:314).

As described, with the realization of the 'hybrid collectif', what we conceptualize as human agency is transformed to recognize that non-human actors (technologies, policies, SOPs) shape interaction in this socio-technical construct and that human agency, as was traditionally developed is transformed by the actors. What we are saying about the case studies is that the distinction between the human and non-human in this actor network has been replaced with the realization that in fact our object of analysis is now a hybrid collectif. This is a finding that is consistent with previous research (Callon and Law, 1995; Noren and Ranerup, 2005) which illustrates how attributes of tools affect the construction of agency.

The experiences from the simulations clearly support the notion that agency is a relational effect. As noted by Lockie (2004:50) '...agency and power are themselves relational effects. Agency comes into being when the actors/actants are partaking in a network, not when they are isolated objects'. The fidelity of the associated models within the federated distributed simulation such as the 3D maps, UAV, radiation models of JSMARTS II; the ocean models, helicopter, aircraft and surface and subsurface models, weapons and sensor models of MALO becomes relevant. As such, the 'inscribed fidelity' becomes activated and relevant when the artifacts are put in use within the simulation. Agency is thereby enacted in the relational network of heterogeneous elements, within a specific network configuration defined by the HLA rules and simulation configuration. Collectively the distributed simulation as a whole

shapes behaviour, sensemaking, SA and decision making stemming from the very inscriptions and translations within the actor network. Agency therefore is realized as a network or relational effect as the objects within the simulations do not exist and function independently.

Rhizome

The relational complexity of the actor network associated with the case studies, depicted in figure 5.1, are topologically similar to that shown in figure 2.4 representing the rhizome. Figure 5.1 shows a network (rhizomal) construct that captures the essence of the ROE. As shown in figure 5.4 the accident aetiology, through AFD maps a rhizome. As a hybrid collectif, pilot error within the rhizomal conceptualization becomes de-centered as a cause with the realization that the multiplicity and heterogeneity associated with the actor network creates a complex aetiology that challenges the linear models. Action rather takes place in ‘hybrid collectifs’ that entangle human actors as well as non-human actants in multiple ways. Tools, for example are not just things that are used to achieve certain ends: ‘They contribute to the making of the universe of possibilities that make action itself’ (Callon and Caliskan, 2005:18).

ANT with its rhizome metaphor radically breaks away from the Euclidean scalar understanding to a relational conceptualization of space in a topological schema (Murdoch, 1998). In a rhizomatic or topological geography, we envision as described in Grabher, (2006:178-179) ‘...time/space consisting of multiple pleats of relations

stitched together’. The ROE and SOPS that were developed years in advance make themselves relevant through time and space to the very instance of the fratricide and thread themselves through the socio-technical domain. Supporting this, Ladkin et al. (2004) through his Why-Because-Analysis (WBA), reveal the nonlinear temporal and spatial characteristics of the accident aetiology thereby reflecting an interweaved and folded nature that within the ANT area of interest entangle actors such as IFF, GPS, AWACS, Command and Control, sensors, weapon systems, SOPs, legislation as described in chapter 4.

Through the hybrid collectif, the event-based ‘domino’ perspective disappears revealing a complex temporal and spatial heterogeneity. What emerges from the analysis of the actor network is the notion that time and space are folded thereby recasting the concept of latent effect/errors as purported by Turner (1978) and Reason (1990), in terms of a network schema. Events, actions, and decisions taken in ‘the past’, becomes relevant and present in this dynamic folding network space. This is particularly demonstrated by OPORD 91-7 that shaped the operations of OEF, but failed to be updated to reflect the new operations. Barad (2007:ix) writes ‘the past is never finished. It cannot be wrapped up like a package, or a scrapbook, or an acknowledgement; we never leave it and it never leaves us behind’.

This section summarized the actor network view of the problem space defining the actor, network, hybrid collectif, relations, and agency. The next section will build

upon this foundation developing the concepts of hardwired politics, illusions of certainty that reside and emerge from the actor network.

5.4 HARDWIRED POLITICS- ILLUSIONS OF CERTAINTY

Illusions of Certainty

Stemming from the thematic analysis of the case studies, informed by the simulation exercises and validated through AFD modeling, illusions of certainty emerge from following the actors and represent a key element that supports the argument regarding decentered aetiology. The concept illusion of certainty will be explained and explored through a conceptual and evidence based discussion that is rooted in issues pertaining to: Expectation; Translation and inscription (Technology); Sensemaking; groupthink; and Trust.

Expectation

Olson, Rose and Zanna (1996:220) argue that ‘Expectancies form the basis for virtually all deliberate actions because expectancies about how the world operates serve as implicit assumptions that guide behavioral choices’. Within the context of accident aetiology, Reason (2004:32) argues that the ‘path to adverse incidents is paved with false assumptions’. The evidence from the case studies show quite clearly how assumptions and expectations permeated the CID process and thereby shaped the decision making and action resulting in the fratricide event. For example the 1991 case study reveals evidence that previous fratricide incidents lessons learned failed to be integrated into the SOPS for the Apache missions in contradiction to the belief and expectation of the land force commander. The authority to engage the targets

identified by the Apache helicopters was given by the land force commander, in the belief that the target coordinates given by the Apache commander were indeed accurate and that SOPs informed by previous fratricide incidents were followed. Similarly, the queries by the Apache targeting helicopter regarding the positional accuracy of the targets were shaped by the ‘apparent and inherent’ accuracy and reliability of the navigation suite. Misreading the coordinates by the Apache helicopter and subsequent validation received by the Apache team and ground team perpetuated the false assumptions that shaped the decision making to engage. Target description was based on previous assumptions and expectations of position integrity thereby contributing to the illusion of certainty that resulted from the convergence of beliefs and expectations. As argued by Woods and Sarter (2010:12) and supporting the notion of illusions of certainty:

...the role of expectations illustrates that attention does not simply flow to salient events bottom up; there is a top-down component where previously cued knowledge about what has been going on, what is expected to occur and the priorities across goals influence what is interesting and, therefore, how focus of attention shifts in time, space and function.

The 1994 Blackhawk incident similarly contains evidence of false assumptions and expectations that are rooted in beliefs and trust dynamics that reside within the actor network. Faraj, Kwon and Watts (2004:191) argue that ‘...a belief can also be viewed as a mapping of cause-and-effect relationships that define “what technology does” and how it relates to other technologies’. These expectations are explicit and revolve

around human, physical and information domains. In accordance with SOPS, friendly air operations in the TAOR were not authorized until sanitization by the F-15 top cover. This established an expectation that any aircraft in the TAOR would therefore be non-friendly. Knowledge of any aircraft operations within the TAOR would therefore be explicit both within the ATOs and SPINS that specified all sorties. This was further supported by the AWACS that ensured coordination of all friendly air operations in that region and facilitated situation awareness to all coalition air operations. As described in chapter 4, a non-responsive mode IV IFF and confirmation from the AWACS of target existence with the phrase ‘hits there’ contributed to a mindset rooted in an expectation that the contacts being painted by the F-15 were indeed non-friendly. Similarly, the visual identification of the Black Hawk helicopters as Hind that was ‘collectively’ confirmed by the other actors (F-15 wingman, visual identification confidence rooted in training) confirmed, within the CID process, the contacts as enemy. The ROE were thereby enabled by the alignment of the actors (including informational, physical and human).

As described by Senge (1990:8), mental models are ‘...deeply ingrained assumptions, generalizations, or even pictures or images that influence how we understand the world and how we take action’. Chapman and Ferfolja (2001:401) discussed several processes through which mental models become flawed in industrial settings, resulting in misreading of situations which resonate with the problem space of fratricide. These processes include ‘...retaining outdated knowledge that no longer applies, accepting

unreliable sources of information at face value, and missing out on critical data because of poor communication within the work organization' (Chapman, 2005:346). The Tarnak farms case study show a similar pattern of expectations that are rooted in the visual identification of ground fire (given the navigational accuracy and geographical significance), the knowledge and information accuracy and currency of the AWACS that did not provide timely SA support coupled with the lack of detailed and transparent friendly activity within the ATO and SPINS. Add to that an ROE that created conditions whereby an expectation of alignment of barriers (material, functional, symbolic, immaterial) to prevent fratricide and authorizing engagement of targets was in place. These barriers are described in the Joint Doctrine Publication 3-09 (2006: I-5):

The destructive power and range of modern weapons, coupled with the high intensity and rapid tempo of modern combat, increase the potential for fratricide. Risk management must become fully integrated while planning and executing operations. Commanders must identify and assess situations that increase the risk of fratricide. Commanders then incorporate guidance into all plans to minimize and control risks by implementing preventive measures. The primary preventive measures for limiting fratricide are command emphasis, disciplined operations, close coordination among component commands, rehearsals, reliable combat identification (CID), effective procedures, and enhanced situational awareness. The risk of fratricide is greatly reduced when engagement decisions are vested with well-trained and qualified personnel.

Special instructions may also specify particular means to prevent fratricide in specific missions.

It is of note that the Ground troops in the Tarnak incident had personal IFF equipment ‘...two glint tape markers, one on the top of the head here, one on the left shoulder. They would wear their IF (infrared) strobe ...Investigators will later discover that neither the strobes nor the glint tape is visible from the altitudes that the F-16s were flying that night’ (Friscolanti, 2005:130-131).

In the context of Hutchins’ (1995a) analysis of ship navigation, the belief system established included the knowledge of individual members of the navigation team, as well as the assumptions that are embedded in standard operating procedures and tools of the trade. Viewing this model through the ANT lens helps to shed light on the emergent concept of illusions of certainty. What we recognize is that the actor network, through the processes of translation and inscription can shape beliefs thereby shaping decision making and action. As demonstrated in the case studies, the actor network can discount, ignore or reinterpret input in a way that they become more consistent with the expectations. Flach et al. (2008:143) argues that discounting of information is often observed on the path to accidents in human– machine systems. In the decision literature, this tendency is termed ‘confirmation bias’ or ‘cognitive inertia’. More generally, terms like ‘attention capture’, ‘tunnel vision’, ‘set effects’ and ‘fixation’ reflect situations where expectations play a dominant role in shaping the experience.

Illusions of certainty have everything to do with expectations. As Weick and Sutcliffe (2007: 23) argue within the context of organizations:

...that expectations are built into organizational roles, routines, and strategies. These expectations create the orderliness and predictability.... Expectations, however, are a mixed blessing because they create blind spots. Blind spots sometimes take the form of belated recognition of unexpected, threatening events. And frequently blind spots get larger simply because we do a biased search for evidence that confirms the accuracy of our original expectations.

Weick and Sutcliffe (2007:24) highlight some examples of those expectations:

...team members expect that a signal intended to alter a flight path will be followed, that a flight crew will be rested, that situation assessments are shared, that the correct weapons are loaded onto aircraft, that fuel is not contaminated, that weather forecasts are accurate and that operators know their jobs.

Within the context of the case studies evidence resides within the expectation of technical reliability, whereby the impact of the IFF in the 1994 case and the Patriot case highlight how a positive or negative response is interpreted to support the expectation. It resides within the expectation regarding inherent inscribed capabilities of actors such as the AWACS in the 1994 case and the Tarnak case as well as the FAC in the A-10 case in terms of knowledge and direction. They are a confirmation source, a source of authority. It links ROE to ATO, SPINS and highlights how management of the air operations and supporting texts and scheduling such as that in the Tarnak case described as 'dysfunctional' (Friscolanti, 2005:206) shape action.

When individuals equate general expertise with situational knowledge they create and rely on unrealistic expectations of those 'experts' (Barton and Sutcliffe, 2009:1341). This 'expertise' denoted as accuracy and reliability participate in the process of inscription and translation whereby actors are inscribed with an apparent expertise thereby persuading (forcing) other actors to recognize this attribute and defer to them. This crosses all domains of human, physical and informational and is reflected in the ROE, SOPs, hierarchical structure of air operations with respect to command and control and technical hegemony that shapes perception and decision making (IFF). The Patriot fratricide is an example of this expectation that has been delegated to the system by virtue of its inherent 'believed' reliability and accuracy rooted in its 'authoritative' performance specifications. It is further inscribed in the SOPs and training thereby translating behaviour to ensure processes are followed. These expectations are relationally rooted to the ROE that are inscribed into the system. Within the context of illusions of certainty at the organizational level Leveson et al. (2006:114-115) describe how a high launch rate without accidents within NASA '...contributes to the perception that the program is safe, eventually eroding the priority of system safety efforts'. This resonates with the case study that notes that the force flew in excess of 50,000 hours without incident (Fratricide). Leveson et al (2006:117) argues that '...High perceived success also creates the impression that a system is inherently safe and can be considered operational, thus reducing the priority of safety, which affects resource allocation and system safety status'. Expectations are reinforced through this illusion of safety, this illusion of certainty.

Illusions of certainty revolve around issues pertaining to reliability and competence across actors such as SOPs, roles and responsibilities. For example, in the 2002 Tarnak case study these illusions of certainty were revealed following the results of the investigation. The factors included:

1. Mission planning and preparation was not consistent across several units.
2. Airspace Control Order breakout, display and use are inconsistent in Operation ENDURING FREEDOM operations.
3. The Coalition Air Operations Center has no capability of recording internal or external communications to aid in debriefing.
4. Ground forces are not required to report live-fire training or activity within the given Air Tasking Order day.
5. Ground forces are not currently represented at the Air Expeditionary Group level.
6. The Airspace Control Order description of the Tarnak Farms did not encompass all types of weapons that were being fired.
7. The JTF-SWA Air Defense Artillery Liaison Officer was not properly trained in Battlefield Coordination Detachment operations.
8. U.S. Air Force AWACS have no capability to record external and internal communications or the Situational Information Display (SID) to aid in mission debriefs.
9. Surface-to-Air Fire (SAFIRE) analysis was insufficient at the squadron level.
10. The 332nd AEG was not managing and monitoring Go pill usage IAW USAF directives.

11. Post-incident actions were not consistent with established USAF procedures (Jeter, 2004:380-381).

Similarly, the Patriot case study highlights how unacknowledged system fallibilities and fascination with blind faith of technologies were implicated in the accident aetiology. As described in Hawley, Mares and Marcon (2010) system fallibilities were known in the 1980's however they were not satisfactorily addressed during system software upgrades, '...nor did information about them find its way into operator training, battle command doctrine, operating procedures, or unit standard operating procedures' (Hawley et al., 2010:306). Following the actors associated with this fratricide highlights how ROE, SOP and system reliability were dysfunctionally aligned, or rather were aligned through an illusion of certainty thereby precipitating the fratricide incident. This illusion of certainty permeated the organizational culture which emphasized 'reacting quickly, engaging early, and trusting the system without question' (Hawley et al., 2010:306). As well this trust in automation shaped the organizational management of personnel '...which tended to place inexperienced personnel in key battle command crew positions' (Hawley et al., 2010:306). The accident aetiology emerges from the hybrid collectif at the intersection of the human, physical and informational domains and as revealed is nonlinear both spatially and temporally. The illusions of certainty that are derived from expectations arising from translation and inscription processes represent a fixation. As Woods and Cook (1999:17) argue '...fixations represent breakdowns in the process of error detection and recovery where people discount discrepant evidence and fail to keep up with new

evidence or a changing situation. This is not new as it has been recognized in such accidents as the Three Mile Island’.

The JSMARTS and MALO simulations support the case study findings with the emergence of illusions of certainty in the matter of expectations regarding radiological dispersion models and the ‘operationalised’ expectations associated with the identification of targets and anti fratricide equipment, procedures and protocols. As discussed the distributed simulations with their inherent inscribed behaviour together shape the conduct of the simulation exercise through established expectations.

Translation and inscription processes

We recognize that technological artefacts are not used in a vacuum. They exist within existing networks and relationships with other actors. With the introduction of new technology, new processes and procedures, new actors, the network will not remain unchanged but either will re-adapt or fall apart (Aanestad, 2003:1). Supporting the notion of illusions of certainty McGuinness and Leggat (2006:1) argue that:

Clearly we want our information to be accurate, not vague; yet the apparently high precision of electronically displayed information can sometimes obscure the actual uncertainty or ambiguous nature of the underlying data or data filtering/fusion processes. The information as it is displayed might not provide any indication of such imprecision; creating the impression that one piece of data is as definite as any other.

As described in the case studies, the negative response of the IFF in both the Black Hawk and Patriot missile case studies illustrate this point. Similarly the text based orders generated through supporting information technology illustrates this point. Effectively combining information is a critical element of combat identification. As noted in Famewo et al. (2007b:7) data-driven information derived from visual cues, sensors and communications must be combined with the cognitively driven information such as expectations and beliefs. With this Famewo et al. (2007b:8) argues that ‘...too much information can cause people to arbitrarily assign weights to information or treat every cue as equal, therefore biasing their assessment of the situation’. It is recognized within the case studies how such biasing effects transpired. For example the Patriot case highlights how the technical illusions of certainty associated with the Patriot anti-ballistic missile model validity were implicated in the decision to fire (supported by the ROE linking the human, physical and informational domains).

