Association for Information Systems
AIS Electronic Library (AISeL)

UK Academy for Information Systems Conference Proceedings 2014

UK Academy for Information Systems

Spring 4-9-2014

Managing Mutual Information & Transfer Entropy In Synthetic Ecologies

Simon Reay Atkinson
University of Sydney, simon.reayatkinson@sydney.edu.au

Michael Harre
University of Sydney, michael.harre@sydney.edu.au

Seyedamir Tavakoli Taba
University of Sydney, amir.tavakoli@sydney.edu.au

Terry Bossomaier
Charles Sturt University, tbossomaier@csu.edu.au

MANAGING MUTUAL INFORMATION & TRANSFER ENTROPY IN SYNTHETIC ECOLOGIES

Simon Reay Atkinson[1], Seyedamir Tavakoli Taba[1], Mike Harré[1], Terry Bossomaier[2], Liaquat Hossain[3]

[1]*Complex Civil Systems Research & Project Management Program, University of Sydney, NSW 2006, Australia,* [2]*Centre for Research in Complex Systems, Charles Sturt University, Bathurst, NSW 2795, Australia,* [3]*Information Management Division of Information and Technology Studies, The University of Hong Kong*

Email: simon.reayatkinson; seyedamir.tavakolitabaezavareh; michael.harre @sydney.edu.au; tbossomaier@csu.edu.au; lhossain@hku.hk.

Abstract

In this paper, we consider transfer entropy and mutual information in terms of their application in the emerging highly interconnected and dynamic synthetic ecologies underpinned by the Cyber. We consider existing models relating to the management of learning and change within organizations and as they may relate to mutual information (MI) and transfer entropy (TE) within socio and info/techno settings, based upon a Mech-Organic perspective. A premise of this paper is that change is costly and that it needs to be seen through a social as well as an info/techno lens. We identify potential improvements to existing models (i.e. for managing change, over time) and applications applied to the management of change by considering alternative models such as transferring knowledge between handovers and how MI and TE may be applied collaboratively within a learning organization.

Keywords: Organizational Annealing, Mutual Information, Transfer Entropy, Resilience, Cascading Failure, Packet-Markets.

1.0 Introduction

This paper considers that there are two predominant, coupled systems at play within contemporary organizations, one to do with collaborative social influence (CSI) in which the social drives the IT (S-I/T) and the other to do with coordination, rule and control (CRC) in which the IT drives the social (S-IT) (Walker et al, 2012; Harmaakorpi et al, 2003). These two systems have different and at times conflicting or antithetical characteristics, one to do with *weaker* social signals and influencing / responding, *over time* (CSI / S-IT); the other relating to *stronger* signals necessary for controlling / reacting, *in time* (CRC / I/T-S) (Ansoff, 1975; Coffman, 1997; Hiltunen, 2010; Hiltunen, 2008). In this respect, 'CRC / IT-S systems seek to program (as opposed to programme) the relationship between technical processes and humans by digitizing performance fidelity and coding for repeatable *risk free* procedures in computer-control (cyber) spaces so that data and communication do not [temporally] contradict each other ' (Reay Atkinson et al, 2012a). By contrast: 'CSI / S-IT systems stress the reciprocal interrelationship between humans and computers to foster improved shared awareness for agilely shaping the social programmes of work, in such a way that humanity and ICT [control] programs do not contradict each other' (Reay Atkinson et al, 2012a). The two systems also have different *signatures,* where CRC / IT-S systems are considered as strong-signal systems, in which: 'System control (through switching) of Information, Data and Communication are the key variables', after, Castells (1996) and Sokol (2003) and *weak-signal* CSI / S-IT systems, in which: 'System Influence (through shared awareness) of Information and *abstracted* social Knowledge are the key variables', after Castells (1996) and Bunge (2010). This is a new, developed *definition* of system variables applied in this paper.

In this paper, Mutual Information (MI) is considered as 'a measure of the amount of information one random variable contains about another' (Cover & Thomas, 1991). MI does not have a time base and so cannot measure flows. Transfer Entropy (TE) is 'a model-free measure of information flows between different time series' which, 'under weak assumptions, allows [for the quantifying of] information transfer without being restricted to linear dynamics' (Dimpfl & Franziska, 2012; Kullback & Leibler, 1951). Unlike MI, Transfer Entropy is 'based on rates of entropy change' (Schreiber, 2000) and so 'captures some of the dynamics of a system' (Tenkanen, 2008). TE may therefore be seen also as a measure of the stability or instability of the system and so, potentially, of chaotic behaviour and cascades, in which 'a failure of a very small fraction of nodes in one network may lead to the complete fragmentation of a system of several interdependent networks' (Buldyrev et al, 2010).

Building on previous work presented at UKAIS 2013, in which we propose a Mech-Organic Perspective based on an understanding of the mechanical (i.e., theoretical and/or applied) and organic (i.e., conceptual and/or subjective) components of information communication systems. We consider *Mechorganics* in terms of 'the *synergistic* combination of *civil* mechanical *systems* engineering, social network dynamics, ICT (essentially the CRC / IT-S) and the management of *interconnected* knowledge, information (and data) *infrastructures* in the *designing* and *composing* of *adaptive* (resilient and sustainable) organizations (essentially the CSI / S-IT)' (Hossain et al, 2013). Examined through the lens of Mutual Information (MI) and

Transfer Entropy (TE), *machine* (CRC / IT-S) and *organic* (CSI / S-IT) gradations exhibit different characteristics.

Considering Mutual Information and the trusts necessary to share and collaborate, Dahl (1957), argues 'agents exert social influence [he defines power in terms of a relationship between people] through the manipulation of a base of resources, and resources like recognition, appreciation, and friendliness as well as economic rewards'. Wrong (1968) saw people exercising *Mutual Influence* and *Control* over one another's behaviour in all social interactions. Anderson (2009) concluded that *mutual influence* and *control* formed a 'convenient intersection between risk, trust and technology' from which Felici (2007), noting the 'complexity of trust' and that it was 'unfeasible to take a definitive model', suggested (see also McKnight & Chervany (2001)) a 'typology of trusts' which may (after Hickson et al (1971)) broadly align with *relational* collaboration, combining aspects of *behavioural* and *structural* trusts (Reay Atkinson, 2011):

> **Relational (Ambidextrous** (He & Wong, 2004)**)** – combining CRC / IT-S and CSI / S-IT: *Situational [Aware] Decision Trust* in which people are entrusted to behave reliably in certain ways based upon system hierarchy, structures, rules and identified sources of power; *Trusting Intention* in which people behave reliably in ways based upon the common understanding of a systems hierarchy, its structures, rules and identified sources of power.

