Complexity and the Social Sciences:
Insights from complementary theoretical perspectives-
Informing an analysis of accident aetiology

A.J. Masys
University of Leicester, UK

Abstract

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, '…rejecting old assumptions about equilibrium in favour of the analysis of dynamic processes of systems far from equilibrium, and respecifying the relationship of a system to its environment' (Walby, 2003).

The term 'System accidents' 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 that resident within the nuclear power industry, aerospace industry and military operations, reflect this aetiology characterized by its nonlinearity and inherent complexity. "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" (Ottino, 2003). The application of Actor Network Theory (ANT) facilitates an examination of complex socio-technical systems focusing on the interconnectedness of the heterogeneous elements characterized by the technological and non-technological (human, social, organizational) elements that comprise the problem space. This paper presents and argues for the integration of complexity theory as a complementary theoretical perspective to the field of sociology as a means of generating insights and increasing explanatory and conceptual depth of analysis. The integration of ANT and complexity theory in analyzing aviation accident aetiology is presented as an example.

Keywords: Sociology; Actor Network Theory; Accident Aetiology

Introduction

The victims and fallout associated with the tragic events of Bhopal, Three Mile Island, Chernobyl, Challenger Space Shuttle and more recently the Columbia Space Shuttle are constant reminders of the dangers associated with complex socio-technical systems.

With the advent of complex coupled systems and the evolutionary introduction of new technology, the aetiology of accidents is changing. 'Since World War II, we are increasingly experiencing a new type of accident that arises in the interactions among components (electromechanical, digital, and human) rather than the failure of individual components. Perrow (1984) coined the term 'system accident' to describe it' (Leveson, 2003).

These failures manifest not as a result of some simple unforeseen cause, but 'from highly complex human activity systems containing large numbers of interconnected subsystems and components' (Midgley, 2003:320). Bennett (2002:1) describes the aetiology of accidents involving complex socio-technical systems as:

> 'Failure, whether human, technological or corporate, is a complex phenomenon. It often arises out of unforeseeable interactions between system components or systems. The seeds of failure may have been sown years-decades , even – before malfunction or collapse. Failure may originate in a complex interplay between social, economic and political factors.'

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.

The systems perspective challenges the hegemony of traditional accident causation models characterized by a paradigm of a 'chain of failures'. According to Leveson (2002) '…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 anatomy of disasters and accidents involving socio-technical systems show an aetiology that reflects an inherent complexity that involves elements beyond the temporally and spatially proximate thereby supporting a 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. We now focus on the interrelationships and the interactions of the actors in an analysis of the behaviour and topology of the system.

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 effects, which are often complex and nonlinear thereby shedding light on the 'system effects' such as emergence, equifinality and mutlifinality. Altmann and Koch (1998:183) remark that 'if the system is analyzed only in terms of its parts, as assumed in atomism and more generally in reductionism, the system-effects are lost without trace'.

Sociology offers an interesting approach to 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 resident in a network of heterogeneous elements that shape and are shaped by the network space.

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 argues that since the world exhibits qualities of wholeness, the relevance of systemic thinking is captured within its paradigm of interdependency, complexity and wholeness (Flood, 1999). Although events can be considered to be discrete occurrences in time and space '…they are all interconnected. Events, then, can be understood only by contemplating the whole' (Flood, 1999:13).

Through analysis of various aviation accidents and in particular cases of fratricide (air-to-ground), the application of the ANT perspective and concepts from complexity theory revealed characteristics of the 'problem space' that helps us understand accident aetiology. The inherent complexity revealed through this perspective focuses on such characteristics as interrelations, interconnectivity and the dynamic nature of the relations that shape the 'social'. The complementary application of complexity theory as a framework helps us to understand the complexity inherent within the 'social'. 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). This is particularly germane to our sociological analysis of accident aetiology involving complex socio-technical systems.

Complexity Thinking

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.

As applied to the social sciences, complexity theory, complexity thinking provides a perspective of the 'social world' that reveals emergent properties, nonlinearity, consideration of the 'dynamic system', interactions, interrelations that is transforming the traditional views of the social as reflected in '…Guastello (1995), Dooley (1997), Eoyang (1997), McKelvey (1997), Zimmerman et al. (1998), Anderson (1999), Poole et al. (2000)' (Dooley et al, 2003).

Addressing issues that lie at the foundation of sociological theory, complexity theory facilitates '…a re-conceptualization and re-thinking regarding the nature of systems reflecting dynamic inter-relationships between phenomenon. The new theorizations of system within complexity theory radically transform the concept making it applicable to the most dynamic and uneven of changing phenomena' (Walby, 2003:3).

Important features that characterize complex systems and their behaviour include the ability to produce properties at the collective level that are not present when the components are considered individually as well as their sensitivity to small perturbations. This dynamic behaviour of complex systems involves interactions at all scales. The complexity inherent within the system may result in changes in behaviour or topology that only become discernable at the macroscale, thereby making the analysis of accident aetiology problematic.