Inscription processes arise within the B-52 case study. As noted in Musselman (2008: 9) ‘why was the product developed to display present position versus the last received coordinates when the battery is replaced? Did no one foresee the possible outcome and hazards posed to the operating crews or were the risk considered low?’. These features of the handheld GPS are hardwired into system. The failure to recognize these characteristics of the system means that illusions of certainty will develop and hence the translation processes will align the other actors to act according with the expectations. The crews failure to recognize the discrepancy stemming from

‘battlefield stress and time constraints’ (Musselman, 2008:9) , represents a misalignment of the heterogeneous actors.

What we learn from the simulation experiment of JSMARTS and MALO that support this is that:

Technologies are not simply passive and are never value neutral, but always exist in value-laden social and technical relations [think of sops, roes linked to technical supporting each other]. During the design phase, objects have embedded within them a ‘script’ or set of instructions that determine how the technology will function and the extent to which it may be shaped by other actors (Williams-Jones and Graham, 2003:276).

Within these synthetic environments, the very nature of the High Level Architecture and the distributed nature of the models (each scripted for a specific purpose: but not necessarily designed for this specific application) parallels the actor network world view. The presentation of the information from the simulations (as actors) shapes the perception and challenges the mental models of the observer (also an actor) that will shape SA and decision making. As noted in Faraj et al. (2004:194) supporting this notion of inscription ‘...beliefs can arise either from the technology histories of particular actors or from interdependent relationships among multiple actors’. This is particularly demonstrated in the simulation experiments. The belief regarding the validity and fidelity of the models (federates) is inscribed into its development histories and is evidenced through another actor (the corresponding documentation that details the models capabilities and limitations). Belief therefore becomes

interrelated to the pedigree of the model, its verification and validation (V&V) evidence (Masys, Roza, Giannoulis and Jacquart, 2008) and its representation. Arising from the simulation experiment and case study analysis it becomes apparent that ‘...objects and other non-human entities do affect human behaviour’ (Williams-Jones and Graham, 2003:273). Artifacts can be designed to ‘...replace human action and constrain and shape actions of other humans’ (Latour, 1992:225). Tracing from ROE to the fratricide incident, actors were aligned to enable the political, military and legal agendas reflected in the ROE (an act of translation and inscription). This actor network enabled action at a distance (Latour, 1992:225). The physical actors within the hybrid collectif determine certain actions through their entanglement with the informational domain (ROE, SPINS, ATO) and the human. Without this alignment, the ROE would not be able to be enabled. For example the employment of IFF (representing the ability to identify and classify an object) can be viewed as ‘...a substitute for the action of people and is a delegate that permanently occupies that position of a human’ (Latour, 1992:234). In the Patriot case study, the IFF represented this ‘identification’ supporting the application of the ROE. The GPS, with its inherent accuracy and reliability, is a substitute for the map reading duties of the aircrew. The GPS is delegated this position in the actor network. With this inherent reliability and accuracy associated with modern navigation systems, expectations thereby emerge regarding reported positional information such as that demonstrated in the Apache case, the A-10 case, and the B-52 case.

From the analysis we see that the process of translation plays a central role in knowledge creation. As described by Calhoun and Starbuck (2003:476):

...a widely shared perception or belief acquires the status of being objective; not only can it affect the actions of many but these many act with the support of objective fact. Indeed to motivate collective action, a perception or belief must be widely shared. When a perception or belief is supported by consensus, it gains the status of truth.

Gartner and Wagner (1996:210) reveal following their application of ANT that ‘...the ways actors inscribe their perspectives and knowledge in texts, technical artifacts, or organizational arrangements may invite misunderstandings or create ambiguity’. In the Black Hawk case this is significant in that the command and control was based on three-year-old guidance; ‘...no one was responsible for integrating the helicopters into the PROVIDE COMFORT mission’ (Eflein, 1998:55). Of note is the findings that Army helicopters were not adequately reflected on the ATO; no ‘individual was assigned to coordinate rotary wing sorties; no reference to helicopters appeared on the fighter pilots briefs; because the ATO was incomplete with respect to helicopters, the flow sheet did not even list them’ (Eflein, 1998:55). Thus, the F-15 pilots could not interrogate the Blackhawks' Mode II despite the ATO stating that Modes II and IV were to be the primary means of identification. This resonates with the establishment of ROE and SROE as described in detail in chapter 4 and reflects the translation and inscription processes that permeate the actor network.

Sensemaking

Sensemaking as described by Weick (1995) informs our understanding of illusions of certainty. Weick (1995:13) defines sensemaking as a continual process of ‘the ways people generate what they interpret’. It highlights the active process of creation that leads to a product of interpretation (Weick, 1995:14). Weick (1995:111) highlights sensemaking as a connection of the frames residing in the past and present. The expectations, beliefs and assumptions that emerge from these frames in turn shape the interpretation of a situation (such as the identification of an object) thereby informing decision making and action.

In terms of sensemaking, breakdowns occur when an inappropriate mental model persists in the face of evidence which does not fit this assessment. Woods and Cook (1999:10) argue that ‘Failures very often can be traced back to dilemmas and tradeoffs that arise from multiple interacting and sometimes conflicting goals’. This is reflected in the relational mapping of the accident aetiology. The translation processes that reside within the CID process from ROE to target engagement reflects an inherent conflict regarding the criteria for target identification as described in the ROE and ATO and the reliability of systems, SOPs and orders to support the ROE.

In order to challenge the illusions of certainty requires an interruption of ongoing patterns of action and to stimulate re-evaluation. What this entails is ‘...giving voice to concerns and seeking alternative perspectives’ (Barton and Sutcliffe, 2009:1337).

The inventive problem solving of AFD with the relational tracing of ANT suggests that there exists the requirement to assess and reassess the assumptions that shape SA and decision making. This is supported by Barton and Sutcliffe (2009:1336) who show quite clearly ‘...that almost all of the incidents ending well included a significant redirection of action, which generally resulted from individuals, often leaders, taking the time to reassess the current situation and operations’. It is argued in the literature that individuals may fail to redirect their actions not because they miss cues signaling the need for change, but because they are so embedded in the evolving situation that they fail to stop and incorporate those cues into a new understanding of that situation. In other words, failure to redirect action is a problem of sensemaking. Sensemaking is ‘the ongoing retrospective developments of plausible images that rationalize what people are doing’ (Weick et al., 2005:409). Sensemaking is the act of reassessing an ongoing situation and giving meaning to our actions. In shaping the mental model, sensemaking is an active process. Rouse and Morris (1986) argue that if a group shares a mental model, it serves as the basis for future event prediction and choice regarding courses of action. Such diagnoses and decisions are all fundamental to the safety process in any organization.

Groupthink

As alluded to earlier, from an actor network perspective the Groupthink phenomena can be recast within the network space to reflect how the actor, a heterogeneous network of elements, can collectively shape action and decision-making through illusions of certainty. Janis (1972) coined the term ‘groupthink’ to apply to a mode of thinking that people engage in when they are deeply involved in a cohesive in-group.

Janis (1972) argues that groups will reach poor decisions as a result of achieving 'group concurrence' suppressing critical inquiry' (Neck and Moorhead, 1995:537). Similarly, the illusions of certainty can be seen as an artifact of a concurrence-seeking tendency within the actor network space. The groupthink model articulated by Neck and Moorehead (1995:546) is recast through an actor network lens, in figure 5.9.

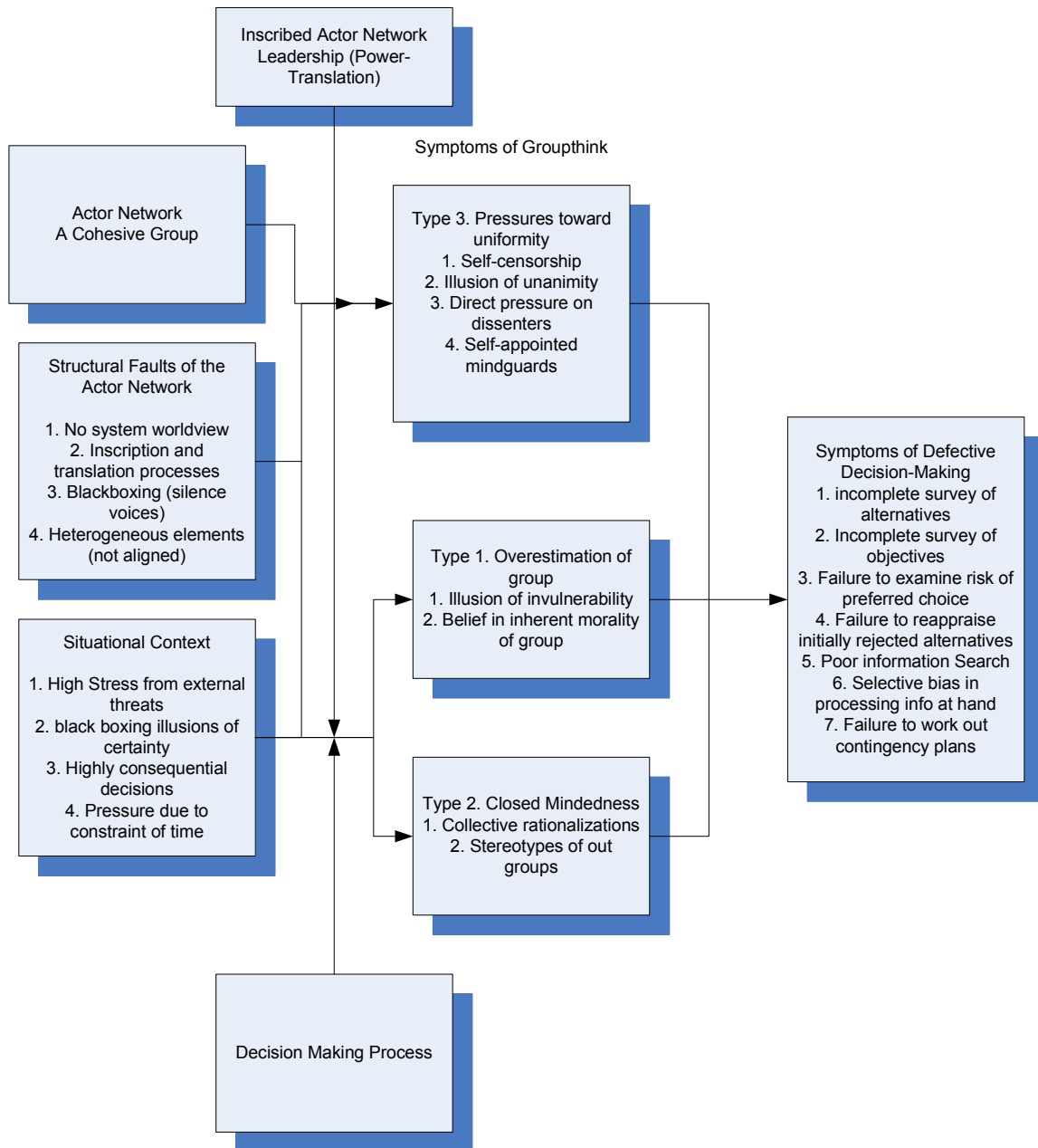


Figure 5.9 - Actor Network Groupthink conceptualization (modified from Neck and Moorehead (1995:546).

We see that the illusions of certainty that emerge within the actor network and shape decision-making is consistent with the concept of groupthink and are a function of the inscription and translation processes and is consistent with Idhe (1990) ‘technological intentionality’. Collectively the groupthink can be seen in the actor network space of

reinforcing, 'translated' processes that force and shape action and decision-making. When group confidence (translated actor) is perceived within the actor network, through concurrence seeking activity such as that facilitated by illusions of certainty, a 'groupthink' emerges from the network construct (one that comprises the socio-technical system as a whole). This 'groupthink' manifestation will translate (force) action that promotes compliance amongst the group (Henningesen, Miller, Eden and Cruz, 2006:41). The actor network groupthink evolves from the relational interconnectivity that intertwines the human, physical and informational domains. Through this, the actor network lens on groupthink recognizes the system influences effect on the decision making process.

In support of the Actor network groupthink concept, translation plays a central role in knowledge creation. As described by Calhoun and Starbuck (2003:476) '...a widely shared perception or belief acquires the status of being objective; not only can it affect the actions of many but these many act with the support of objective fact. Indeed to motivate collective action, a perception or belief must be widely shared. When a perception or belief is supported by consensus, it gains the status of truth'.

Take for example the IFF that failed to respond in the Patriot incident. The illusion of certainty associated with the Patriot as a system became a truth that shaped action and decision making. The inherent Patriot system characteristics that '...the operating protocol was largely automatic, and the operators were trained to trust the system's software' (Patriot System Performance Report, 2005:6) supports the notion of illusions of certainty. The illusions of certainty stemmed from the very low

probability failures that was purported of the system gained the status of truth and thereby shaped trust of the system. The characteristics of the systems such as the training, SOPs, ROE converge to support the groupthink. Similarly, the Black Hawk case reflected an ‘actor network’ consensus that aligned all the actors (ROE, AWACS, visual confirmation) that precipitated the decision and action. The A-10 incident reflects a distributed groupthink that exists with the physical, human and informational domains (comprised of the communications, ROEs, informational discipline, forward air controllers) that support the target identification and subsequent weapon engagement resulting in fratricide. In this case assumptions persisted within the communications regarding the target location that emerged on both the ground controller and A-10. The use of the reflector panels in a manner inconsistent with SOPs contributed to the illusions of certainty and the groupthink through rationalization of the visual identification.

The Black Hawk visual identification of the Hind was shaped by the SOPs, lack of IFF, lack of communication, lack of appropriate flight following by the AWACS in spite of the very different visual features between a friendly and enemy helicopter. As noted in Charmaz (2005:527), ‘...silence speaks to power arrangements. It also can mean attempts to control information, to avoid redirecting actions, and, at times, to impart tacit messages. The “right” to speak may mirror hierarchies of power: Only those who have power dare to speak. All others are silenced....In all these ways, silence is part of language, meaning, and action.’ This is reflected in the hegemony of the technical reliability, organizational competence (AWACS) and orders. The ROE

speak through and are enacted by the alignment of the network of heterogeneous actors. The socio-technical groupthink represents the power of the inscribed artifacts and translation processes in shaping SA, decision making and action. This resonates with the establishment of ROE and SROE as described in detail in chapter 4.

When people have a strong opinion or belief about the state of the world, they are more likely to seek evidence or cues that confirm this belief (Famewo et al., 2007b:33).

Trust

Within the socio-technical domain, trust has been widely discussed in the Human Factors and automation literature and is understood to be a predictor of system use, appropriate reliance on automation, and strategies for system use. As described in Lippert and Swiercz (2005) trust as a concept transcends the person-to-person notion to include inanimate objects. An object which is trusted can be a person, place, and event or object (Giffin, 1967). Muir's (1987) work on trust identifies three common trust elements that are applicable across domains to include human and machines: the description of trust as an expectation or confidence; the focus of trust toward a specific person, place or object; and the presence of multiple characteristics of trust referents. As argued in Cox, Jones and Collinson (2006:1123) '...trust is an important element of an effective organization and it plays a central role in the coordination of social actors' expectations and interactions' and is thereby relevant to the topic of accident aetiology.

Within the CID process, as garnered from the thematic analysis, within case and cross case, trust tends to reduce uncertainty allowing for ‘...specific (rather than arbitrary) assumptions about other social actors’ future behaviour’ (Ellingsen, 2003:197). The actor network analysis reveals the impact of trusting behaviour on safety outcomes with regards to fratricide. Trust is examined not in terms of trust in human interactions or trust in human–system interaction but rather trust within the relational context of the hybrid collectif. Through this lens, the foundations of trust are explored within the hybrid collectif interconnecting the human, physical and informational domains.

The positive and negative affects of trust on safety operations has been researched in domains of transportation (Jeffcott, Pidgeon, Weyman and Walls, 2006) and energy industry (INSAG-4, 1991). ‘All bases of trust have the potential to directly influence a trustor’s expectation and beliefs about the other’s trustworthiness and willingness to engage in trusting behavior’ (Schobel, 2009:318-319). For example, trust in another’s technical competence creates a confidence that another person has the necessary training to complete a task safely. However, it does not indicate whether the person will carry out the task in a safe way, or openly communicate about mistakes (Conchie and Donald, 2008:101). This is best described in the context of the 1991 case study in which the authorization to engage the targets rested with the land force commander, who well aware of the requirement for certainty with respect to identification and ROE, ‘trusted’ the Apache commanders positional and contextual description of the targets. This reflects an Institution-base trust with the potential to affect trusting beliefs and intention. This is mainly due to structural assurance beliefs (i.e. that proper

contextual conditions such as ROEs, SOPs and regulations are in place) (Schobel, 2009:320). High levels of institution-based trust may also have detrimental effects on safety. Trust in the mechanisms that support safe flight operations that reside within the process of command and control, orders and regulations have shown in the case studies to be implicated in unsafe operations. High levels of institution based trust may foster the assumption that the other has already checked the component and did not detect an unsafe state. Trust in information that has been directly inferred from others' behavior within institutional contexts may lead to reliability losses. This is reflected across all case studies and is particularly clear regarding the reliance of informational domain specific references to air tasking resident within the ATOs. Both in the 1994 and 2001 case study, misalignment of orders and procedures developed that shaped the belief and expectations of target identity as earlier referenced.