Mutuality based on trust may occur only if certain conditions are met and structural relationships maintained, over time. As observed by Rosabeth M. Kanter (Ernest L. Arbuckle Professorship at Harvard Business School): 'true freedom is not the absence of structure...but rather a *clear* structure that enables people to work within established boundaries in an autonomous and creative way.' Considered in terms of *Mutual Information*, CSI / S-IT organic systems are more likely to develop collaborative structures, over time, that have considerable information about one another. Whereas, CRC / S-IT machine systems are more likely to apply cooperative structures, in time, for satisfying certain market or pricing mechanisms, e.g. in a Stock Market or on a production line. Two conclusions potentially apply. The first is that CSI / S-IT organic systems may better be able to withstand 'shocks' (where we consider a shock to be seen in terms of 'an instantaneous loss of *Mutual Information* and rapid increase in *Transfer Entropy*), although the loss of MI may also be significant'. The second is that 'CRC / IT-S machine systems may be less able to withstand shocks but that the loss of *Mutual Information* / increase in *Transfer Entropy* may be proportionally less significant and recovery that much quicker'.

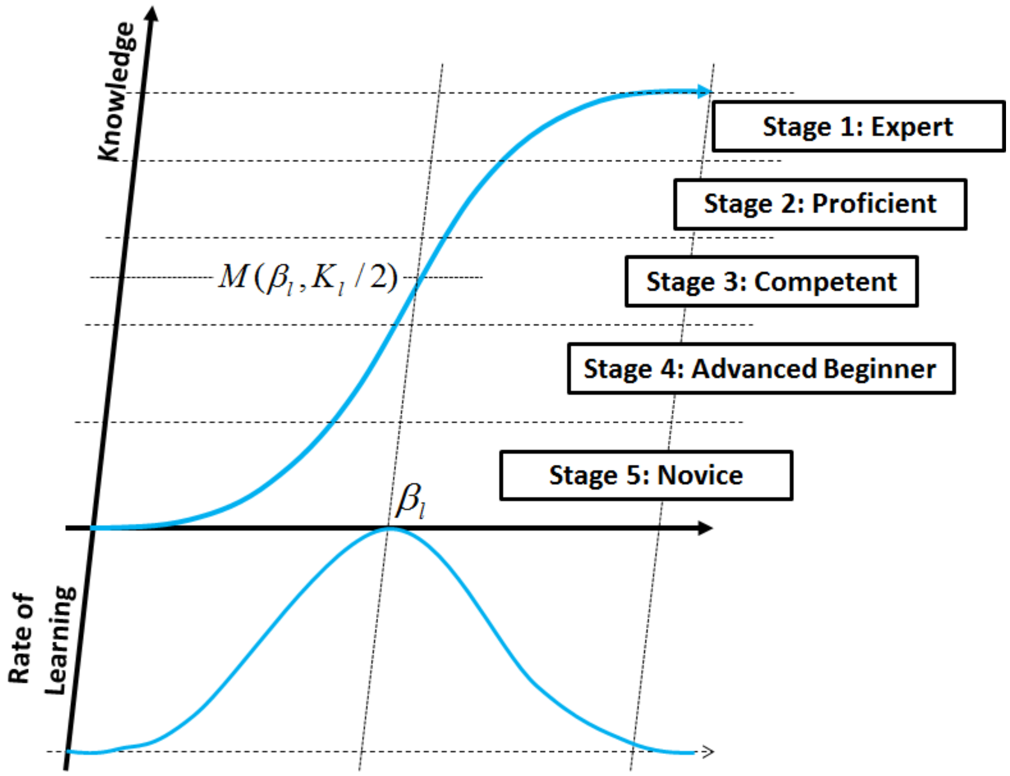

Figure 1: Dreyfus' Learning Model developed from Wozniak (Wozniak, 1999) and Modis (Modis, 1994) (see Reay Atkinson et al (Reay Atkinson, 2012b))

Mutual Information and Transfer Entropy also have potential application in both learning and forgetting curves (Wozniak, 1999). An argument being that learning involves both the transfer of mutual information in some form of social setting in which it becomes knowledge (see Bunge (2000)) and that this learning also involves discarding or forgetting old / irrelevant information through Transfer Entropy. Situating the Dreyfus' (1987) five stage learning model within the Modis-Verhulst-Ebbinghaus (Verhulst, 1838; Wozniak, 1999) learning curve (Modis, 1994), it is possible to *conceptualise* the learning experience. Dreyfus' (1987) recognised that not everyone will reach the systems-expert level in a particular subject. They understood that the [learning] programme needs to allow for individual / team learning and reflective capacities; skill-fade and changing learning rates as new sciences / technologies emerge and older ones mature, beyond β_l, see Fig 1. Modis & Debecker

(1992) also recognised that a change occurred at the mid-point, $M(\beta_l, K_l/2)$, between an increasing and a decreasing rate of learning. So, although MI continues to increase towards the proficient / expert stages, the rate of Transfer Entropy may also be increasing as the rate of learning decreases and forgetting increases.

Building on work by Modis and Debecker (1992), Modis (1994) identified a typical succession of growth and learning / change processes where ‘chains of logistic curves with different time scales may proceed in parallel’; connecting ‘natural growth and chaos like states’. In other words, the system may be more vulnerable to shocks and rapid increases in Transfer Entropy at the beginning and end of the learning curve. How this may be managed provides a focus for this paper. If one considers the recent behaviour of highly computerised (CRC / IT-S) stock markets in terms of an organizations’ ability to manage Mutual Information and Transfer Entropy (given rapid changes in both e.g. the Flash Crash of the US stock market on 6 May 2010) then it may be possible to consider alternative means of gradation that would allow for graceful degradation of “packet markets” operating at ‘microstructural levels’ (Easley et al, 2011).