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 rather is a set of interrelated, interconnecting parts creating through their interaction new system properties, which do not exist in a loose collection of individual objects. The realization of this reification corrects many of the failures and mistakes of classical and modern science, 'especially in their attempts to understand and explain complex phenomena and processes' (Altmann and Koch, 1998:186).

Germane to this work is the departure from linear models of accident causation to the acknowledgement of an inherent non-linearity of complex socio-technical systems thereby recognizing the multiplicities whose causes and effects are always dependent on a variety of influences.

Complexity theory thereby provides a framework that facilitates sociological analysis focusing on systems recognizing qualities of nonlinear dynamic behaviour and emergence.

Actor Network Theory

As discussed in detail in Masys (2004, 2005), 'ANT . . . is a relatively new, and still rapidly developing, direction in social theory that has emerged from post structuralism – the writings of Foucault and Deleuze (and Guattari) in particular – and sociological studies of science (e.g. laboratory studies) and technology with the writings of Serres, Latour and others such as Callon and Law being particularly significant (Smith, 2003)'.

'ANT was developed to analyse situations in which it is difficult to separate human and non-humans, and in which the actors have variable forms and competencies' (Callon 1999:183).

Focusing on the socio-technical domain, ANT views the world as heterogeneous and thereby rejects the 'artificial' schism between the social and the technical as illustrated in Latour (1993), Callon (1986a, 1986b), Law (1987), Law and Callon (1988).

Latour (2005) refers to the 'social' as a trail of associations between heterogeneous elements '…a type of connection between things that are not themselves social'.

Recasting the social in terms of associations, relations, characterized by an inherent heterogeneity, and complex interconnectivity is a fundamental paradigm shift that challenges the traditional understanding of 'social' and in so doing facilitates insight into the world of complex socio-technical systems.

Fundamental concepts of ANT are the conceptualization of the Actor and the Network.

An actor-network, as cited in Aanestad and Hanseth (2000), 'is *a heterogeneous network* of human and nonhuman *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 (Aanestad and Hanseth, 2000).

The choice to use ANT as a theoretical framework for the analysis stems from its ability to analyze occasions offered by accidents and breakdowns whereby as Latour (2005:81) remarks '…all of a sudden, completely silent intermediaries become full-blown mediators; even objects, which a minute before appeared fully automatic, autonomous, and devoid of human agents, are now made of crowds of frantically moving humans with heavy equipment. Those who watched the Columbia shuttle instantly transformed form the most complicated human instrument ever assembled to a rain of debris falling over Texas will realize how quickly objects flip-flop their existence. Fortunately for ANT, the recent proliferation of 'risky' objects has multiplied the occasions to hear, see, and feel what objects may be doing when they break other actors down.' ANT considers both social and technical determinism as flawed and thereby suggests a position that takes into consideration the socio-technical perspective such that neither the social nor technical are privileged. Hence ANT, as a theoretical perspective for this work provides a mechanism to examine accident aetiology from a systems viewpoint embracing a complexity paradigm. The properties associated with the ANT perspective allow one to approach the accident analysis without privileging either the social or technical elements recognizing the interconnectivity, nonlinearity and emergent behaviour that so characterizes accident aetiology and resides within complexity thinking.

Discussion

The ANT perspective that views the 'social' as an emergent characteristic of the network space complemented by the framework of complexity theory challenges the traditional cause and effect paradigm that is resident within the technical based approaches to accident aetiology. As an integrating element, complexity theory provided not a methodology per se, but rather 'a conceptual framework, a way of thinking, and a way of seeing the world' (Mitleton-Kelly, 2004).

A core feature of complexity theory is its fundamental re-thinking of the nature of systems, recognizing the simultaneously dynamic and systemic inter-relationships and interconnectivity. Dekker (2005:31) points to the requirement for a systems perspective with regards to understanding accident aetiology. He 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, operator). Emergent properties do not exist at lower levels; they cannot even be described meaningfully with languages appropriate for these lower levels'.

Through the application of Complexity Theory we are introduced to non-linear processes such that small changes in inputs can have dramatic and unexpected effects on outputs. As articulated by Urry (2004):

> 'This complex systems world is, according to Axelrod and Cohen, a world of avalanches, of founder effects, or self-restoring patterns , of apparently stable regimes that suddenly collapse, of punctuated equilibria, of 'butterfly effects', and of thresholds as systems suddenly tip from one state to another'.

It is from this analysis (integrating ANT and Complexity Theory) that the hegemony of 'pilot error' is dispelled and replaced by an aetiology characterized by a 'de-centered causality'. The inherent complexity revealed through this perspective focuses on such characteristics as interrelations, interconnectivity and the dynamic nature of the relations that shape the 'social' as an emergent property. The actors within this network space do not preexist, rather they emerge as a result of an entangled interconnectivity, or as Barad (2007) argues as an 'intra-relating'.