Mismatches between trust in the system and actual system performance result in inappropriate human monitoring and information-sampling behavior resulting from translation processes associated with ROEs that permeate the network space and emerge within the SOPs. Such is the case with the Patriot fratricide in which the Patriot operator uncritically counted on the reliability of automated systems. This phenomenon is called complacency. Due to the opacity of automated systems, trust mismatches may occur which undermine the benefits of automation (as within the patriot fratricide case in which overreliance on system capability precipitated the accident). Trust thereby emerges as a central component of safety performance.

The simulation exercises revealed how trust in federate capabilities shaped the development of situation awareness and decision making. Realization of the divergent properties of the federates capability in terms of performance (speed, sensor range) prompted the user to re-evaluate the tactics employed and decisions made.

Safety specific trust and distrust is modeled in figure 5.10 representing how these two factors affect safety operations. Drawing upon this model, it is clear that the mapping of the trust and expectations as described within the context of the case studies highlights how dysfunctional trust and distrust affected safety performance.

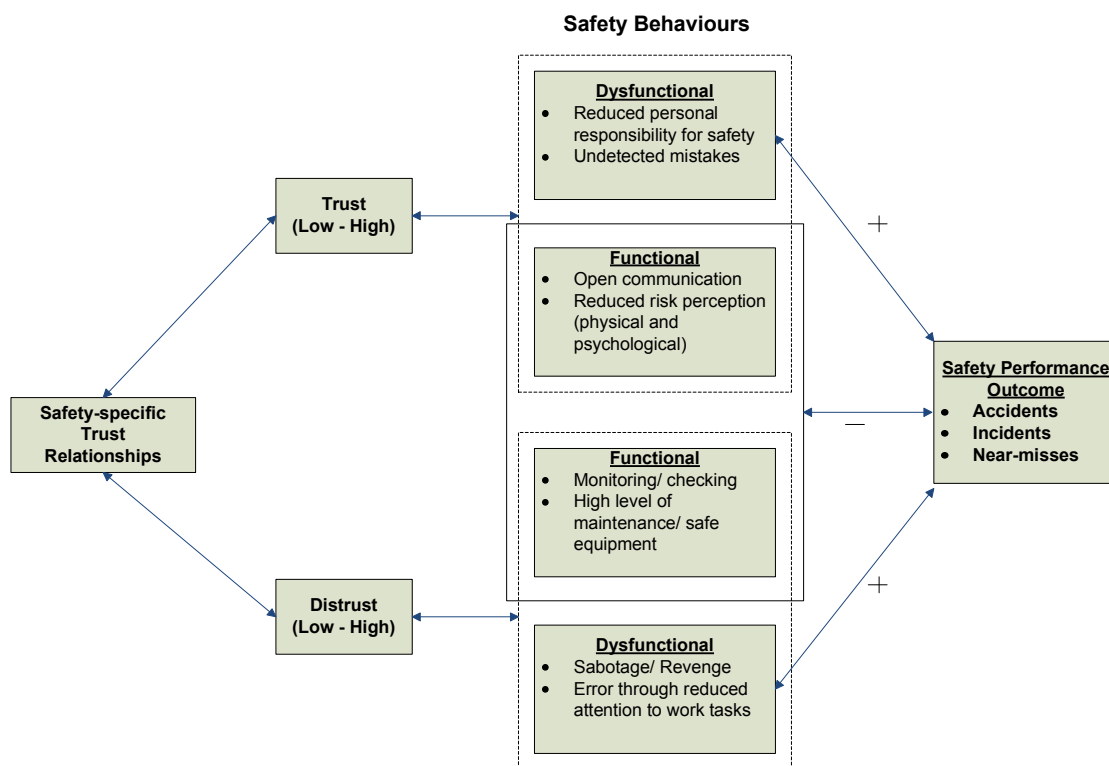


Figure 5.10- Model of the functions of safety-specific trust and distrust (Conchie and Donald, 2008:101).

Clearly the 1991 case study shows the undetected mistakes associated with misreading the navigation information, similarly the 1994 case shows the reduced personal responsibility for safety as the wingman ineffectively conducted an identification run thereby corroborating an already misidentified target. Trust emerges from the Patriot case in which personal responsibility was delegated to the automation of the system. Similarly the A-10 case study in which positional assumptions and the authority and capability invested in the FAC facilitated a dysfunctional trust. Evidence from the case study supports that both trust and distrust have a role in safety performance in operations.

Information trust refers to a user's willingness to accept a given piece of information into a decision-making process when the use of "bad" information could be a critical mistake. This is significant because as we begin to trace the actor network (follow the actors) what emerges is the process of translation that encourages other actors to the support dysfunctional trust (figure 5.10). The information source that 'forced' the land commander to order the strike in the Apache case study stems from the belief and trust in the pilots reporting of the contact position and assumptions based on belief of tactical SA. Similarly, the pilot's belief in the agreement of the land staff on his target can be seen to bias his decision. Similarly with the 1994 case study, the pilots trust of the IFF and the visual confirmation (that really was never received) created conditions that enabled an ROE that precipitated the decision to fire. The AWACS silence on this issue reinforced the perception. What becomes apparent is how, through the network analysis, the qualities of precision, accuracy and reliability are translated into

operational capabilities and safety qualities. These qualities shaped the actions of the pilot by creating expectations rooted in trust. NVG, GPS, laser guided bombs, radar warning receivers, IFF, AWACS, training, SOP all entangle their inherent and relational properties upon each other and the network as a whole to impose and stabilize certain characteristics, qualities, and attributes of the actor network. This is particularly revealed through the AFD modeling exercise that showed, using the inventive problem solving, the space of possibilities in which fratricide can be created. Trust thereby becomes an inscribed feature of the actor network that shapes action. Lee and See (2004:54) define trust as, ‘...the attitude that an agent will help achieve an individual’s goal in a situation characterized by uncertainty and vulnerability’. Trust in technology (or other actors such as ATO accuracy and timeliness) mediates the relationship between users’ belief about the actor’s capability and their reliance on the actor. Supporting the findings of Wang, Jamieson and Hollands (2008:292) and Jamieson, Wang and Neyedli (2008:27) and from the case studies and simulation experiments it became apparent that trust in an actor (technology, ROE, SOP) acts as an attitude shaping mechanism mediating the relationship between the users’ belief about the acting capabilities and their reliance on the aid.

Trust is an underlying characteristic resident within the actor network that informs combat identification and decision making. An important aspect of this that is explicit in the case study descriptions is the affect of information aggregation and decision making within the context of fratricide. As described in Famewo et al. (2007a:21) information aggregation involves ‘...both weighing and combining information (cues)

that is selected for relevance to the decision in a preceding process of information gathering. The information aggregation stage involves combining quantitative and/or qualitative information into a single output (e.g., estimate, probability, belief, or hypothesis) used to make a judgment'. It is argued by Famewo et al. (2007b:29) '...people often fail to use information aggregation strategies and instead choose a single opinion, estimate or judgment provided by an advisor or information source'. The pilot or user may seek to use the information derived from a particular actor based on their perception or belief of the actors accuracy and certainty. The IFF response in the 1994 and Patriot case studies is an example. Weighting, in terms of the amount of attention operators give to a cue is shaped by many factors such as trust in the use. Wickens et al. (1999) describes a weighting as the amount of attention people give to a specific cue. This weighting can be affected by many factors such as the saliency of the cue, the association of the cue to a correct choice based on previous experience. The weighting of the IFF in the 1994 case study or the weighting of the positional information derived from incorrect use of the navigation system is supported by other cues in an actor network groupthink to support the trust in the combat identification and lends itself to support the notion of a socio-technical groupthink. Factors supporting the belief include the accuracy of the ATOs, the silent confirmation of other actors in the system such as the AWACS or the land commander in the 1991 case study. Famewo et al. (2007b:30-31) emphasizes that '... Trust, certainty, relevance and importance of cues all affect how people subjectively weigh cues and sources of information (Yaniv, 2004; Wickens, Pringle and Merlo, 1999; Horrey and Wickens, 2001).

As described in Famewo (2007b:32) ‘...Military research has also suggested that people dismiss inconsistent information when making a decision’. Perrin, Barnett, Walrath, and Grossman (2001) studied how U.S. Navy personnel identified unknown aircraft. Information inconsistent with their judgment was recalled less often than consistent information, suggesting that the inconsistent information was weighted and processed less (an instance of socio-technical groupthink). It is also possible that the inconsistent information was reinterpreted to fit with a known pattern such as a schema, script or prototype already present in the experienced personnel’s cognitive repertoire. As stated by de Vries (2005:7), ‘analogous to interpersonal interactions, trust in a system's capabilities will influence its user's decision whether or not to delegate control to it, or whether or not system-generated advice should be followed’. In each case study, this notion of following or not following system-generated advice is apparent.

The simulation experiments provide excellent support whereby the inherent properties of the distributed models within the HLA established expectations of performance. The User thereby ‘trusts’ the fidelity that shapes expectations and decision making and action. As demonstrated earlier, this is reflected within the world of modeling and simulation with the adage: ‘Garbage in, Hollywood out’ characterizing how user can be seduced by the apparent validity of models that look realistic when in fact the underlying construct and coding is incorrect (garbage).

Black boxing of technology with inherent ‘perceived’ characteristics of certainty create conditions of trust within the actor network in terms of expectations that have been inscribed and translated. The statement from the A-10 incident whereby ‘All this kit has been provided by the Americans. They’ve said if you put this kit on you won’t get shot....You’ve got an A-10 with advanced technology and he can’t use a thermal sight to identify whether a tank is a friend or foe. It’s ridiculous’ (Barkham, 2003), illustrates how expectations and trust were built into the actor network. Similarly, the Tarnak incident reveal how the technological and organizational (process) solutions ‘inscribe’ a sense of reliability, set expectations and form a trust relation that permeates the actor network shaping standard operating procedures, orders and decision making. What is presented is a complexity view of trust, facilitated by the actor network theory perspective.

What emerges from the analysis is a hybrid collectif that thereby decenters the accident aetiology. Validating Woods and Cook (1999:23-24), the AFD (inventive problem solving) and system dynamic modeling shows how a single action has multiple effects (both intended and ‘side’ effects). As well faults and dysfunctionality within the actor network will produce multiple disturbances that converge to result in a fratricide incident. As the pilot and in fact pilot error becomes realized within a network of heterogeneous elements, pilot or human error is recast as distributed across multiple actors (Woods and Cook (1999:26). Cognition cannot be separated from the tools that support it. From the realization of the hybrid collectif, it is recognized that pilot error in terms of cognition is ‘... fundamentally public and shared, distributed

across agents, distributed between external artifacts and internal strategies, embedded in a larger context that partially governs the meanings that are made out of events (Woods and Cook, 1999:26).

Illusions of certainty emerge as well in post accident investigations in which hindsight bias can also affect the operators involved in the accident as well as the investigators. Flach et al. (2008:132) report that the operators, themselves, can also find that it is impossible to turn back time, to ‘see’ the world as it looked prior to an accident. The Black Hawk incident described by Snook (2000) was full of risk, role ambiguity, operational complexity, resource pressure, slippage between plans and practice. However in post accident investigation, the ambiguity, risks and complexity gets converted into binary simplicity (a choice to err or not to err). What becomes apparent from the analysis in terms of knowledge is echoed in Woods and Cook (1999:13) that ‘. . . bits and pieces of knowledge, in themselves sometimes correct, sometimes partly wrong in aspects, or sometimes absent in critical places, interact with each other to create large-scale and robust misconceptions’.

The argument presented show how illusions of certainty within the actor network are one rooted in issues pertaining to expectations, translation and inscription, sensemaking, groupthink and trust.

5.5 SITUATION AWARENESS

As described by Dean and Handley (2006:9) one of the three components that comprise Combat Identification is SA. Through the analysis, SA emerges as an issue within the case studies, is subsequently explored through the simulations and mapped and validated through AFD modeling. Complementing the cognitive paradigm of SA discussed in chapter 2, the ANT lens reveals SA as a distributed network construct of heterogeneous elements. This concept is informed by the distributed cognition approach (Hutchins, 1995, 1996) which presents a shift of focus from the individual actor to ‘how information is represented and how the representations are transformed and propagated through the system’ (Hutchins, 1995b:287). This holistic approach to SA is advocated by Hutchins (1995); Stanton, Salmon, Walker and Jenkins (2009); Salmon (2010); Stanton (2010) and Stanton et al. (2010) who argue for the need to take a systems perspective that includes the human operators and the tools and technology that they use.

Analysis conducted during the JSMARTS II experiment, and MALO experiment supports the notion that our experiences are mediated by the ‘technology’ and the underlying ‘social’ as characterised by the inherent relationality of the actor network (figure 5.11). As described earlier, the opacity of the federates involved in the simulation exercises led to an expectation with regards to the attributes and behaviour both individually and collectively from a federation perspective. The expectations shaped sensemaking, decision making and action. This is supported by Perrow (1984) who argues that sensemaking is an act of interpretation by an actor to garner understanding about a feature of the world. The creation of mental models as tools for

interpretation are shaped by the sensemaking processes which is a function of the presentation of information from the environment, however these mental models may be incomplete or internally inconsistent (de Vries, 2005). It is this sensemaking that lies at the foundation of the model of situation awareness (Endsley, 1999). From the actor network perspective, the socio-technological medium from which the actors derive their mental models and situation awareness presents some special challenges for sensemaking. Drawing upon Weick et al. (2005) we adopt a frame of inquiry that considers sensemaking as emerging from the interactions of different pieces of organizational knowledge distributed across artifacts, people, metrics, and routines (Weick and Roberts 1993; Hutchins 1995; Tsoukas 1996). As Dunbar and Garud (2009:399) argue ‘...Sensemaking around emergent events occurs as these distributed knowledge resources become interwoven into ‘action nets’. This concept of sensemaking emerging from distribution of artifacts and people brings to the forefront the processes of inscription and translation in shaping awareness, action and decision making.

As argued by Aanestad et al. (2003:4):

Common sense would have it that cognition is something that goes on inside people’s heads, not outside. Socio-technical studies, however, reveal that cognition is not only an individual’s achievement. The way work is organized socially, materially, spatially and temporally comprises crucial aspects in distributed cognitive work, such as within the team responsible for navigation of large ships (Hutchins, 1995).

Through the ANT lens, SA derives from a distributed collaborative environment thereby emphasizing the importance of the larger picture, including the material, social and organizational dimensions. JSMARTS II and MALO TDP reveal this. The federate representations within the simulations shape the way the operators viewed the world. As a distributed simulation, the federates (HLA) come hardwired with their inherent characteristics. Their collective behaviour arises from the integration of all the elements (complete with built in assumptions) inscribed. The effectiveness of the simulation is dependent on the accuracy associated with its interrelationships as compared to the real world. In post exercise debrief it was revealed that certain inherent limitations and constraints existed within the federate models by virtue of the conscious and intentional development of the HLA federation (in other words the characteristics of the federate models were inscribed with specific qualities and fidelity in support of the developers agenda). With a superimposed 3D model of the environment (figure 5.12), an assumption (illusion of certainty) was made as to the reliability, correctness and fidelity of the actor network. Described earlier was how apparently high precision of electronically displayed information can sometimes obscure the actual uncertainty or ambiguous nature of the underlying data and thereby affect SA. The distributed simulation provides a window into the complexity in the real-world in terms of the interdependencies and interrelationships. In particular the temporal displacement associated with the model development from the actual execution emphasizes the inscription and translation processes as they transcend the proximate.

In terms of SA, the experiment revealed how the elements of the simulation, including hardware, software, sensors, programmers, participants together shaped the situation awareness through its representational fidelity.