This paper is divided into three sections. In the first section, we consider organizational health in terms of problem solving. In the next we consider how organizations may apply Transfer Entropy and Mutual Influence to their learning structures and in the final section we consider how this may be applied to enable organizations to work more successfully in the Cyber- and in highly computerised, microstructural packet-switching and packet-marketing type structures.

2.0 Coping or Failing

Warren and Warren (1977) considered ‘organizational health’ and concluded that ‘healthy organizations’ have ‘a critical capacity for solving problems’. They identified three dimensions of connectedness (see also Thibaut and Kelley (1959)): *identification* with the organization (they referred to as neighbourhood); *interstitial interaction* within the organization and *existential linkages* outside the organization. Considerations of health apply equally to organizations working with/in the Cyber and their capacity for “problem solving” and so controlling, in time, and influencing, over time. It is contended that successful companies are constantly “balancing” between the exploitative (delivered in time by coordination, rule and control) and the explorative (delivered over time through collaborative social influence). The capacity for balancing between coordination & control (the *exploitative*) and collaboration and influence (the *explorative*) to keep an organization "in kilter" is known as "ambidexterity" (He & Wong, 2004). This ability to dynamically balance between the two, may be indicative of a system's ability to "problem solve" and its health.

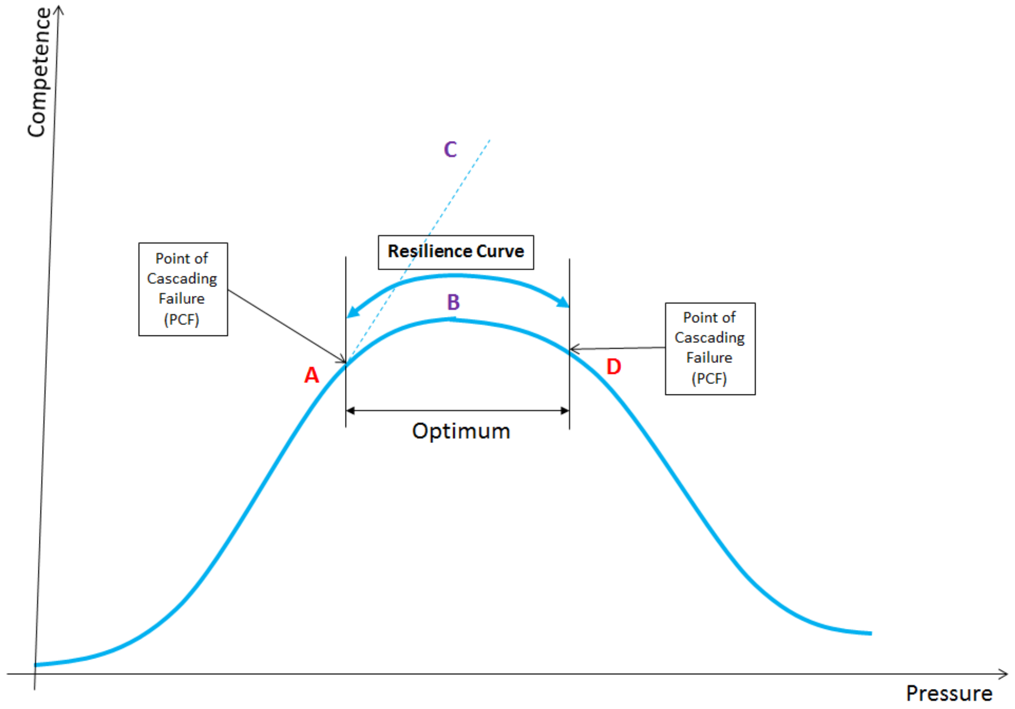

Figure 2: Simple Competence v Pressure Curve

A traditional view of the individual 'competence versus pressure' model is shown in Figure 2: 'as pressure increases so does performance (A) until the organization / individual reaches a peak (B). Applying simple linear targets, can suggest the individual carries on being more and more productive (C). In actual fact, organizations / individuals start to show adverse reactions or stress. Things start to be forgotten as people become overly focussed on meeting targets (the rabbit in the headlights); people become irritable and perhaps fearful; they make silly mistakes and are increasingly unable to *reflect* clearly and act coherently. As the pressure increases this becomes worse, performance drops and the organization / individual starts to exhibit a variety of physical symptoms, e.g. days off sick / absenteeism (D)' (Reay Atkinson & Sharma, 2007). There are a number of potential limitations to the curve. In actual fact there may be two points of cascading failure, one when pressure is put on the system beyond an *optimum*, position D; the other when pressure is taken off, or position A. The second critique of the model is that the optimum is in effect a convex as opposed to concave curve. As Plato concluded in ‘The Republic, ‘if a freshly minted utopia were ever to be successfully established…[the only way] would be downhill’ (Juarrero, 1999). The position described by Plato has similarities to that identified as the ‘Point of Cascading Failure’, at either position A or position D.