The analysis methodology of ANT, 'Following the actors', revealed the notion of a complex co-evolving ecosystem characterized by '…intricate and multiple intertwined interactions and relationships. Connectivity and interdependence propagates the effects of actions, decisions and behaviours …, but that propagation or influence is not uniform as it depends on the degree of connectedness' (Mitleton-Kelly and Papaefthimiou, 2000).

Revealed in the analysis and as discussed in detail in Masys (2006), Foucault's notion of disciplinary power helps to explain the inscription and translation processes within ANT as applied to socio-technical systems. The analysis of the inherent interconnectivity within complex socio-technical systems reaffirms Foucault's perspective that power is embodied in heterogeneous micro-practices and power is seen as enacted and discontinuous rather than stable and exercised by a central actor (Thompson and McHugh, 1995) (cited in Rolland and Aanestad, 2003). As articulated by Yeung (2002), '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.' Further as articulated by Yeung (2002),

> '…causal power can be ascribed to relational networks when their relational geometries generate an *emergent* effect such that the sum of these relations is much greater than that of individual actors. The geometrical configurations of these *emergent network relations* provide the central dynamic to drive networks and to produce spatial outcomes. Power is thus constituted collectively by network relations and its influence can only be realized in a relational sense through the exercise of its capacity to influence. Actors in relational geometries do not possess power *per se*. Through their practice, actors perform the role as the agents exercising that emergent power inscribed in relational geometries.'

Combing ANT and complexity thinking with Foucault's conceptualization of power, highlights how the micro-practices 'constantly get configured and re-configured as 'disciplinary technologies' (Aanestad and Hanseth,2000), as reflected in design and organizational decisions. The 'hardwired politics' and power emerge as the 'deleted voices' that permeate the network space, the relations and the actors and shape decision-making and the accident aetiology.

The network space 'worldview' captures the system perspective of aviation accident aetiology revealing the 'social' in terms of this 'hardwired politics'. The analysis revealed that the term pilot error is pejorative, a reflection of an event-based approach to accident causation that fails to capture the nonlinearity inherent within accident aetiology. A de-centered causality dispels the hegemony of 'pilot error', thereby facilitating an accident 'model' that is characterized as dynamic, nonlinear with emergent properties and embracing features resident within complexity theory. This entails a rethinking of some fundamental concepts such as notions of causality, agency, power, space and time. As Barad (2007: 394) argues, '…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.' Deleuze's perspective of space-time as "folded, crumpled, and multi-dimensional" (Deleuze,1995) is germane to the conceptualization of ANT. It is this very nature of this space-time schema that "the coordinates of distance and proximity are transformed by a folding, refolding, and unfolding that eschews ideas such as linearity" (Smith ,2003).

As Latour (1996:238) remarks '…the social as actor network is hybrid: it is a heterogenesis that consists of discursive, human, and material elements, which simultaneously coexist, and which cannot be separated from one another'. Complexity theory, as a complementary theoretical perspective to sociology, increases the conceptual depth of analysis and understanding regarding accident aetiology involving complex socio-technical systems.

Conclusion

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.

Through an analysis facilitated by ANT, the hegemony of 'blamism' associated with 'pilot error' is replaced with a de-centered accident aetiology that is revealed within a network of heterogeneous elements. Hard-wired politics (reified as 'illusions of certainty') and power characterize the network space; thereby shaping the aetiology of the accidents and transcending the linearity associated with traditional understanding of accident aetiology. The contribution of complexity thinking to sociology and in particular to the study of complex socio-technical systems is reflected in our attention to the dynamic processes, interconnectivity and relationality facilitating a rethinking regarding the concept of system. The application of complexity theory facilitates a paradigm shift complementing the perspective of ANT and systems theory. Together ANT and Complexity Theory provides a framework for thinking through larger implications of theories detailing accident aetiology. It reworks our understanding of what happens in accidents. The results of this work are far reaching in terms of how we view socio-technical systems and accident aetiology.

References

[1] Aanestad, M. and Hanseth, O. (2000). "Implementing open network technologies in complex work practices: a case from telemedicine", in Baskerville, R.E., Stage, J. and DeGross, J.I. (Eds), Organizational and Social Perspectives on information Technologies, Kluwer Academic Publishers, Dordrecht, 2000, pp. 355-69.

[2] Altmann, G., Koch, W.A. (1998) Systems: New paradigms for human sciences. Gruyter, New York,1998. pg 183.

[3] Barad, K. (2007) Meeting the Universe Halfway:quantum physics and the entanglement of matter and meaning. Duke University Press. Durham & London 2007.