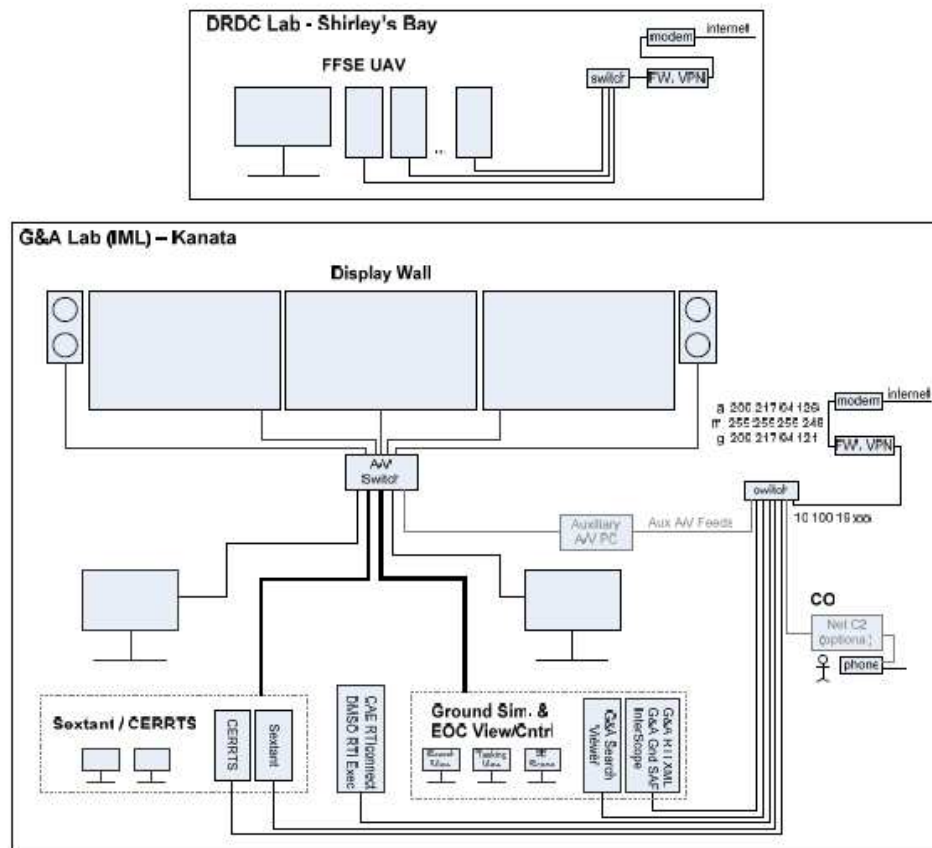


Figure 5.11 Physical Connectivity for Experiment and Demo in JSMARTS II



Figure 5.12a-Simulation Views of problem space

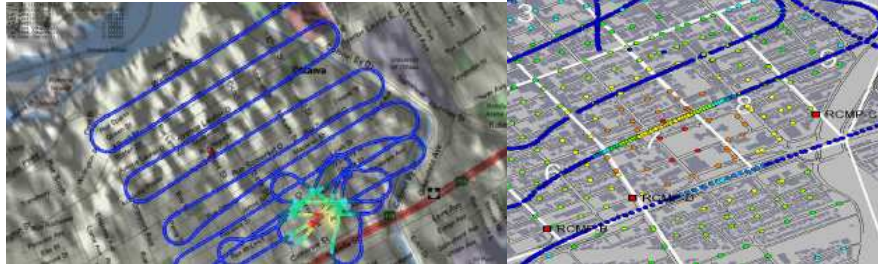


Figure 5.12b - Images of Synthetic Environment from JSMARTS II

The SA construct within the case studies that resulted in the misidentification stemmed from an interrelated network of human, physical and informational factors as depicted within the AFD model of SA (figure 5.13).

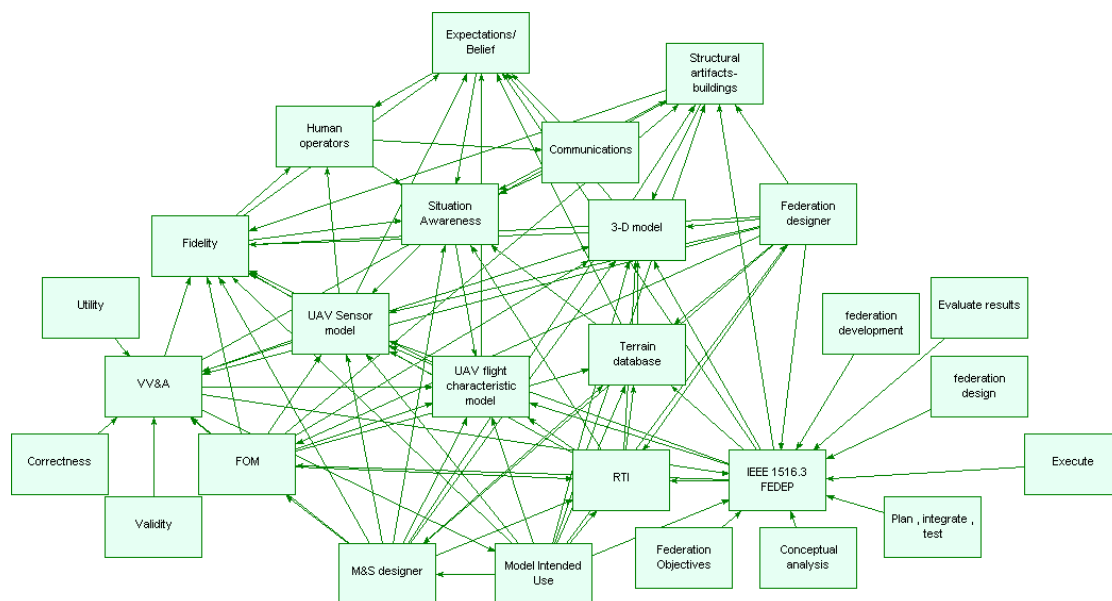


Figure 5.13: SA relational mapping within JSMARTS

The AFD analysis reveals how SA within the SE is distributed among the network of heterogeneous elements and how small changes or ‘discrepancies’ within the network

can propagate and affect the SA. The pathways to an accident are complex, interrelated and interdependent, relations thereby necessitate cohesion and alignment of the actors.

Equation (5.1) as reported by Bosse et al. (2007:93) characterizing SA in terms of a combination of perception, comprehension and projection represents a cognitive paradigm and is consistent with Endsley (1999).

$$SA = \text{Perception} \cup \text{Comprehension} \cup \text{Projection} \quad (5.1)$$

SA as revealed by this work in terms of a construct resident within a network of heterogeneous elements implies that the actors, in terms of their state and function, be taken into account when considering accident aetiology. This systems perspective of SA challenges the cognitive perspective, where SA is something that takes place in the head, and acknowledges the information quality, quantity and uncertainty that plays significant roles. Recognizing the systemic nature of SA, derived from the ANT analysis, and reflected and validated through AFD, equation 5.2 illustrates the heterogeneous nature of SA (Masys, 2008) as described through the actor network lens.

$$SA = f(\phi) = f(\phi, \beta, \lambda) \quad (5.2)$$

The functional terms represent elements within the human, physical and informational domains. Viewing the system in terms of a dynamic network space of heterogeneous elements, the decision-making and cognition is shaped within the context of a larger

distributed system of artifacts. As articulated by Hollnagel and Woods (1983) and Hutchins (1995), one can look at operational systems (network constructs) as a single-but-distributed cognitive system (network). The proper unit of analysis is then not an individual focusing on individual cognition, but is informed by distributed cognition (within a network space) that shapes and gives form to decision making for it is these very cognitive activities which are distributed across multiple actors (both human and non-human).

Attaining and maintaining SA, as a network construct is a collaborative process that comprises awareness of location, activities and intentions, which must be distributed across the system (Roth, Multer and Raslear, 2006:981). From the case studies we see that this was not the case. The translation processes within the actor network aligned actors creating an illusion of certainty that within an actor network groupthink created a convergence that precipitated the accident. Coupled with an inherent confirmation bias the actor reflects a tendency, as shown in the video and audio tape of the 1991 case study, to attend to information that is consistent with the preferred hypothesis and to discount information that is inconsistent (Klayman and Ha, 1987). The sensemaking research described in Gore, Banks, Millward and Kryriakidou (2006:931) given the cognitive frameworks is enriched by the Actor Network perspective illustrating how the processes of interpretation and meaning production reside within the dynamic Actor Network shaping SA and decision making.

5.6 DECENTERED AETIOLOGY

The ANT approach toward the problem space provided a lens into the nature of the system influences on the behaviour of the actors and the network dynamics; a shift from blaming to seeing the systemic nature and contribution of the actor network; and insights from thinking systemically. With regards to causality and accident aetiology, we draw upon Sterman (2001:16) who argues that:

...we use cues such as temporal and spatial proximity of cause and effect. In complex systems, however, cause and effect are often distant in time and space, and the delayed and distant consequences of our actions are different from and less salient than their proximate effects- or are simply unknown. The interconnectedness of complex systems causes many variables to be correlated with one another confounding the task of judging cause.

This systems dynamics view of complex causality is reflected in the work of Perrow (1984), Leveson (1995), Reason (1997), Woods and Cook (1999), Bennett (2001), Dekker (2005), Hollnagel (2006).

ANT becomes a toolset to support ethnography of distributed cognition systems.

The Actor Network perspective reveals a de-centered aetiology that is reflected by the distribution of relational network of heterogeneous elements that participate and shape action and inaction. What becomes apparent is that the attribution of blame is reexamined. Opening the black box of pilot error we realize that the accident aetiology resides as a property of the associations within the hybrid collectif rather than human agents. As Latour (1994: 34) remarks:

The prime mover of an action becomes a new, distributed, and nested series of practices whose sum might be made but only if we respect the mediating role of all the actants [which can be human and non-human] mobilized in the list. Action thus emerges from association and responsibility becomes distributed within the network of humans and non-humans.

The ANT analysis of the case studies, simulation exercises and AFD modeling supports this notion of de-centered aetiology. As shown in the AFD model figure 5.4, the key leverage points do not reside in any one actor; it becomes a matter of heterogeneous engineering. As described earlier, the pilot is a heterogeneous network. Pilot error is therefore a relational notion that resides within the network dynamics. Through the actor network analysis we recognize the emergence of complex causality (within the network space). As a point of causality, it suggests that as noted in Rossiter (2007:300):

...that there might exist many metaphysical shades between full causality and sheer non-existence: things might authorize, allow, afford, encourage, permit, suggest, influence, block, render possible, forbid and so on, in addition to ‘determining’ and serving as a “backdrop for human action”. Thus, agency itself is not a singular quality that expresses human intentionality; rather it is “an effect and an accomplishment “of complex interrelations or “chains of influences” involving humans and non-humans.

Mediating action is co-shaping what is happening. Take for example Latour's (1992) examples of speed bumps mediating people's driving behaviour by encouraging them to drive slowly; door springs mediating the speed with which people can enter a building, by giving them only a certain amount of time to enter; heavy weights attached to hotel keys mediating whether or not people return those keys to the reception desk, because they are usually too cumbersome to carry around for a long time. The mediation of action according to Latour (1992) has the form of 'prescriptions' that can be expressed in language as a 'script', a series of instructions on how to act (Verbeek, 2005:129). This is the basis of the argument whereby actors, a network of heterogeneous elements co-shape what is happening. The pilot is no longer the center of the accident aetiology. But what does this tell us about understanding and preventing accidents? It places us within the actor network, thereby allowing us to have a systems perspective on the accident. This is supported by Aanestad (2003:14) who argues that '...this illustrates that an artefact's capacity for action or influence is relational and not essential. It occurs or plays out in relations, when the artefact is part of an actor network; it is not a feature that is objectively present in an autonomous and isolated entity'. We see an entangled state, a state of possibilities as reflected in the AFD modeling. This relational perspective gives way to a network entangled view.

Carroll (1995:188) argues that 'the discussions of root cause seduction, sharp end focus, solution driven search, and account acceptability suggest that incidents are not viewed typically as learning opportunities but are reacted to with myopic causal analyses and familiar solutions that seem to fit the situation'. The actor network

perspective, as demonstrated in this thesis, challenges the root cause seduction and attribution of pilot error by opening the black box to reveal the social, as described in Latour (2005). What is realized is that traditional attributions of blame and human error fail to capture the ways in which new technologies are inevitably enrolled into complex social power struggles. The case study analysis reveals that operational reliability and safety, be it within a military operational context or aerospace industry, resides within the system.

Perrow (1984) and Reason (1990) argue that technology shapes human cognition and action. The ANT perspective reveals (in all case studies presented), that the aetiology of the accident or incident is resident within a network of heterogeneous elements (without differentiating between human and non-humans). The aetiology is one characterized by a de-centered causality. Contained within this paradigm, the latent failure theory (Reason, 1990) emerges as a relational element of the network space. What is constructed and conceptualized as ‘barriers’ to prevent fratricide are actually a part of the dynamic actor network. These opaque, black boxed barriers represent material physical, functional, symbolic and immaterial actors revealing the hardwired politics and illusions of certainty. In this de-centered aetiology, we explore pilot error and consider the organizing qualities of other actors such as technology and how these actors contribute to the aetiology through their controlling effects (Perrow, 1984) (resulting from processes of inscription and translation). It is important within this actor network construct that we do not consider just one piece of technology but rather view it from a systems perspective to see how the ‘technology’ as a system and part of

the actor network defines the operator and his/her actions and regulates a space of possibilities. As described in Lambright (1994:48), ‘the actor at times seems part of the ‘seamless web’, in which political, economic, and technological artifacts are brought together’. We see within the limitations of event-based model of accident aetiology the inherent inability to capture the complex interconnectivity of the relational construct.

5.7 CONCLUSION

The discussion contained in this chapter provided an interpretation of the problem space from an actor network theory perspective. This actor network lens provided insights into the problem space of fratricide that gave rise to the opening of the black box associated with pilot error, revealing a de-centered aetiology that arises from the actor network conceptualization of the hybrid collectif. The processes of translation and inscription give rise to a hybrid collectif such that ‘...like humans, non-humans can act, have intention (mediated), can delegate, distribute responsibilities etc’ (Oudshoorn, Brouns, and van Oust, 2005:85). The AFD modeling that was derived from following the actor reveals the hardwired politics that permeate the network space. They also therefore reveal the leverage points in the accident aetiology that can have significant impact on operations by revealing the space of possibilities enabled through the TRIZ methodology of inventive problem solving. The distributed simulation becomes analogous to the actor network whereby actors (federates) within the simulation (representing the actor network) are relationally interconnected and through their inscribed behavior and attributes influence perception, sensemaking,

decision making and action (all key elements of combat identification). Emerging from the analysis is the realization of situation awareness as a network construct of heterogeneous elements.

Chapter 6

Conclusion

6.1 INTRODUCTION

Human error is a prevalent finding in many accidents involving complex socio-technical systems (Perrow, 1984; Reason, 1990; Woods et al., 1994; Leveson, 1995; Endsley, 1999; Helmrich, 2000; Bennett, 2001; Shappell and Wiegmann, 2001; Johnson, 2003; Hollnagel, 2004; Dekker, 2005). With regards to accident investigations, Woods and Cook (1999:28) argue that hindsight biases often results in a distorted view of factors that contribute to the aetiology of an accident. It silences the uncertainties and demands that actors face thereby ‘...supporting the belief that human error often is the cause of an accident and that this judgment provides a satisfactory closure to the accident’. In fact, it is suggested in Flach et al. (2008:130) that hindsight bias leads to ‘...an illusion of a linear, causal world; when, in fact, we live in a chaotic, uncertain world’.

Challenging the ‘old’ thinking regarding the attribution of blame associated with pilot or human error, Hollnagel (2004:xv) remarks that within the new paradigm, ‘...accidents are seen as emerging phenomena in complex systems, and as the result of an aggregation of conditions rather than the inevitable effect of a chain of courses’. Dekker (2004:4) notes that ‘...if we cannot find a satisfactory answer to questions such as ‘how could they have not known?’, then this is not because these people were behaving bizarrely. It is because we have chosen the wrong frame of reference for

understanding people's behaviour'. This statement resonates with the opening of the black box via the application of ANT. This thesis entitled "Fratricide in Air Operations: Opening the Black Box, Revealing the Social", applied Actor Network Theory as a lens to facilitate a systems thinking-based analysis to examine the key dynamics that reside in the black box of pilot error associated with fratricide. The 'black box' has become an opaque representation of a complex problem space. It is by opening the black box that we reveal the 'social' that characterizes the accident aetiology associated with fratricide. As noted by Flach et al. (2008:126) '...the world is not a fixed stage independent of the actors who pass through it. The actors are participants whose actions contribute to the creation of the stage'. Recognizing this, a systems perspective has been taken (without privileging either the technical or human) revealing a de-centered 'aetiology' resident within a network of heterogeneous elements.