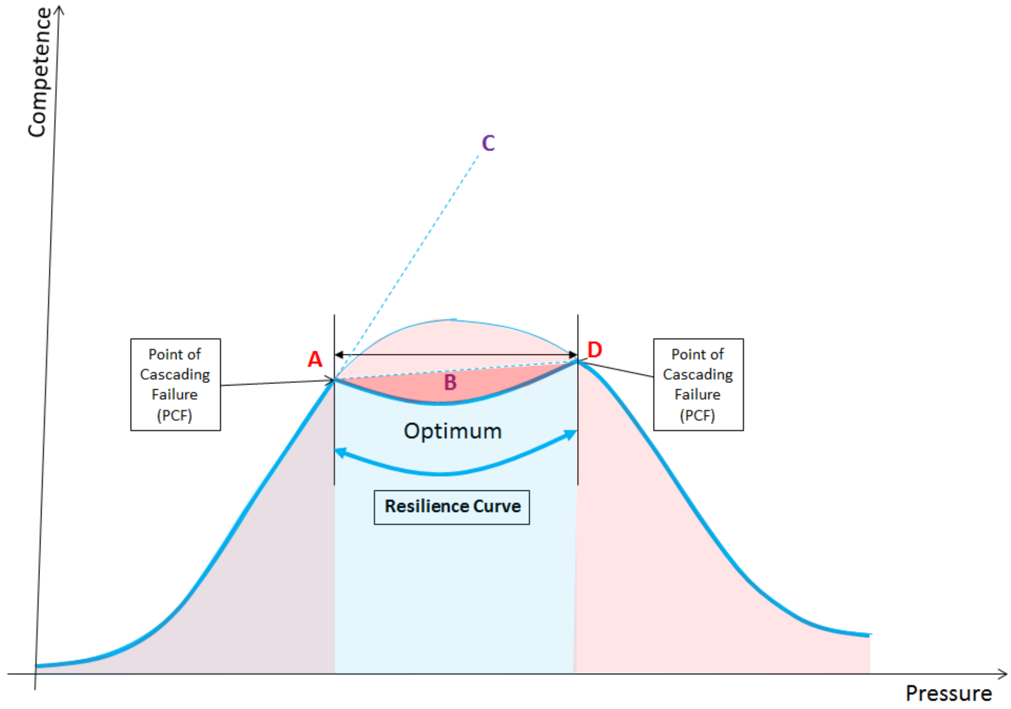

Figure 3: Sub Optimal Resilience Curve

Accepting, for the moment, the lack of a time base and that change can be applied to a static or frozen model, from this perspective Mutual Information increases to point B and then some form of change occurs and Transfer Entropy begins to increase, as MI decreases. The supposition is that the Transfer Entropy increases to such an extent, perhaps through a shock to an already stressed / pressurised system, that it moves into instability and cascading failure (Buldyrev et al, 2010). The reverse is also known to happen when pressure / stress is taken off a social system, position A. An alternative model may be suggested. In this model an optimum is previously identified but instead of continuing to increase expectation of performance (in terms of competency) and pressure beyond point A, performance demands on the system are in actual fact ‘governed’ as pressure increases. This effectively creates a ‘sub-optimal curve’, Figure 3. It is suggested that by dynamically managing system MI and TE about position B that this a) creates resilience in the system (by allowing the organization to adapt over time to changing existential pressures – the resilience curve) and b) provides *indication* when the system may be erring toward failure. In other words, this model allows an organization to *hunt* about its optimum position by sacrificing some performance for resilience. A traditional view of Change Management is shown by the 'step change' applied to a IT-S control type system in Figure 4. Change creates an instantaneous (linear, over time) response from the system until it reaches the required change state. At this point there is some *hunting* as the system settles to its new state and awaits future demands.

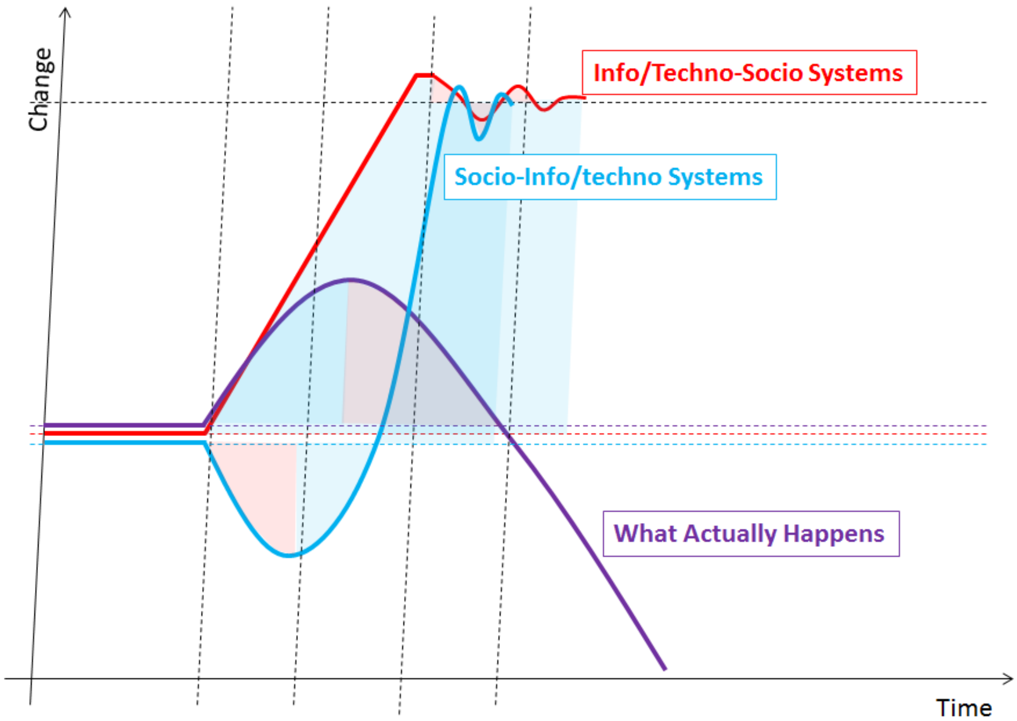

Figure 4: Change Dynamics IT-S System versus S-IT System and what actually happens when wrongly applied (McOwat, 2001; McOwat, 2007; Reay Atkinson, 2011)

As described by McOwat (2001; 2007), what happens when this model is applied to a socio-info/techno system, is that the system responds as directed to meet set targets. Over time, because of lack of investment and the recognition that change is costly to any organization (there are often very good individual and collective reasons not to change) performance actually falls off, Figure 4. As described by Longstaff (2010) and Reay Atkinson et al (2012a), what actually happens may be as follows:

> 'Initially, managers and practitioners combine to set and agree targets. The targets appear reasonable and practitioners, consultants and [managers] are satisfied. At

> about the three year point (2-3 years is the average time managers / practitioners remain in a particular post in the Public Sector corresponding to a 100% turnover in staff every 4.5-6 years (CIPD., 2009)) those initially responsible for agreeing and setting the targets move on, through promotion, selection, transfer or on leaving [MI reduces]…Targets continue to be met…satisfaction reportedly continues to grow and the managers remain "satisfied" that targets are being achieved. At the five year point, the rate of change / satisfaction begins to reduce [Transfer Entropy Increases; Mutual Information decreases]…anyway, the manager / practitioner only has a year to do and is seen to have done well: why rock the boat? By this stage, on average, [in the UK NHS] there has been 100% turnover in staff since the change programme was implemented [MI decreases; TE increases]…Strategic, co-adaptive (collaborative / federated) and agile core knowledge [MI] has been stripped from the organization [TE]. After 10 years…the [Organization] no longer has in place the proficiency and expertise [MI] to agilely design alternative possible futures or provide plausible explanation of intuition and invention of reason (phronesis) see Dreyfus' (1987)'.