[4] Bennett, S. (2002)Victims of Hubris? The Decline and Fall of Pan Am and Swissair. Scarman Centre, Leicester.

[5] Callon, M. (1986a). The Sociology of an Actor-Network: The Case of the Electric Vehicle. Mapping the Dynamics of Science and Technology. Calon, M., Law, J. and Rip, A. (Eds). Macmillan Press, London: 19-34.

[6] Callon, M. (1986b). Some of the Elements of a Sociology of Translation : Domestication of the Scallops and the Fishermen of St. Brieuc Bay. Power, Action & belief. A New Sociology of Knowledge? Law, J. (Ed). Routledge & Kegan Paul, London: 196-229.

[7] Coakes, E. (2003) Socio-technical Thinking- An Holistic Viewpoint. In Clarke, S., Coakes, E., Hunter, M.G., Wenn, A. Socio-technical and human cognition elements of information systems. Information Science Publishing. Hershey.pg 2

[8] Dekker, S. (2005) Ten Questions about human error. A new view of human factors and system safety. Lawrence Erlbaum Associates, Inc. New jersey. pg 10.

[9] Dooley, K.J., Corman, S.R., McPhee, R.D., Kuhn, T. (2003) Modeling High-Resolution Broadbrand Discourse in Complex Adaptive Systems. Published in Nonlinear Dynamics, Psychology, & Life sciences. Vol. 7, number 1, January 2003. pp. 61-85.

[10] Flood, R.L. (1999) Rethinking the fifth discipline: Learning within the unknowable. Routledge, London. pg 13

[11] Latour, B. (1993) We have never been modern. Harvester Wheatsheaf, Hemel Hempstead.

[12] Latour,B. (2005) Reassembling the Social: An Introduction to Actor network theory. Oxford University Press.

[13] Law, J. (1987). Technology and Heterogeneous Engineering: The Case of Portuguese Expansion. The Social Construction of Technological Systems: New Directions on the Sociology and Hostory of Technology. Bijker, W.E., Hughes, T.P. and Pinch, T.J. (Eds). MIT Press, Cambridge, Ma: 111-134.
[14] Law, J. and Callon, M. (1988). Engineering and Sociology in a Military Aircraft Project: A Network Analysis of technological Change. Social Problems 35(3): 284-297.
[15] Leveson, N.G. (2002) System Safety Engineering: Back to the Future. Aeronautics and Astronautics, MIT.
[16] Leveson, N. (2004) A New Accident Model for Engineering Safer Systems. *Safety Science*, Vol. 42, No. 4, April, pp. 237-270
[17] Masys, A.J. (2004) Aviation Accident Aetiology: A systemic examination of Fratricide using Actor Network Theory. Proceedings of the 22nd International System Safety Conference (ISSC), Providence, RI, 2-6 August 2004. pp. 413-423.
[18] Masys, A.J. (2005) Aviation Accident Aetiology: A Systemic Examination of Fratricide using Actor Network Theory. Published in the Proceedings of the International System Safety Conference, Providence, Rhode Island. 2005.
[19] Masys, A.J. (2006) Understanding Fratricide. Insights from Actor Network Theory and Complexity Theory. Published in the Proceedings of the International System Safety Conference, 2006. Albequere, New Mexico. 31 July-5 August 2006.
[20] Midgley, G. (2003) Systems Thinking. Sage Publications. London.
[21] Mitleton-Kelly,E., Papaefthimiou, M.C.(2000) Co-evolution of diverse elements interacting within a social ecosystem. Feast 2000 International Workshop on ‘Feedback and Evolution in Software and Business Processes’, Imperial College, London, UK, July 10-12, 2000.
[22] Mitleton-Kelly, E. (2004) Complex systems and evolutionary perspectives on 0rganisations: The Application of Complexity Theory to Organisations. [http://www.psych.lse.ac.uk/complexity/PDFiles/publication/EMK_The_Principles_of_Complexity.pdf].
[23] Ottino, J. (2003), “Complex systems”, AIChE Journal, Vol. 49 No. 2.
[24] Rolland, K.H., Aanestad, M. (2003) The Techno-Political Dynamics of Information Infrastructure Development: Interpreting Two Cases of Puzzling evidence. Retrieved from http://heim.ifi.uio.no/~margunn/2003/IRIS26.pdf
[25] Smith, R.G. (2003) World City Actor-Networks. Progress in Human Geography, 27 (1) 2003.
[26] Urry, J. (2004) Small Worlds and the new social physics. Global networks 2004.pg 3
[27] Walby, S. (2003) Complexity Theory, Globalisation and Diversity. Presented to the conference of the British Sociological Association, University of York, April 2003.
[28] Yeung, H.WC. (2002) Towards a Relational Economic Geography: Old Wine in New Bottles? Paper Presented at the 98th Annual meeting of the Association of American Geographers, Los Angeles, USA, 19-23 March 2002.