As reported in House of Commons Committee of Public Accounts (2006-07:5) 'The Department has failed to develop viable Combat Identification solutions to counter the risks of friendly fire incidents, despite their devastating effects, and despite the recommendations made by the Committee of Public Accounts in both 1992 and 2002'. The paradigm of systems thinking permits a view of the world as a complex system in which as noted by Sterman (2001:10) we come to the understanding that 'you can't do just one thing' and the 'everything is connected to everything else'. This is supported by Senge (1990:73) who is of the opinion that the discipline of the systems approach lies in a shift of mind: in seeing interrelationships rather than linear cause-effect chains

and seeing processes of change rather than snapshots. Systems thinking thereby is an appropriate approach for communicating such complexities and interdependencies. This thesis supports the work of systems theorists of accident aetiology and recasts it within a network construct revealing important features of the problem space and solution space. Further it supports the findings of Bennett (2000) in terms of his holistic analysis and thereby supports Reason's (1990) view that history matters in terms of influencing actions and events. This work expands these findings and characterizes the socio-technical problem space as a Hybrid Collectif (Callon and Law, 1995) and further introduces the concepts of hardwired politics and illusions of certainty as insights into the argument that pilot error is not an explanation but is something to be explained. This chapter provides an overview of the findings and presents some concluding remarks regarding the research conducted for this thesis.

6.2 OVERVIEW OF THE PROBLEM SPACE

Expanding upon the linear event based view of accident aetiology and with the subsequent rise of the systems perspective (Perrow, 1984); accident models based on systems theory are now being viewed in terms of interactions among humans, machines, and the environment (Leveson, 1995). This has given rise to a network view recognizing the complex causal factors acting in a space characterized by temporal and spatial heterogeneity. As such, a systems perspective gives rise to a view of multiple and interdependent events associated with an accident thereby, recognizing that accidents cannot be accounted for by single variables or factors.

Through the ANT lens, neither the human or non-human are privileged but rather the actors are treated symmetrically and in this way facilitate a tracing of the relations that uncover the ‘social’ that permeates complex socio-technical systems. Emerging from the research this actor network analysis reveals 3 domains: Physical/ Human/ Informational that define the problem space. From actor network theory we view the 3 domains as interrelated. The intersection of these domains represented by the symbol ϕ (figure 6.1) encapsulates the actors that reside within the actor network. It is at this intersection of the domains that the hybrid collectif emerges, whereby the dichotomy between human and non-human (technical) is erased, representing a socio-technical entangled state space.

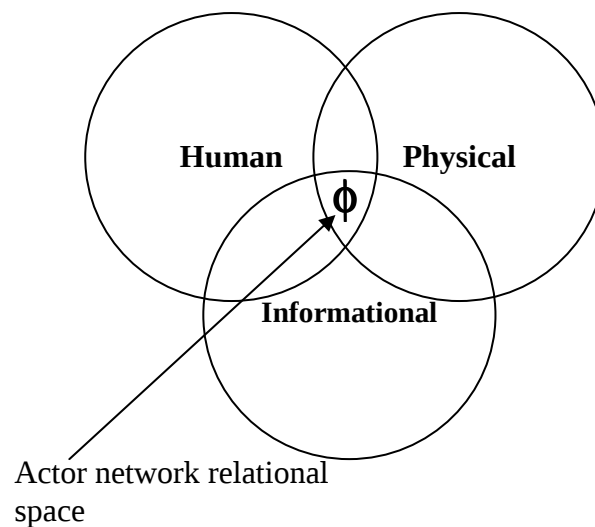


Figure 6.1- Domains of accident aetiology.

Safety emerges as ‘...the outcome of the quotidian engineering of heterogeneous elements: competencies, materials, relations, communications, and people that are integral to the work practices’ (Gherardi and Nicolini, 2000:11). Safety can therefore

be viewed as an emergent property of a socio-technical system, involving the human, physical and informational domains. The ANT analysis reaffirms the concepts purported by Turner (1978) and Perrow (1990) in terms of system accident and here recognizes that management and organizational issues reside at the intersection of the 3 domains.

Research from the cognitive domain has gone a long way in highlighting many of the issues pertaining to human error. Busse (2002:88) argues that ‘...the nature and causes of failures due to human error remain relatively poorly understood ... the focus in the community of aviation researchers and practitioners could still be shown to be on a “blame and train” approach, rather than to focus on a meaningful, contextual analysis of human error’. Dekker (2003:99) argues that ‘...if you want to understand what went on in the mind, look in the world in which the mind found itself, instead of trying to pry open the mind. Constraints in the world can, for example, arise from the engineered interface or the organizational context’. Through the ANT lens on the problem space we ‘reveal’ the social in terms of a relational construct giving rise to a network conceptualization of the system. Human error/pilot error is therefore seen within the context of a system in order to explain its aetiology. The techno-centric myopic view that permeates the socio-technical systems fails to reveal the interrelations between networked actors of the problem space. The insights garnered from this analysis have revealed an accident aetiology that considers the networked relational perspective of ANT and the dynamics afforded by complexity theory. The holistic approach facilitates a more grounded understanding regarding the attribution

of pilot error. Further, it complements the work conducted by Busse (2002) as well as Busse and Johnson (1998) in terms of error analysis and cognitive theory.

Through complexity theory we recognize that:

Interactions among certain dynamical processes can create...new properties that are not the simple sum of the components that constitute the higher level. In turn, the overall dynamics of the emergent distributed system not only determine which parts will be allowed into the system: the global dynamics also regulate and constrain the behavior of lower-level components (Flach et al., 2008:128).

The new and rich imagery associated with complexity theory fosters an awareness and sensitivity to dynamic processes and emergence. With systems theory, together they provided a perspective and understanding of the problem space that is holistic and qualitative. The traditional linear model becomes a 'special case', a simplification of a nonlinear world. The use of metaphors, analogies and imagery in this thesis draw attention to important and relevant aspects of the accident aetiology. The power of these tools and the approach in general allows us to view the problem space with a consideration of '...notions like nonlinearity, sensitivity to initial conditions, feedback loops, unpredictability, process and emergence' (Tsoukas, 1998:305). The analysis revealed that there exists a disproportionality of 'causes and effects', in which as Urry (2002:59) remarks, past events are never 'forgotten'. The complexity paradigm revealed within this thesis that nonlinear processes are an underlying characteristic of the socio-technical domain, recognizing that changes are

discontinuous, fluid and fluxing. The ANT approach (informed by complexity) suggested that the inherent nonlinearity associated with the accident aetiology arises from the multiplicity of interconnected relational actors in the network whose identity is considered opaque from the mechanistic linear perspective associated with accident models. The dynamic network space opens up to a space of possibilities resulting from the complex intra-actions resident within the network space.

6.3 ACTOR NETWORK

The application of actor network theory has been instrumental in opening the black box of pilot error. Actor network theory presents all entities (people, concepts and actions) as taking form and attributes as a function of their relation with other entities (Law, 1999). A network, as proposed in Baygeldi and Smithson (2004:119) ‘...can be described as a dynamic system of communication, cooperation and partnership between individuals and groups’. Within the context of this problem space and the actor network perspective, we expand upon this to remap the individual and group to a network of heterogeneous elements both human and non-human giving rise to a schema of interconnectivity and relationality. Within this topological construct, Urry (2003:122) describes how the micro/macro distinction loses its meaning since ‘...both micro and macro are local effects of hooking up to circulating entities (Latour, 1999:19)’. As such, this challenges our notions of far/close, small scale/ large scale and inside/outside (Latour, 1996:370) and forces us to think in terms of associations and relations within the case study analysis. ROE shaped by political, military and legal advisors displaced in time and space become present in the operations through the inscription and translation processes within the actor network. Not only do the case

studies reflect this actor network schema but information infrastructures (Faraj et al., 2004) and for that matter distributed simulations such as that demonstrated by the JSMARTS II and MALO experiments can be seen as heterogeneous actor-networks that consist of a particular configuration of more or less aligned human and non-human components.

We recognize from the analysis that:

1. Non-humans have significance and are not simply resources or constraints
 - a. Non humans intervene actively to push action in unexpected directions.
2. Entities are interactive effects
 - a. They are networks of associations of human and non-human.
3. Action results from the complex interactions resident within the actor network that is dynamically shaped by inscription and translation processes.
4. The actor network lens reveals that action cannot be explained in a reductionist manner, as a firm consequence of any particular previous action (Callon and Law, 1997:172).

This thesis shows and supports the findings in the literature that: ‘action is equivalent to specific and materially heterogeneous relations...hybrid collectifs. These relations, human and non-human, carry action, they exert it, and they modify it’ (Callon and Law, 1997:172). What we purport is that if we wish to understand action then we need to explore the patterns of relations that reside in fraticide.

Hybrid Collectif

The case studies analyzed reveal this nature of hybridity through the paradigm inherent within ANT. The complex socio-technical system that so characterizes systems of today is viewed as a network construct of heterogeneous elements relationally interconnected via aligned and opposing interests simultaneously coexisting forming what we refer to as a 'hybrid collectif'. It is argued that 'Pilot error is not an explanation but is something to be explained. The 'opaque' veneer of 'blamism' that characterises pilot error obscures the fact that it is comprised of a network of alliances (Brey, 2005). This radical relationality characterizes the hybrid collectif such that as noted in Lockie (2004:50) '...Action, intentionality...derive from relations between entities rather than from either individuals or totalities'. Technological intentionality as described by Verbeek (2005) and revealed in the analysis emerges from the interconnectivity and context. This encapsulates what lies at the foundation of our understanding of pilot error and fratricide. The network schema that is applied to understanding accident aetiology is supported by Hollnagel (2004:123): '...the essence of a systemic model cannot be captured by any of the tree based representations or by simple graphs...the notion of sequential development which is inadequate to show the functional dependencies...the obvious alternative is instead to use a complex graph such as a network.'

JSMARTS II and MALO simulations illustrated the distributed heterogeneous nature of situation awareness and reaffirms the concept of the hybrid collectif. It demonstrates as William-Jones and Graham (2003:275) argue that 'Entities whether

people or technologies, are not fixed and do not have significance in and of themselves. Instead, they achieve significance through relations with other entities'. The case studies show that such actors as policies, behaviours, motivations, and goals that reside in the actor are translated from one actor to another; and actors are themselves translated and changed in their interaction with others (Callon, 1986). As noted in Brey (2005:76) and for which is confirmed in this thesis, '...that any fact about the competencies and performances of a particular technical artefact is the product of a network of actants that jointly work to "produce" this fact.' The attribution of an 'enemy target' in the CID process is such a 'produced' fact. This arises from the 'illusions of certainty' and hardwired politics in the actor network as described in detail in chapter 5. The hybrid collectif that emerges from the network reaffirms that artefacts that comprise the actor network cannot be understood in isolation. Ottino (2003) argues the same point with regards to complex systems. Thrift (1996:1468) makes a supporting observation:

...no technology is ever found working in splendid isolation as though it is the central node in the social universe. It is linked- by the social purposes to which it is put- to humans and other technologies of different kinds. It is linked to a chain of different activities involving other technologies. And it is heavily contextualized.

Within the context of this thesis, the technology (actors) that is embedded within the network such as GPS, LGB, computer displays, NVG, thermal imagers, IFF, secure communications are relationally connected to the 'pilot' (actor) and shape action and

inaction. Through ‘follow the actor’, the processes of inscription and translation are revealed such that the hardwired politics and illusions of certainty become visible.

Causality as shown in the case studies is reflected in the comments of Barad (2007:394) ‘...future moments don’t follow present ones like beads on a string. Effect does not follow cause hand over fist...causality is an entangled affair’. Technologies, texts, artifacts or non-human actors must be recognized as enablers of the network forming this hybrid collectif. In fact as described in chapter 5, the analysis reveals how the boundaries between humans and non-humans become ever more blurred. In this relational space ‘...it makes no sense to talk of a machine, computer, technology in general than it does to talk of a “human” in general’ (Graham, 1998:178). Agency, to emphasize the point from the analysis is something that is generated within the network space, a relational effect. As noted in Middleton and Brown (2005:314) ‘If it looks like the agency is stacked with the humans, this is only a peculiarity of the local topology of the network’. The argument for non-human agency has profound consequences in how we view aviation accident aetiology. The recognition of non-human agency lends itself to a decentered ‘network’ view. As noted in Dolwick (2009:42):

The argument made by ANT is that agency can be extended to all artefacts, since their existence already causes changes in behaviour, routines and abilities: in order to understand human behaviour we must study the technological artefacts. The technology is not a passive recipient of experience; it contributes to the creation of experience.

The decentered aetiology that is characterized by the hybrid collectif reveals that as argued by Dolwick (2009:42) ‘...if one were to try to draw a map of all of the actors present in any interaction, at any particular moment in time, instead of a well-demarcated frame, one would produce a highly convoluted network with a multiplicity of diverse dates, places and people’. Pilot error is therefore not an instant in time but the entanglement of an actor network, of multiple spaces and multiple times as described in chapter 5. The actors are relationally linked with one another in webs or networks. They make a difference to each other. They make each other be (Dolwick, 2009:45). People, organizations, technologies, politics are the result of heterogeneous networks (Cressman, 2009:4).

Of particular interest in the actor network is the realization that “knowledge” can take material forms. It appears in communications, SOP, orders, ATO, ROE, AOI. It appears in the form of skills embodied in aircrew (Latour and Woolgar, 1979). The actor-network view of fratricide reveals that knowledge is a process of “heterogeneous engineering” in which bits and pieces from the social, the technical, the conceptual and the textual are fitted together, and so converted (or “translated”) thereby shaping sensemaking, situation awareness, action and decision making (Law, 1992:2). The management of this knowledge becomes a key enabler for safe conduct of operations. This recognizes that ‘...all these elements are involved in a constant process of generation rooted in organizational practice and called the “engineering of heterogeneity” (Law, 1992).

6.4 SITUATION AWARENESS

Endsley's (1999) understanding of SA is a dominant approach within the military and aviation domains. As the perception, comprehension, and projection components of SA characterize mental attributes, awareness is therefore understood to be resident within the human. Given the systems perspective of the problem space and the distributed networked view enabled through ANT, this work supports the argument of Artman and Garbis (1998:151) that '...the predominant models of situation awareness (SA) are inadequate for the study of systems operated by teams. The reason for this is that these models are based on mentalistic assumptions focusing almost exclusively on individuals'. Treating the whole socio-technical system as the unit of analysis, the ANT analysis supports the notion that SA is an emergent property (Stanton, 2010:30) that arises from the interaction within the actor network (hybrid collectif).

It has been argued by Dekker (2005a:92) that the 'Loss of situation awareness is accepted as sufficient explanation too quickly too often, and in those cases amounts to nothing more than saying human error under fancy new label'. This analysis suggests that to understand SA in complex systems is to look at the relationality inherent within the network of heterogeneous elements. Building on the foundation of situation awareness as proposed by Endsley (1999), what emerges from the analysis, as described in chapter 5, is that SA is conceptualized as a construct, resident within a network of heterogeneous elements (Masys ,2004; 2005; 2006). With this in mind, SA is characterized as a dynamic quality of the network space where history matters and context matters. What we garner from such insight within the domain of M&S is that

actors cannot be considered independent from each other and the environment (Van Dyke Parunak, 1996). The JSMARTS II and MALO TDP experiments support the notion of SA arising from a network of heterogeneous elements and thereby support the notion of distributed SA. The implications of the ANT perspective of SA is that it contributes to the theoretical knowledge of cooperative practices of distributed teams (actors) and points to ways it can be deployed to support SA and thereby enhance overall safety and effectiveness (Roth et al., 2006). The SA construct recognizes the impacts of emerging technologies, texts and SOPs on aviation safety and to provide guidance for design and introduction of the technologies, procedures, and processes (Roth et al., 2006). Recognizing the systemic nature of SA, we present an equation (6.1) that highlights the dynamic, heterogeneous nature of SA (Masys, 2008), where the functional terms represent elements within the human, physical and informational domains.

$$SA = f(\phi) = f(\phi, \beta, \lambda) \quad 6.1$$

The ANT analysis highlights the possibility of functional networked ‘collaborative’ processes that reside within the network space that participate in the development and maintenance of shared situation awareness in a distributed awareness system. It is through the relational tracing of ANT and AFD modeling that we begin to recognize the distributed nature of SA within the system. This is supported by the propositional networks described in Stanton (2010:3).

As described in Macrae (2005:46) ‘...situation awareness and combat identification are influenced by perceivers’ habits, their beliefs about what is, and their beliefs about what ought to be’. Plaskoff (2003:163) argues that ‘...completion of actions and problem-solving (or cognition) is based on distributed access to information and knowledge and a coordinated shared understanding amongst participants’. In this sense action arises as a collective phenomenon distributed amongst human, physical and informational domains. This network construct of SA is supported by Artman (2000: 1114) who argues that:

...situation awareness is not simply the sum of individual SA or a completely group level idea of a situation, it is an actively communicated and coordinated accomplishment between several members. This accomplishment emerges in a context where artefacts and information technology partly structure the possibility of sharing and distributing information.