Through the lens of Mutual Information and Transfer Entropy, what appears to occur is that some form of existential pressure – acting potentially as a 'shock' – is administered to the system. Rather than allowing a socio-info/techno system to change, this 'change impetus' creates a loss of Mutual Information and an increase in Transfer Entropy. Collaboration, based on old certainties, is no longer possible and people need to find their way and new 'values and common reference points' (Reay Atkinson, 2013a). In reality, a period of negative change occurs during which time Transfer Entropy increases and Mutual Information (including the opportunity for collaboration) decreases. How long this continues, it is posited, is based upon the amount of investment made into a socio-info/techno organization before and after the decision has been taken to change. There is no guarantee that the change will go as directed so, before an organization can change, it also needs to explore and identify the bases upon which change may take place.

There are important learning and coping strategies that would appear to emerge from this analysis, also to do with potential implications for managing Post Traumatic Stress Disorder or PTSD: 'UK Service personnel returning from the Falklands were analysed in terms of stress. The theory suggested at the time was that those from broken families might suffer more stress related symptoms than those from more stable families. They did not. What was found was that individuals from a stable and supporting background bounced back more quickly' (Donnelly, 2006-; Reay Atkinson & Sharma, 2007). It was concluded 'that a supportive family and platoon / ship / unit network allowed the service-person to cope by limiting the extent of Transfer Entropy occurring after the existential *shock* of conflict and creating new reference points (MI) about which collaborative learning and coping strategies might emerge'.

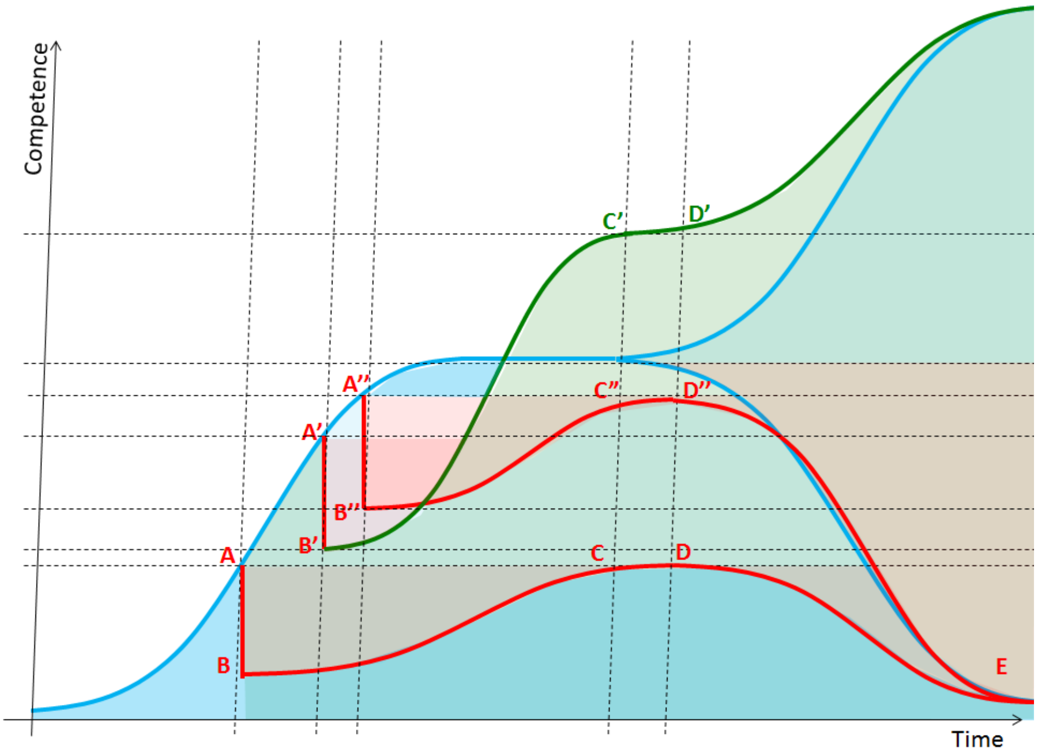

Figure 5: Managing Shock (TE) and Collaboration (MI) Over Time

From experience in Northern Ireland, it was also learned how people adapted to operational shocks during a tour of duty. An individual arrived 'in theatre' with a level of competence based largely upon previous experience, education and training (MI) for the job they were going to do. They arrived with a basic level of competency from which they were expected to learn / improve on through experience. Three other important observations were also made (Reay Atkinson & Sharma, 2007):

1. If the individual suffered a 'shock' early in their tour (A) then there was an immediate loss of competency A-B but, more significantly, that individual would never recover to a level of competency higher than they were when the shock occurred by the end of their tour, B-C/D;

2. If the individual suffered a shock A'' later in their tour the same immediate increase in TE occurred, A"-B", and although the individual would not recover to a level above that when the shock occurred, the overall loss in competency and MI was much reduced (A"-C"/D") as compared to A-C/D. The conclusion drawn was that the later an individual suffered a shock, the better – which obviously meant something different to those wishing to destabilize an organization.
3. If the individual was part of a close knit collaborative (shared aware) networked team with high MI, then although the individual may suffer the same shock than when working alone / as an individual, A'-B', just as the shock was mitigated and shared, so the individual and team learned. Consequently, the final competency level (C'-D') was improved. The organization had become more adapted and able to cope with existential shocks than it had been beforehand or would have been if operating as a group of loosely connected individuals.

The subsequent behaviour of the organization was not necessarily examined. It is conjectured an individual who was part of a close-knit team would respond to change a) from a higher position of MI (than the other organizations), C"-D"; so b) future change (TE), may be less significant and c) they might achieve a higher level of competence than those 'starting from scratch'. Similarly, whereas individualistic models may never achieve lasting change in the way and may wish to shed / forget (D/D"-E), as quickly as possible what Mutual Information they had learned, a team was more likely to retain base level skills over time and revert, if anything, to higher competency levels (perhaps C"-D"), Fig. 1.

3.0 Planning for Transfer Entropy and Change

Another form of non-learning, over time, can occur between watch changes e.g. as a ships bridge watch-keeping team comes on or off duty. The crew will have learned their local environment and be mechanistically, situation and shared aware. The oncoming watch will be aware of their requirements and the system constraints they are working in but not the detailed organic environment they are coming into. Depending upon that environment, watch changeover times might be increased and / or watches increased in length to cover particular moments of stress, e.g. transiting the Dover or Malacca Straits. For individuals going off watch, it is important that they discard the local environmental knowledge (TE) while retaining their mutual system skills and mechanical ship awareness (MI). Considered, over time, it might be acceptable for the system to retain a basic level of Mutual Information to sustain requisite levels of competency, for example in an assembly plant, Figure 1. If changes occur during the time, 'on shift', this can be managed by bringing forward the handover. In this way while the system competency level, A, remains the same the effectiveness gap, D-E, between oncoming and outgoing teams can be reduced.

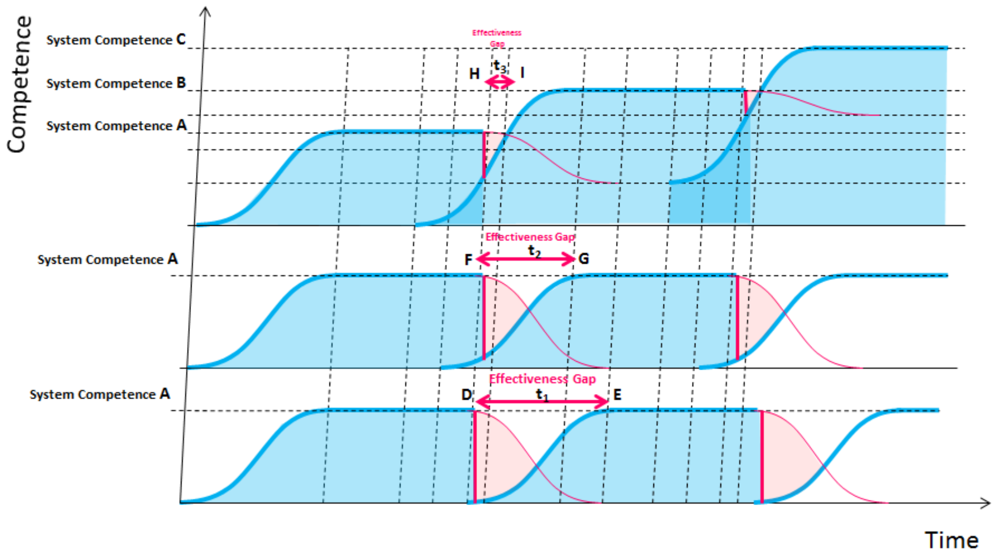

Figure 6: Managing Shift / Watch Competency Levels

In the maritime domain, a study of crew changes in naval operations revealed the need for better situation awareness support for incoming personnel (Endsley & Strater, 2005; Keller et al, 2008). In a context where the ecology is relatively stable and acceptable mechanistic competency levels are well established, it may not be necessary for the organisation to learn / improve its levels of competency. In which case, Transfer Entropy and the *Effectiveness Gap* can be reduced from A-E (t_1) to F-G (t_2), see Fig. 6. In a more dynamic and changing ecology, not learning between watch / shift handovers can create existential threats to an organisation, e.g. transiting the Malacca straits at night. In this instance, it may be necessary to improve competency levels and retain these over time (A-B; B-C). This can be achieved by bringing forward the oncoming watch / shift and delaying the handover with the outgoing team. In this case, the *Effectiveness Gap* is reduced significantly to H-I (t_3) and overall competence levels may also increase, over time. The issue of not-learning or 'flat-lining' in a changing ecology where one is being tested may add considerably to the likelihood of shocks to the system. Initially, US HQ staffs in Iraq and Afghanistan undertook tours of 6-9 months. It was soon appreciated that, to adapt to the ecology and to be effective over time, tour lengths needed to be increased (despite the significant impact on separation). These were extended to 12 months and for HQ staffs to 15 months; allowing for a 3 month handover between on-coming and outgoing staffs. The British Army's performance in both Iraq and Afghanistan has come under close scrutiny and has been described as 'contributing to UK *Strategic Failure*' (UK-PASC., 2010). The UK maintained 6 month tours for all but those staff deploying to US HQs. Anecdotal evidence suggests that there was limited learning between *tours* and that learning between the Army and the UK Government was similarly limiting, i.e. both were 'flat lining':

The Soviet Russian concept of Razvédka Bóyem, for 'describing intelligence gathering through battle' may, in its wider understanding, be thought of as 'the *abductive* gathering and capture of information (and data) for testing (by *induction* and *deduction*) through social exchange' (Reay Atkinson et al (2009). It is this testing that appears important to enabling an organization to adapt and to manage both its Mutual Information and the risks of Transfer Entropy occurring rapidly or over time (as in skill fade). Considering the suggested definition for Razvédka Bóyem as including 'testing…though exploration and exploitation' this returns to *ambidexterity* and *Relational* Trust considered in terms of being *Situation Aware* (in which people can be entrusted to *behave reliably* in certain ways based upon a systems hierarchy, its structures, cooperative rules, controls and identified sources of power (the CRC / IT-S *machine*)) and having *Trusting Intention* (in which people will behave reliably in certain ways based upon the common understanding of a systems hierarchy, its structures, rules and identified sources of power (the *organic* CSI / S-IT)).

In order to create the *relational trusts* necessary for *exploration* and *exploitation* (ambidexterity), it may be necessary for organizations to continuously test and so adapt to their ecology. We suggest that this testing process involves the 'gaining and losing of *Mutual Information* and *Transfer Entropy* in discrete and manageable *packages*, so that the risks of shock and / or catastrophic degradation and cascades can be dynamically minimised'. It is concluded that, in managing change, an organization needs to allow for both changes to Mutual Information and Transfer Entropy – and for both to be influenced, over time, and controlled, in time, such that each complements the other.