6.5 HARDWIRED POLITICS AND ILLUSIONS OF CERTAINTY

Policies, SOP, technology, and training all participate in the creation of illusions of certainty and hardwired politics within the system that shape action, sensemaking and decision-making enacted through inscription and translation processes. As described in Woods (2006:24) ‘...accidents have been noted by many analysts as ‘fundamentally surprising’ events because they call into question the organizations model of the risks they face and the effectiveness of the countermeasure deployed’. In other words, the organization is unable to recognize or interpret evidence of new vulnerabilities or ineffective countermeasures until a visible accident occurs’ (Woods, 2006:24). Recall

that prior to the 1994 Black Hawk incident as noted in Snook (2000:3) that is was stated that:

For over 1000 days, the pilots and crews assigned to Operation provide Comfort flew mission after mission, totaling over 50,000 hours of flight operations, without a single major accident (statement of John M Shalikashvili, Chairman of the Joint Chiefs of Staff).

The ANT approach reveals the requirement to reframe the understanding of operations in terms of system interrelationships. Through this shift ‘...one notices initial signals that call into question ongoing models, plans, routines, and begins processes of inquiry to test if revision is warranted’ (Woods, 2006:24).

As reported Rosen and Rappert (1999:20) ‘...design of artifacts can prohibit certain users or compel particular kinds of uses’ and become reflected in the design and implementation of ROEs and supporting architecture that shaped decision making. As described in this research and supporting Viseu (2005:113) ‘...Objects are not passive containers of human designs and desires. They are actors in that they do things, ie by existing they actively shape and transform the character of that which they are part of’. The illusions of certainty that follow so called ‘safety devices’ increase the complexity of the system and in their own ways, through translation, silence or delete voices that reside in the black boxes of the network. They contribute to the opaqueness of the system. Redundancy, reliability and capability claims participate in the creation of illusions of certainty. Within the aviation domain, Perrow (1999:128) notes that ‘as the technology improves, the increased safety potential is not

fully realized because the demand for speed, altitude , maneuverability and all-weather operations increases’. Such is the case with fratricide. As new ‘technical’ solutions (with their inscriptions) become part of the system space, their effects are not realized in advance due to the opaque complexity of the problem space and the lack of a systems view (figure 5.6). Verbeek (2005:131) in his analysis remarks that ‘Artifacts influence the way in which people do things, and this influence could be deliberately inscribed into them’. This is supported by the Actor Network analysis.

What became apparent is ‘technical mediation, whereby artifacts co-shape the relational world (network space) by influencing or ‘...giving shape not only to people’s actions but also to people’s experiences’ (Verbeek, 2005:139). The actors such as the ROE, SOP and sensor displays not only mediated the ‘pilots’ actions but also their experiences as well. Supporting Dekker (2002b), this research reveals that technology, instead of reducing human error, rather changes it and often aggravates the consequences. Viewing pilot error as a socio-technical phenomenon (as a network of heterogeneous elements relationally interconnected) recognizes that safe and effective flight operations are achieved by the entire socio-technical system as a collective. The actors (human, physical and informational) are integral part of whole system and the way it works.

6.6 ACCIDENT AETIOLOGY AND HUMAN ERROR

Dekker (2003:103) remarks ‘...systems that pursue multiple competing goals in a resource-constrained, uncertain world resist quick fixes. The construction of cause is

our final illusion of understanding.... Were we to really trace the cause of failure, the causal network would fan out immediately, like cracks in a window, with only our own judgment to help us determine when and where to stop looking, because the evidence would not do it for us'. The ANT analysis in this thesis reveals how translation and inscription processes align interests and goals within the actor network. The causal network described by Dekker (2003:103) is revealed and validated. The notion of heterogeneous engineering and pilot error in terms of accident aetiology arises from the hybrid collectif whereby the demarcation between the pilot and plane is not clear. Molloy (2005:16) argues that '...the human soldier becomes part of the technology; he is but another piece of hardware, wired into it and modified by it'. The notion of the network, as used in actor-network theory, and illustrated in this work provides a description of the complex webs of actor relations effectively serving to decenter the pilot error and to overcome the binary between subjects and objects. Safety then becomes viewed as '...an emergent system property, arising in the interactions across components, subsystems, software, organizations, and human behavior' (Woods, 2006:28). The AFD models, through the inventive problem solving provide an illustration and validation revealing that a single action will have multiple effects (both intended and 'side effects') and a fault will produce multiple disturbances and these disturbances will cascade along the lines of physical and functional interconnection (Woods and Cook, 1999:23-24).

The accident aetiology is captured within the systems dynamic model at figure 5.6, and resonates with Albert and Hayes (2007:17) who argue that '...couplings across the

arenas of the operating environment mean that cause and effect are all but impossible to forecast and at times very difficult to understand in retrospect. This occurs because secondary and tertiary effects may prove crucial and because of the potential for cascading effects and influences across arenas (for example, military to political, economic and informational) and domains (physical, informational, cognitive and social)'. The accident aetiology, and specifically fratricide as revealed in the analysis is the result of associations rather than human agents. As noted by Latour (1994:34) and supported by the analysis, the fratricide results form a 'new, distributed, and nested series of practices whose sum might be made but only if we respect the mediating role of all the actants [which can be human and non-human] mobilized in the list'. Action thus emerges from associations distributed amongst the humans and non-humans. It is the network construct, the mesh that supports action arising from a distributed set of competencies.

The ANT and complexity worldview reveal within the case studies an inherent multiplicity and entanglement that characterizes the accident aetiology. It is this frame of reference that shed light on our understanding of the question 'how could they not have known that the target was a friendly?' The complex dynamics associated with accident aetiology involving complex socio-technical systems highlights how nonlinear processes and complex processes result in a disproportionate cause-effect relationship. Leveson (2002) speaks to the observation that technological safety fixes themselves sometimes create accidents. Within our case studies we see how technologies and actors designed to improve safety (such as night vision capability,

improved weapon and navigation accuracy, and identification technologies, ROE) actually are implicated in the evolution of the accident through illusions of certainty. Leveson (1995:79) points out major factors that explain why past efforts to reduce risk have been unsuccessful. Here we contextualize them in terms of fratricide:

- (1) Technology fixes used to eliminate the specific causes of past fratricide incidents and not the basic design flaws associated with the system thereby reflecting a lack of a systems view;
- (2) the design of the anti-fratricide devices and barriers is based on false assumptions of linearity;
- (3) the fratricide 'fixes' increase the complexity and precipitate accidents rather than prevent them.

The three factors are reflected in the influence diagram (figure 5.6).

What we see in the case studies is an apparent component in the drift process in the interpretation of past "success". In this sense the absence of failure is taken as positive indication that risks and hazards are well understood and that barriers and countermeasures are present and effective. As noted by Woods (2003:4) and reflected in the case studies that '...An organization usually is unable to change its model of itself unless and until overwhelming evidence accumulates that demands revising the model. This is a guarantee that the organization will tend to learn late, that is, revise its model of risk only after serious events occur'. However, when we inform ourselves through the advent of systems dynamics we recognize the space of possibilities and unanticipated side effects. Sterman (2002:504) argues '...today's solution become tomorrow's problems....At the root of this phenomenon lies the narrow, event-

oriented, reductionist worldview most people live by. We have been trained to see the world as a series of events, to view our situation as the result of forces outside ourselves'. When it comes to revising our risk models, systems dynamics can help us expand the boundaries of our mental models so that we become aware of and take responsibility for the feedbacks created by our decisions (Sterman, 2002:505).

The influence diagram at figure 5.6 reflects the assertion of Hollnagel (2008:4):

...the success of eliminating the large problems, where the "mechanisms" are easy to understand, inevitably and unfortunately leaves the problems that are harder to understand. Adverse outcomes are not always due to cause-effect chains or a linear propagation of the effects of a malfunction, but may also arise from unusual combinations of conditions that involve poorly understood characteristics of the socio-technical systems.

Pilot error/ human error thereby is entangled within the hybrid collectif and the accident aetiology associated with fratricide becomes decentered.

6.7 HETEROGENEOUS ENGINEERING PRINCIPLES

It is well recognized in this thesis the dynamic and interconnected nature of the actor network and how it affects action, inaction and decision making. As noted in Shadrack, Lussier and Hinkle (2005:4) and demonstrated from an actor network perspective 'introducing new technology is not manipulating a single variable, but a change that reverberates throughout a system transforming judgments, roles, relationships, and weightings on different goals'. What becomes apparent from the

analysis is that ‘improvements’ and changes to the system such as the introduction of new radios and the retention of legacy capabilities (Black Hawk incident) creates new paths for failure. It emphasizes how side effects of change as articulated by Woods and Hollnagel (2006:5) are ‘...the most common form of failure for organizations and individuals’. Senge (1990) considers ‘fixes that fail’ to be an organizational archetype that emerges in many organizations when the systemic causes of incidents are not understood (Carroll, 1995:188). If we wish to understand the processes by which the socio-technical world emerges and functions we must move beyond single perspectives (cognitive, politics, the social) and rather attempt to understand how all of these elements combine to create the phenomenon in question.

In addressing the issue of fratricide we turn to systems thinking and the analysis here that shows us as Senge (2006:64) remarks:

...that small, well-focused actions can sometimes produce significant, enduring improvements...this is the principle of leverage. ...The only problem is that high-leverage changes are usually highly non-obvious to most participants in the system. They are not ‘close in time and space’ to obvious symptoms.

This necessitates that we think in terms of ‘...processes of change rather than snapshots’. This systems perspective that is realized by ANT reveals that the actor (human or non-human) is part of the feedback process thereby shifting our awareness from linear causality to complex causality whereby the actor is influenced and influencing the problem space (figure 5.6). Senge (2006:78) remarks that ‘a linear

view always suggests a simple locus of responsibility. When things go wrong, there is either blame...or guilt'. Through the application of ANT, the accident aetiology is characterized as decentered and resident within a network of heterogeneous elements. Supporting this Woods and Cook (1999:28) argue that '... it is easy for organizations to produce what appear to be solutions that in fact exacerbate conflict between goals rather than help practitioners handle goal conflicts in context'.

Recognizing the interrelationality inherent within the hybrid collectif, heterogeneous engineering principles: Cohesion, Alignment and Separation (CAS) (Reynolds, 1987) emerge derived from the thematic analysis and examination of the Systems Dynamics models and AFD analysis, recognizing the dynamic interconnectivity that exists in complex socio-technical systems. Within this thesis, we can contextualize these three heterogeneous engineering principles as follows: Cohesion refers to the act or state of cohering, unity or sticking together. This implies a sense of unity, common purpose associated with the actor network 'design' and operation. Alignment refers to developing the capacity of the actor network to create the results its members truly desire. It builds on the discipline of developing a shared vision (Senge, 2006:218). Separation (distributed) refers to a point, line, or means of division, an intervening space. Within the context of this work, it pertains to avoiding a groupthink (separation of influence) such that it supports a questioning attitude.

Figure 6.2 presents a visualization of these 3 principles. Effective operations require alignment of goals and capabilities that reside within the actors. When applied to

fratricide we see that the problem space presented by the case studies represents a violation of one or all of these principles. In all case studies the principle of cohesion is violated in terms of the unity of action within the network presenting a relational disconnect through illusions of certainty. Similarly, the principle of alignment is violated through the realization of competing distributed agendas and translation processes that shape the SA, sensemaking, decision making and action.

The principle of separation is violated with regards to the efficient and effective knowledge sharing, creation and access and emerges as a socio-technical groupthink. To better understand accident aetiology involving complex socio-technical systems, we must conceptualize organizations (networks) as systems where knowledge is distributed across artifacts, people, metrics, and routines and hence enables heterogeneous engineering principles.

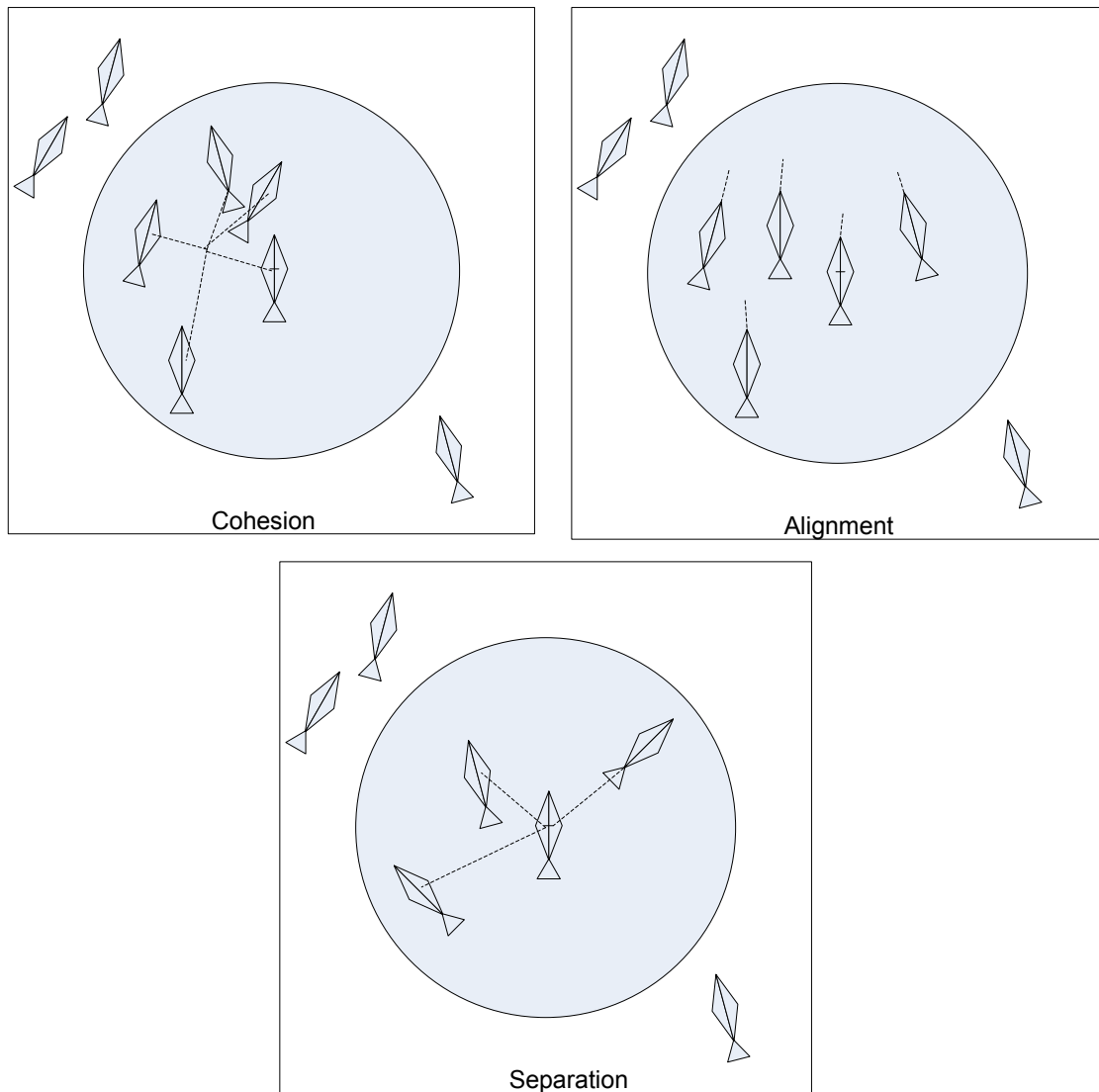


Figure 6.2-Cohesion, Alignment, Separation Visualization (Usuki and Sugiyama, 2003:787)

Presented in a form of a safety triangle (figure 6.3) these three principles circumscribe the focal points of knowledge management and organizational learning. The inverted triangle highlights the volatility of ‘manufactured’ safety and the dynamic responsiveness to an ever changing context.

As described in chapter 5, issues pertaining to knowledge management and organizational learning emerge from the analysis and are central to the CAS model. Knowledge Management facilitates the systematic, effective management and utilization of knowledge resources available to an organization (Demarest, 1997). Here we use an Actor Network lens and view the network of heterogeneous elements at the systemic level to realize three fundamental phases: knowledge creation/collection, knowledge access, knowledge sharing. With the rapidly changing environment that characterizes the problem space of this thesis, the focus that emerges from the analysis draws upon the need for the creation of knowledge to prevent existing knowledge from obsolescing quickly. ‘Operational Innovation’ is about solving problems and adaptation to the dynamic environment. Realized from the analysis that knowledge enables actions and decisions, we view the knowledge flows as transformations within the actor network supporting knowledge creation, retention, transfer and utilization. From the standpoint of heterogeneous engineering, knowledge engineering in deployed operations requires an understanding of knowledge flows in order to facilitate as articulated by Newman (2005:302) ‘...the foundation for a comprehensive methodology, supporting both the analysis and design of holistic knowledge-based systems’. The knowledge flows that we speak of exist within the socio-technical domain of action and exist within the hybrid collectif. It is important to recall a lesson learned from this analysis: ‘Tools mediate knowledge’.