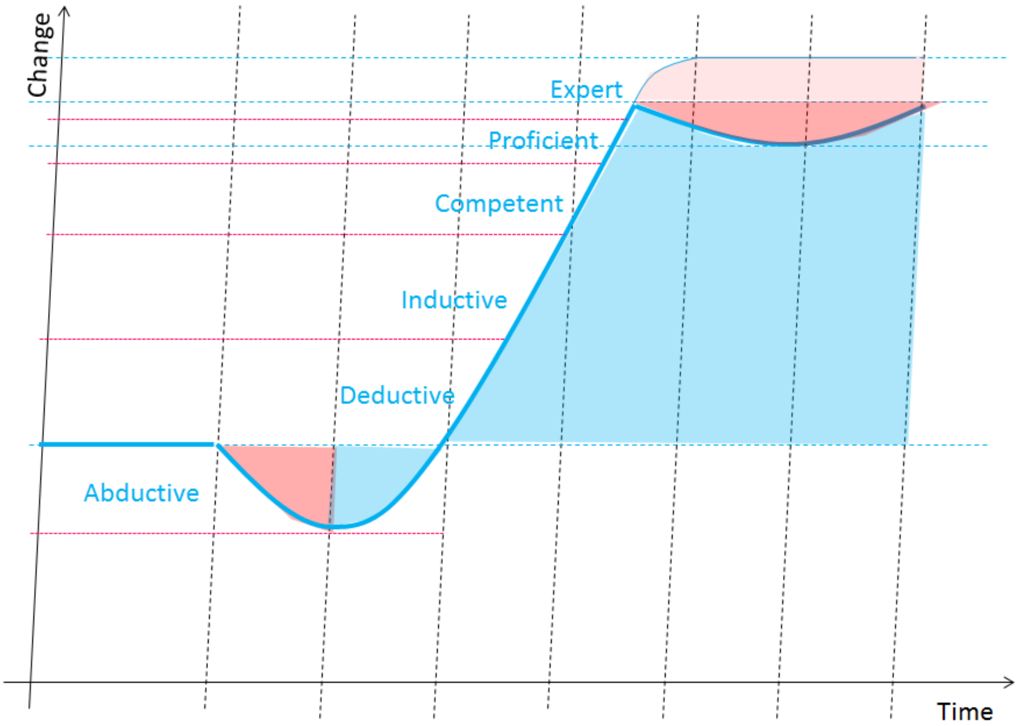

Figure 6: 6 Stage Dreyfus Learning Model

We consider the first phase of change to be *abductive*, identified by Charles Peirce ([1878], 1931) as the third type of logical reasoning, specifically applied in '*exploratory* data analysis…suggesting a pattern for further inquiry [and contributing] to the conceptual or qualitative understanding of a phenomenon' (Yu, 1994). Abduction may be thought of as the process of *selecting* the best hypothetical explanation (H) for an observed phenomenon (P) among different explanations which are sufficient for P. The purpose of abducting is to choose the hypothesis / proposition which should be tested, not to assert or take on that hypothesis (Sullivan, 1991). *Abduction* is identified as the first step in any change process – being about suggesting new hypotheses by looking for the pattern in a phenomenon (Peirce, [1878] 1931). It is a time when old certainties defined by Mutual Information are changing. Transfer Entropy requires managing, structure and guidance if learning and adaptation is to take place. Peirce further identified abduction as being complementary for deduction and induction; not their opposite: 'it is the *firstness* (possibility, potentiality); deduction, the *secondness* (existence, actuality); and induction, the *thirdness* (generality, continuity)' (Yu, 1994).

As applied to the Dreyfus' change dynamics learning models (Figs. 1 & 4) it is suggested there may be six stages to learning. The first stage is the *adductive* stage, during which time new hypotheses / propositions are put forward for testing. These feed into a *deductive* stage, where the system looks for examples of existence and actuality; this stage feeds into the inductive stage, where one is developing general models of the new 'human terrain' better *fitted* to the emerging ecology. After these stages, levels of competency and proficiency within the organization may be achieved. Once these levels have been reached, the organization returns to a structured period of *abduction*, during which time the organization dynamically 'gathers, tests and assesses manageable information and knowledge *packets* through *exploration* and *exploitation*' – Razvédka Bóyem. It was based upon this wider understanding that Reay Atkinson et al (2009) considered the concept of Information Capture and Knowledge Exchange (ICKE – pronounced 'Ike' after President Eisenhower) and considered as 'the *abductive* gathering and capture of information (and data) for testing (by *induction* and *deduction*) through social exchange' (Reay Atkinson, 2011; Reay Atkinson et al, 2009; Szilard, 1964 (1929); Bunge, 2000; Yu, 1994; Peirce, ([1878] 1931); Yin, 2009). ICKE is seen as an *annealing* process, during which time an organization is tested and so hardened to potential shocks, where *organizational annealing* may be:

> 'the altering of an organization to increase its *adaptability* and make it more *workable*. It involves maintaining an organization above *critical mass* ('a sufficient number of adopters in a social system so that the rate of adoption becomes self-sustaining and can, by itself, create further growth, after Oliver et al (1985)' and managing its Mutual Information and Transfer Entropy by existential *stressing* and interstitial *de-stressing* so as to improve system *shared awareness* and *resilience*'.

4.0 Within Synthetic Ecologies

We consider a Synthetic Ecology to be:

> 'a system (being or entity) that adapts, over time, by combining, through design and by natural processes, two or more dynamically interacting networks, including organisms, the communities they make up, and the non-

> living (physical and technological) mechanical components of their environment'

In their examination of two control groups applying Pressure Immobilisation (PIM) for the 'field management of bites by venomous snakes', Simpson et al (2008) concluded that neither written instructions nor intense training with feedback adequately prepares individuals to apply PIM [correctly]…to limit venom spread'. The two groups were given different levels of training and then monitored, hours days and months afterwards to assess individual effectiveness. It was determined that 'whilst the entire developing world, and much of the developed world, longs for a simple, inexpensive, effective, universally applicable solution to snake-bite first aid, PIM is not the answer'. PIM may have been overly complicated for even well trained individuals to apply in emergency and episodic (unexpected) conditions when working alone. The Mutual Information necessary for real time, *critical* problem solving was insufficient to overcome skill fade / forgetting, potentially exacerbated when dealing with a patient in *shock*.

Frankenberger and Badke-Schaub (1999) studied the information-seeking behaviour of designers with respect to the design situations they were in and distinguished between 'routine work' and 'critical situations'. They reported that designers contact their colleagues for information and knowledge in nearly 90% of *critical* situations. No amount of training (MI) may prepare an individual for retaining information about complicated info/techno (mechanical) rules and procedures, given skill fade / forgetting over time and time-critical shock (Transfer Entropy). What appeared necessary for these practitioners to be effective was for the knowledge and information (MI) to be *synthesized* by the organisation; for this knowledge to be *tested* (over time) in a trusted *safe-to-fail* learning ecology (Juarrero-Roqué, 1991) and for individual practitioners to be in contact with colleagues even in emergency situations – to give them the confidence and competence to deal effectively with the crisis at hand; so limiting Transfer Entropy in and over time (Figs 5 & 6).