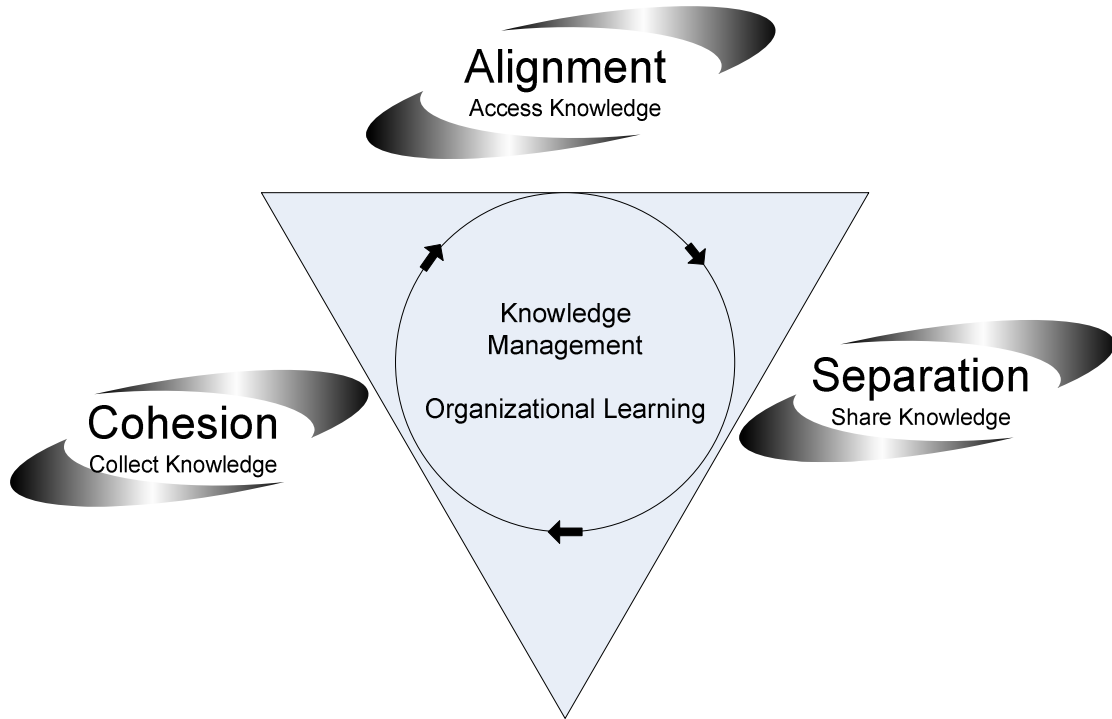


Figure 6.3 –Principles of heterogeneous engineering: Presented as a safety triangle.

Within the context of fratricide, the requirement of Knowledge integration emerges, thereby extending the scope of knowledge sharing. This is an enabling element of the learning organization, where we view the knowledge as not only distributed, but effectively used to perform a task and to generate new knowledge. Within our 3 domains of physical, human and informational, Knowledge Management becomes a function of the hybrid collectif casting knowledge as complex and multidimensional. Knowledge becomes a central figure in shaping the illusions of certainty whereby the mental models are constructed from seven constituents: knowledge based on historical site-based understanding that are generalized and applied to various contexts; knowledge acquired from unreliable or inaccurate sources; knowledge formed in

ambiguous and complex environments; interpersonal variations in knowledge and practices based upon that knowledge; distribution and access structures of knowledge; channels of interpersonal communications; and correct sources perceived as unreliable (Chapman and Ferfolja, 2001:401).

One of the essential requirements of any Knowledge Management strategy to address these issues is collaboration in order to garner a collective knowledge. The 'social' dimension of Knowledge Management, within the actor network perspective focuses on the inter-relationality that exists within the actor network of both human and non-human actors. A challenge faced by distributed teams (human and non-human) is that knowledge is often fragmented, thereby creating issues pertaining to preservation and reuse within a learning organization. To address these challenges it is recommended that collaboration be a centerpiece of the 'operationalised' Knowledge Management deployed strategy. Shared knowledge enables '...team members to interpret cues, make decisions that are compatible and take correct actions' (Wilson et al., 2007:3). The complex changing environment of modern warfare demands an integrated learning and collaboration model. This requires new knowledge to be generated continuously and managed in a systematic way. Considering the illusions of certainty that reside in the system shaping the mental models in terms of '...deeply ingrained assumptions, generalizations, or even pictures or images that influence how we understand the world and how we take action' (Chapman and Ferfolja, 2001:399) what is required within the context of organizational learning is double-loop learning that challenges and reframes mental models. This resonates with the requirement to

integrate lessons learned from military training and operations (GAO/NSAID-95-152-1994). Loermans (2002:288) argues that the combined disciplines of Learning Organization and Knowledge Management provide the theoretical framework within which this can occur which supports its centrality within the CAS model circumscribed by the heterogeneous engineering principles of Cohesion, Alignment and Separation.

6.8 SOLUTION SPACE

Gadsden, Krause, Dixon and Lewis (2008:1) articulate the current status of fratricide research. They state that:

Broad programmes of R&D covering the three components of Combat ID are in place amongst the TTCP countries but, to date, comparatively few friendly fire mitigation solutions have been fielded. This tends to be due to the problems of delivering compatible solutions across Coalition partners and the affordability of technological solutions. There are variable levels of R&D effort expended against these components but the bulk of the activity has been focussed on technological solutions for Target ID and SA. Solutions have been proposed for all Combat ID operational environments but with varying levels of success.

Outteridge et al. (2003:22) present a combat identification model that highlights the importance of considering both the human and technical dimensions of fratricide (figure 6.4).

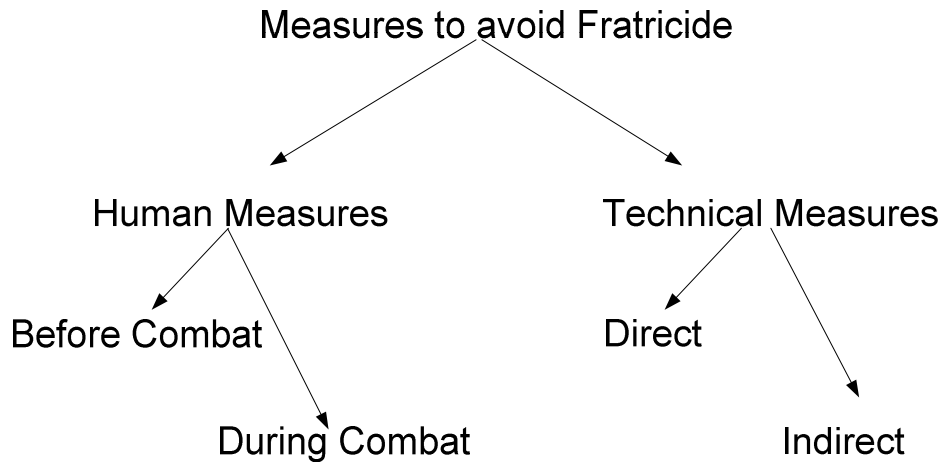


Figure 6.4 - Model of CID.

From the ANT perspective the view of the solution space is expanded and reinterpreted in terms of the hybrid collectif (figure 6.1) encompassing the entanglement of the human, physical and informational domains.

With consideration of the Illusions of Certainty that emerge, Woods and Cook (1999:18-19) argue for a variety of techniques that can reduce breakdowns stemming from fixation. These include the requirement to develop and voice a fresh point of view of the situation to break the fixation; development of system architectures where some actor acts as the ‘devils advocate’ critiquing assessments; and providing new kinds of representations about what is going on in the monitored process. What this points to is collaborative sensemaking, within the actor network sense whereby all actors are implicated in the process of creating actionable knowledge within an environment, leading to shared execution. The translation and inscription processes described in chapter 5 lend itself to understanding the process of collaborative sensemaking which involves many stakeholders’ expertise, integrating and reconciling different perspectives and behaviors. Cohesiveness can be achieved through

articulation and reconciliation process based on an established common understanding of a situation. This leads to a collective understanding of the relevant entities and causal relationships that influence action.

As leverage points within the AFD model, key points of interruptions are required to counter the actor network groupthink. Sensemaking is unlikely to occur unless individuals are in some way interrupted. Once interrupted, actors appear to make unfolding situations 'sensible' and in the course of this re-evaluation, they cease or change their original action. Weick and Roberts (1993:357) coined the term "collective mind" defining it as '...a pattern of heedful interrelations of actions in a social system'. The essence of a collective mind is to coordinate tasks and capabilities carefully. Weick and Roberts (1993) suggest that collective mind development depends on the heedfulness of interrelating. They suggest that settings described as interdependent, nonroutine, and complex require the presence of collective mind.

Mindfulness thereby emerges as part of the solution space. With regards to heterogeneous engineering and recognizing the translation and inscription processes of ANT, small failures are noticed (the principle of preoccupation with failure), and their distinctiveness must be retained rather than lost in a category (reluctance to simplify). People need to remain aware of ongoing operations if they want to notice nuances that could be symptoms of failure (sensitivity to operations). Attention is also crucial for locating pathways to recovery (commitment to resilience) and the knowledge of how to implement those pathways (deference to expertise), all of which are fundamental

principles of High Reliability Organizations (Weick and Sutcliffe, 2007: 9-17).

Hopkins (2007:8) argues that:

...warning signs are usually ambiguous and may well have innocent or unproblematic explanations. The important point is not to default to the assumption of normalcy but to investigate the signals which are appearing until they are either demonstrated to have an innocent explanation or, alternatively, are confirmed as unambiguous indicators of danger. This is exactly what mindful organisations do.

A leverage point that emerges from the analysis stems from the quality of mindfulness: do not discard other events because they appear on the surface to be dissimilar. Although the fratricide events are unique, they do reveal common patterns (illusions of certainty) that can be addressed to help create foresight about potential risks before failure or harm occurs. This requires a shift of analysis to recognize common patterns across incidents. This approach is rooted in organizational learning.

Within the context of this thesis and as explained in chapter 5, SA is described in terms of a construct, resident within a network of heterogeneous elements. This reflects the importance of the relationality that resides within the network. The actor network becomes essentially a workspace for an awareness system. It reveals the importance of understanding the effect of how ‘...incorrect or incomplete mutual assumptions, knowledge, or beliefs can contribute to breakdowns in communication and coordination’ (Roth et al., 2006:968). The illusions of certainty that emerge within

the actor network exemplify the effect of such assumptions and uncertainty. The maintenance of awareness is dependent on all actors and the relations that reside within the actor network as it shapes cooperative practices associated with distributed teams that is so important in this context of fratricide. These insights expand the theoretical knowledge base on the contribution of cooperative practices of distributed teams to safety (Roth et al., 2006:969). Currently the NATO Identification System (NIS), referred to as the STANAG 4162, is being developed. It is an algorithmic process to improve the identification capability of Command, Control, Communications (C3) and weapon systems using a Bayesian approach to automatically combine identification information from different source declarations and to provide an assessment of the target identity to the operator. Lessons learned from this thesis suggest caution is required to ensure that this approach considers the effects on the socio-technical system as a whole recognizing the hybrid collectif. This thesis thereby emphasizes a design orientation that recognizes principles of ‘heterogeneous engineering’.

Follow on work

The findings of this thesis provide insights that can inform future research initiatives in the area of heterogeneous engineering, human error and situation awareness. In particular one of the most significant research initiatives would focus on the further developing and employing the heterogeneous engineering principles to facilitate collaboration and coordination in complex socio-technical systems to build ‘safety’ within the domains of defence, security, energy and medicine. Exploring and

developing the heterogeneous engineering principles within the context of ANT will aim at ‘...aligning the interests of the actor network (ie having all their influences fit together) (Masys, forthcoming). The alignment of the network is obtained through processes of translation of interests in order to align them with the interests of other actors. It recognizes the difficulties in designing and deploying new technologies and processes as they can combine to create new complexities that make human systems more brittle (Woods and Sarter, 2010:7-8).

The application of modeling and simulation has proven to be very valuable for this work. Further exploration of the ‘virtual environment’ is recommended to facilitate the research on SA and human error. Appendix D provides a brief list of topics for further research.

6.9 CONCLUSION

Woods and Cook (1999:26) argue that success and failure belong to the larger operational system and not simply to an individual. Dekker (2003:98) supports this arguing that the point of learning about human error is not to find out where people went wrong; it is to find out why their assessments and actions made sense to them at the time, given their knowledge, goals, tools, and limited resources (Dekker, 2003:98).

This thesis draws upon an interdisciplinary body of knowledge such as human factors, sociology, engineering, physical sciences, organizational theorists, management science, psychology, cognitive science to help in the opening and interpreting the black box (giving voices to the deleted and marginalized). Multiple cases of fratricide

provided rich data and facilitated the search for patterns thereby developing insights into complex ‘social’ phenomena. The resulting analysis does not reflect an exact ‘causal’ rendering of the accident aetiology, such as that reflected in the work of Snook (2000), Leveson (2002) and Ladkin and Stuphorn (2004), but provides a ‘relational’ perspective that informs traditional conceptualizations of accident aetiology.

The actor network theory perspective provides a mechanism that reveals a rich, contextual mapping of the socio-technical relations that reside within the network space. Law (1992:4) argues (but contextualized for this work) that pilot error are never located in bodies and bodies alone, but rather that an actor is a patterned network of heterogeneous relations, or an effect produced by such a network. Law (1992:4) argues that ‘...a machine is also a heterogeneous network -- a set of roles played by technical materials but also by such human components as operators, users and repair-persons. So, too, is a text. All of these are networks which participate in the social’.

The socio-technical domain is revealed as a complex interconnected, relational entangled state that emerges as a hybrid collectif of human and non-human actors. It is recognized within this thesis that there is a great benefit to the sociological perspective with regards to the socio-technical domain. Techno-mediated relations have changed the landscape and timescape and through this have silenced and deleted voices through black boxing.

It is argued that linear thinking is a myopic perspective that does not recognize the multiple interrelations and entanglement that characterizes the network space and therefore is not an effective mode for understanding complex socio-technical domain. The emergence of the hybrid collectif, Illusions of Certainty, Hardwired Politics, decentered aetiology and heterogeneous engineering principles mark a significant contribution to the body of knowledge regarding complex socio-technical systems. The work presented extends and complements the work of Rasmussen (1982), Reason (1984), Perrow (1990), Toft and Reynolds (1999), Bennett (2002), Johnson (2004), Leveson (2004), Dekker (2005), and Hollnagel (2006).

Appendix A: Papers Published

The following papers stemming from this research were published:

Masys, A.J. (forthcoming) 'The emergent nature of risk as a product of 'heterogeneous engineering' in S. Bennett (ed) *Innovative thinking in risk, crisis and disaster management*, UK: Gower Publishing.

Masys, A.J. (2009) 'Systems Thinking and Fratricide: Operationalizing Knowledge Management and Organizational Learning' *International Journal of Knowledge, Culture and Change Management* **9**(11): 95-108.

Masys, A.J. (2008) 'Root (Rhizomal) Causal Analysis: A Systemic Understanding of Accidents and Disasters' in the Proceedings of the 26th *International System Safety Conference*, Vancouver, BC, 24-29 Sep 2008.

Masys, A.J. (2008) 'Pilot Error: Dispelling the hegemony of blamism. A case of de-centered causality and hardwired politics' *International Journal of Disaster Prevention and Management* **17** (2): 221-231.

Masys, A.J. (2007) 'Complexity and the Social Sciences: Insights from Complementary Perspectives. Informing an analysis of accident aetiology' Presented at the Seventh *International Conference on Complex Systems*, Boston, 28 Oct-2 Nov 2007.

Masys, A.J. (2006) 'Understanding Fratricide: Insights from Actor Network Theory and Complexity Theory' in the Proceedings of the 24th *International System Safety Conference*, New Mexico, USA, 31 Jul- 4 Aug 2006.

Masys, A.J. (2005) 'A Systemic Perspective of Situation Awareness: An analysis of the 2002 Mid-Air Collision over Uberlingen, Germany' *International Journal of Disaster Prevention and Management* **14** (4): 548-557.

Masys, A.J. (2004) 'Situational Awareness. An Actor Network Theory Perspective' in D.A. Vincenzi, M. Mouloua and P.A Hancock (eds) *Situation Awareness and Automation: Current Research and Trends*.

Masys, A.J. (2004) 'Aviation Accident Aetiology. A Systemic Examination of Fratricide Using Actor Network Theory' Published in the *Proceedings of the 22nd International System Safety Conference (ISSC)*, Providence, Rhode Island, 2-6 August 2004.

Masys, A.J. (2004) 'Syndromic Surveillance and Bioterrorism: Embracing the Network Centric Warfare Paradigm' *International Journal of Disaster Prevention and Management* **15** (5): 351-355.

Masys, A.J. (2004) 'Aviation Accident Aetiology: A Catastrophe Theory Perspective' *International Journal of Disaster Prevention and Management* **13** (1): 33-38.

Appendix B

Anticipatory Failure Determination (AFD)

Anticipatory Failure Determination (AFD) is an application of TRIZ (Theory of Inventive Problem Solving). It is an efficient and effective method for analyzing, predicting and eliminating failures in systems, products, and processes (Kaplan, Visnepolschi, Zlotin and Zusman, 1999). The AFD modeling process guides users in documenting the situation, formulating the related problem(s), developing hypotheses, verifying potential failure scenarios, and finding solutions to eliminate the problem(s). It accomplishes this through a series of steps described in chapter 3. AFD has two broad applications:

1. Failure Analysis: determination of the cause of a failure that has already occurred.
2. Failure Prediction: determination of possible failures that have not yet occurred.

Traditional failure analysis focuses on the question ‘How did this failure happen?’ In terms of failure determination, AFD poses the question ‘If I wanted to create this particular failure, how could I do it?’ In terms of failure prediction it poses the question ‘If I wanted to make something go wrong, how could I do it in the most effective way?’ Failure prediction thereby reflects an iterative application of failure determination to envision all the possible end states, mid states, initiating events and possible scenarios leading to these states. This methodology thereby views the failure as an intended consequence.

What differentiates this methodology from conventional techniques as Failure Mode and Effects Analysis (FMEA) and Hazard and Operability Analysis (HAZOP), is the perspective from which potential failures are determined. With conventional techniques, the process of failure prediction proceeds linearly from an articulation of the system's function(s) to what may occur if there is a failure (absence) in delivering these functions. The strength of AFD modeling lies in the 'inventive approach' (TRIZ) that recognizes inherent conflicts within the system. In AFD, the power of the technique comes from the process of deliberately "inventing" failures. The analyst thereby must look to invent, cause and create failures. In the case of past failures, the analytical process challenges one to invent a past failure. In future failure prevention, the focus is on inventing, creating or devising the most catastrophic failures conceivable thereby exploring the space of possibilities (figure B1).

The AFD modeling environment facilitated the relational mapping of ANT, and through the 'inventing failure' generated the space of possibilities. The application of AFD complements ANT by facilitating a platform in which to explore the relationality inherent within the actor network and thereby reveal pathways and conditions supporting fratricide.

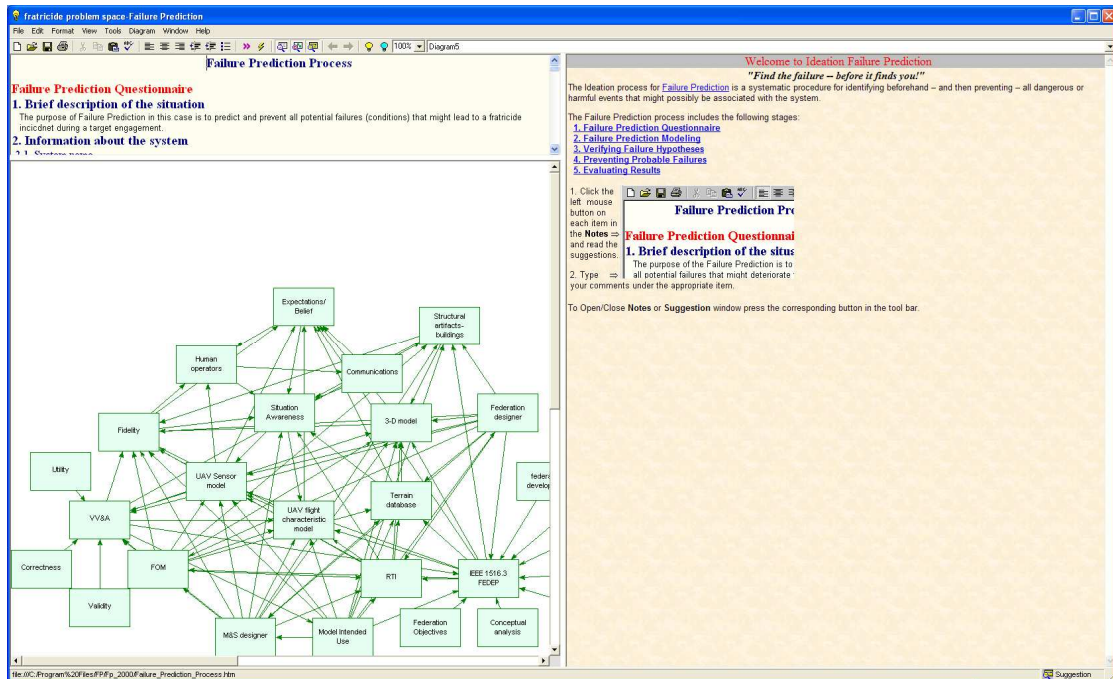


Figure B1: Screen shot of AFD modeling environment

Appendix C: JSMARTS II/MALO Overview



Extract from JSMARTS II Fact Sheet (developed by DRDC Ottawa)

The DRDC Ottawa Future Forces Synthetic Environments section (FFSE) has been established to provide an R&D centre of excellence in the area of Synthetic Environments (SE) and Capability Engineering (CE). In their fullest application, these fields are broad, far reaching, and interact with a significant number of activities conducted by many different R&D groups within DRDC, and many different capability and project planning, management, engineering, and support groups across the Department of National Defence and other government departments (OGD).

An FFSE initiative, termed '*JSMARTS*', leverages an Assistant Deputy Minister (Material)-led, enterprise-level effort to embrace the integration of Simulation and Modelling in Acquisition, Rehearsal, Requirements and Training (SMARRT). JSMARTS has established itself as an emerging new way of conceptualizing the development of distributed simulation events by markedly moving away from large-scale, monolithic simulation-based exercises in favour of rapidly constructed, minimally developed simulation environments – characterized as a simulation-based 'pick up game'.

Capability Engineering (CE) is presently being defined and developed within FFSE through the Collaborative Capability Definition, Engineering and Management Technology Demonstration Project (CapDEM TDP). CE extends traditional systems engineering to 'system-of-systems' and includes the use of M&S tools and processes to support Capability Analysis for Capability Based Planning.

The main purpose for JSMARTS II is to conduct an experiment that will demonstrate that existing defense M&S capability can be used in civilian emergency management environments, yielding new capability in emergency management simulation and analysis that will be of interest to both communities.

Objectives of JSMARTS II

- a. Macro – Demonstrate that the use of M&S is an effective tool for Capability Engineering (CE) analysis of homeland security requirements and also showing that a civilian emergency management synthetic environment can be interfaced with a defense federation; and
- b. Micro – Conduct a CE analysis/experiment looking at multiple capability states focused on a homeland security scenario with terrorists threatening the detonation of a dirty bomb. The scope of the experiment is to locate a radiological source within a sub-section of the City of Ottawa using ground vehicles (cars) and an unmanned aerial vehicle (UAV).

Participant Observation: Objectives

The JSMARTS II experiment provided an opportunity to examine and evaluate the dimensions of Situation Awareness and explore the processes of inscription and translation within a controlled Synthetic Environment. With this in mind, as a participant observer, the problem space was viewed from an actor network perspective, as a hybrid collectif, to garner insights into understanding SA.



Figure C.1- Simulation Views of problem space



Figure C.2- Images of Synthetic Environment from JSMARTS II

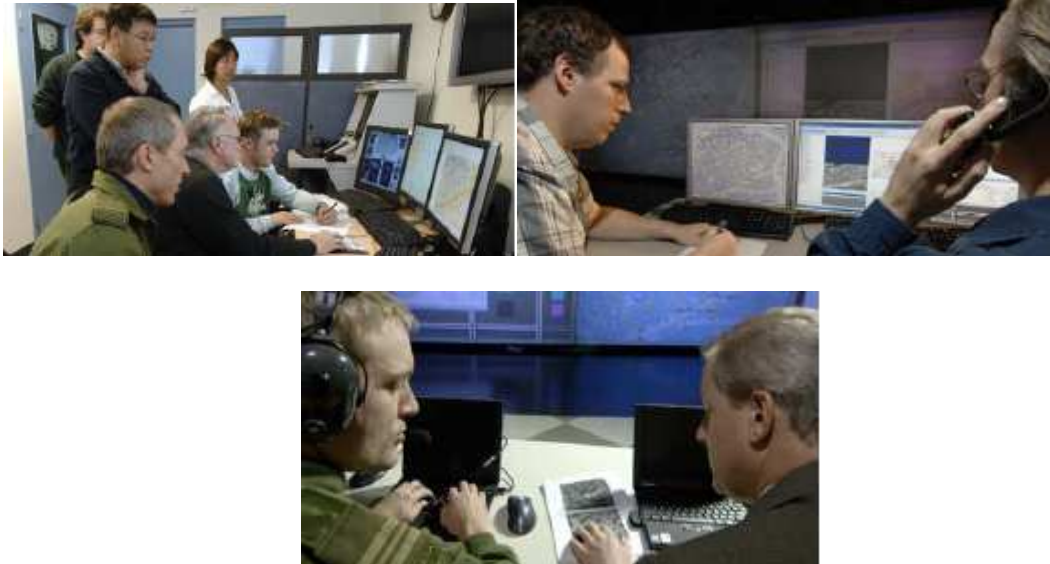


Figure C.3- JSMARTS II participants (actors)

Overview of Maritime Air Littoral Operations (MALO)

The goal of MALO was to demonstrate and validate the application of modelling and simulation technologies supporting both constructive and virtual man-in-the-loop simulation and synthetic environments elements to facilitate tactics and doctrine development. The MALO tool also facilitates operational training and education in support of tactics and doctrine development.

The MALO Project developed and demonstrated a limited synthetic environment (SE) of the Maritime Air Littoral Operational Environment required for a Maritime Air platform to operate as part of a task force. The SE was developed and executed based on High Level Architecture (HLA) distributed Federation Technology. The Project demonstrations focused on two specific applications in the context of littoral/C4ISR task force operations: namely multi platform, multi sensor, Anti Submarine Warfare (ASW) and Anti-Surface Warfare Task Group support operations; and the application

of airborne sensors to coastal and overland surveillance and targeting. The MALO system consisted of a network of computers, a selection of platform and sensor models and databases, and a tactics development and assessment system operating under a HLA run time infrastructure in accordance with the demonstration specification.

Objectives of MALO

The primary objectives of MALO include:

- a. Provide a High-Level Architecture (HLA) MALO federation capable of interfacing with human-in-the-loop (HITL) air platform federates such as the back-end maritime helicopter simulator to be provided by the Transitional Synthetic Environment (TSE) Project with capability for interconnections to other federates in future via the Canadian Advanced Synthetic Environment (CASE) Project. MALO will include the capability to run with federates of constructive models and simulations or with inclusion of man-in-the-loop federates where required or practical;
- b. Demonstrate the capability to generate and analyze a scenario of a task force in a littoral setting focusing on anti-submarine warfare as well as coastal and overland surveillance and targeting. This will include the establishment of sensor, environment, scenario generation and model requirements.

Participant Observation: Objectives

The MALO TDP provided an opportunity to examine and evaluate the dimensions of Situation Awareness and translation and inscription processes of ANT within a controlled Synthetic Environment. With this in mind, as a participant observer, the problem space was viewed from an actor network perspective to garner insights into understanding SA. Acting in the capacity of Subject Matter Expert pertaining to above water and underwater surveillance operations, I participated in a number of scenario development exercises providing a level of verification and validation for the simulation. It was during these exercises that I was able to examine the nature of SA within a synthetic environment.

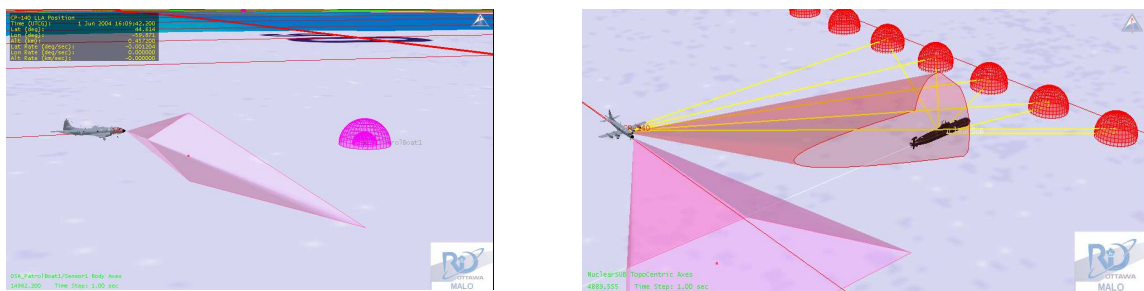


Figure C.4 – Images from the MALO Synthetic Environment

Appendix D

Follow-on Research

7.1 INTRODUCTION

As articulated in Johnson and Wetmore (2009:441),

‘The complex relationship between society and technology, coupled with the fact that a range of actors influence technology based on an incomplete knowledge of how it will behave and what its effects will be, mean that we confront a world that is difficult to understand and predict. How can all of this be managed? How can we steer socio-technical development to solve problems and realize values that are essential to human wellbeing?’

These are some of the questions that can be explored within the context of the research initiatives listed below. To further develop the ideas within this thesis the following research initiatives are suggested:

Resilience Engineering: Informing the paradigm through Actor Network Theory

‘Resilience engineering is emerging as a new paradigm in safety management, where ‘success’ is based on the ability of organizations, groups and individuals to anticipate the changing shape of risk before failures and harm occur’ (Hollnagel et al., 2006).

Resilience is the ability of organizations to maintain control in order to stay outside the accident region. Resilience engineering therefore requires powerful methods, principles and tools to enable this goal. In this proposed research thrust, a ‘heterogeneous engineering’ paradigm rooted within ANT would be explored to

inform resilience engineering. It brings to the forefront emergent behaviour and nonlinear processes that characterize complex socio-technical systems. Treating the system from an ANT perspective (without human/non-human distinction), the researcher would explore the hardwired politics and illusions of certainty that permeate complex socio-technical systems and their inherent affect on the resilience of the system in addition to exploring the dynamic health of a system. By introducing the concept of 'hybrid collectif' the analysis would examine the intersection of human, physical and informational actors of socio-technical systems to inform safety management.

Awareness Systems: A Distributed Construct

Aviation industry, through the Crew Resource Management (CRM) paradigm, has shown great interest in understanding situation awareness. Similarly, other domains characterized by dynamic and complex environments with high information loads and variable and dynamic risk, such as medicine (ie. anesthesiology), nuclear power generation or petrochemical plants are cognizant of the implications of poor SA. This proposed project investigates further developing our understanding of SA. Within this research thrust, we ask ourselves the questions: What are the information requirements and relational interdependencies that can be optimized by soldiers, airmen, medical doctors, nuclear operators or emergency management staff to maintain a high degree of SA?

This highlights the need for varying levels of information resolution to meet the requirements of the situation and with that draws upon knowledge management processes of collection/creation, access and sharing (CAS) principles.

This requires the exploration of concepts such as ‘collective perception’ within the actor network and how to make sense of complex sensed data at the conceptual level by a group of collaborative actors (human and non-human). What is realized in this study is the pervasive connectivity and relational nature of the actor network, thereby facilitating an exploration of the human, physical and informational domains of the problem space.

Risk: An examination of how risk is realized within the ANT construct and the propagation of risk within the Actor Network. (This is currently being developed and will be included as a chapter in a forthcoming book ‘Innovations in Risk, crisis and disaster management’).

If we consider risk not as an abstract concept but as materially contingent, then we need to examine the material practices that configure humans and non-humans into sets of causal relations from which risks emerge (Robins, 2002:15). This proposed research will examine how hardwired politics and illusions of certainty shape risk perception. Through an examination of the hybrid collectif, risk communication will be analyzed with a focus on the interconnectivity of the human, physical and informational domains. The politics of risk and manufactured risk (emergent risk) will be examined within the context of ANT.

Situation Awareness/ Network Enabled Operations- exploring the socio-technical domain.

As cited in Woods et al. (1994:72) previous studies strongly suggest that one source of error in dynamic domains is a failure to revise situation assessment as new evidence comes in. Military operations are characterized as an information-rich environment whereby information is received from multiple sources with various formats in highly dynamic and unpredictable environments, needing rapid data fusion and recovery, high reliability and dissemination. The management of information and knowledge becomes an essential role of all components within the organization. Unreliable, misleading, false or poorly disseminated information threatens operational effectiveness. The research presented in this thesis argues that SA is not something that takes place in the head of the individual, but is resident within a network of heterogeneous elements. This 'system' view recognizes that decision-making is shaped by the actors and artifacts within the network space and argues for a more inclusive definition of agency to include both human and non-human agents. This research proposal focuses on the necessity to explore and develop metrics for this distributed nature of SA across the network and to work within the Network Enabled Operations Paradigm.

CONCLUSION

The research topics described in this appendix reflect how theoretical/ methodological/ practical results and insights from this thesis can be applied and expanded across various domains. Currently the results and insights from this thesis are informing departmental S&T in various applications for defence and security.

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