In their study of workers in a manufacturing environment, Nembhard and Uzumeri (2000) concluded that 'workers who learn more gradually, tended to reach a higher steady-state rate of productivity [TE reduced]'. And that 'workers who learned more rapidly [MI improved] also tended to forget more rapidly [TE increased] during breaks in production'. They concluded that, 'regardless of whether the task is procedural or manual, managers may reallocate [those] who learn more rapidly to short production runs'. This appears consistent with work by Rowland (2006), Leach (2004), Foreman (1991) and Goffman (1963) suggesting that some people cope with Transfer Entropy (*change* and *shock* – the stress of battle, for example (Rowland, 2006)) and some with *steady-state*, better than others. This suggests that organizations may need to retain behavioural 'variety' (Ashby, 1957) within their structures: people capable of leading change <u>and</u> those for managing steady state. Individuals capable of learning rapidly may exhibit 'leadership characteristics, notably in crises' (Rowland, 2006) and 'use 'initiative as a matter of habit' (Dixon, 1977). These characteristics may be 'visible, identifiable, sometimes anti-social and disruptive' (Dixon, 1977; Jacoby et al, 2005); even showing 'abnormal and awkward, uncommon practices' (Sternin & Choo, 2000). In times of *stability*, we suggest organizations often rid themselves of such people and so, also, the *variety* necessary for complex problem solving (Reay Atkinson, 2010; Reay Atkinson et al, 2013b; Reay Atkinson et al, 2012b) in times of instability and change.

'The "flash crash" of May 6th 2010 was the second largest point swing (1,010.14 points) and the biggest one-day point decline (998.5 points) in the history of the Dow Jones Industrial Average. For a few minutes, $1 trillion in market value vanished' (Easley et al, 2011). In considering these crashes, the "metaphor of bubbles" have been used (Marsay, 2013). When bubbles burst (or are burst), someone stands to gain – the $1 trillion does not simply vanish, just ask George Soros! A significant issue behind the 2010 Flash Crash was high-frequency, automated (CRC / IT-S) microstructural *machine* trading. Working in a highly synthesised, CRC / IT-S, packet-switching ecology, traders were seeing largely what they wanted to see and the Mutual Information appeared consistent with their models of the market. However, as identified by Easley et al (2011) and by Dimpfl and Franziska (2012), the Mutual Information was actually changing quite rapidly in the 60 minutes prior to the crash.

Easley et al (2011) identified what they called a Volume-Synchronized Probability of Informed Trading (VPIN) Flow Toxicity metric. VPIN looks at the *quality* of the Mutual Information contained within the market and how it is *changing, over time*. It considers how liquidity is being provided to the market to enable its "packet-switching", pricing mechanisms to work. Easley et al (2011) compared "informed traders" (e.g. market aware managers of hedge funds with high MI, managing core liquidity and who intuitively *know* the market conditions) with "uninformed traders", they called "Market Makers" (speculators coming into the market with low MI but cash to spend). They consider order flow toxicity as a 'measure of the probability of informed traders [inadvertently (e.g. as they exit the market) and potentially] adversely selecting uninformed traders to enter the market'. The more the informed traders selected uninformed traders, the more toxic market liquidity became. At a certain point, the order flows become too toxic (highly *speculative* (TE increasing) and less *informed* (MI decreasing)) and Market Makers also begin to withdraw. Liquidity is increasingly toxic and Market Makers, sensing the absence of informed traders (MI decreasing), also begin to withdraw – so increasing the 'concentration of toxic flow in the overall market volume' (TE increasing). Machine feedback mechanisms force even more Market Makers out (MI decreasing; TE increasing) so causing a cascading effect, in which failure even in a small part of the overall market can 'lead to the complete fragmentation of [the] system [and its] interdependent networks [or a rapid increase in TE]' (Buldyrev et al, 2010).

5.0 Organizational Immunisation

This paper looks at Mutual Information and Transfer Entropy as applied in changing and dynamic, often highly technologically focussed *synthetic* (Cyber) *ecologies*, where change can be rapid to the point of creating shocks and the ability to manage and learn from shocks, dynamically, is time-constrained. Particularly in emerging microstructural markets, *mechanistically* driven by computerised packet-switching – hence *packet-markets*.

We posit that it may be possible to identify different forms of Mutual Information; how it is changing over time and that this may provide indication and warning of impending shocks to organisations, e.g. VPIN. Some of our more detailed modelling and analysis of mechorganic type enterprises is also showing this to be the case (Reay Atkinson, 2011).

Finally, we suggest that *organizational annealing* (which may also provide for *organizational immunization*) improves *situational awareness* and *resilience*. This is likely to require a new form of mathematics based on learning during times of instability, uncertainty and change (Reay Atkinson et al, 2013b), described as either *metamatics* (Goodger et al, 2012) or *metadetics* (Reay Atkinson et al, 2013c). Simple control measures or circuit-breakers may create *shocks* in collaborative market-spaces by, in actuality, reducing Mutual Information and increasing the likelihood and conditions for Transfer Entropy. We put forward theoretical predictions leading to the new organisational immune theory. We argue that organisations are made up of actors, their dependencies which evolve around internal and external systems, structure process and environment. Organisations are increasingly seen as complex social systems in which functioning at the optimised level could be largely dependent on the micro and macro system level structural dynamics that make the whole. It is also important to highlight that micro to macro level organisational dynamics are adaptive, complex leading them to produce self organisation, non-hierarchical and emerging patterns. It is also observed that the traditional hierarchical control-command structure for operations do not necessarily function in situations where there are changes in the environment demanding organisations or a group of actors to adapt their structure, process and procedure of operations based on nature of changes in the environment. It is therefore, complex adaptive and self organised behaviour dynamics could be evident and seen situations of coordinated response to disasters or unpredictable situations. Yet, the understanding of the self organised behaviour or organisations is limited to date. In this paper, we put forward a new direction to organisational science research by introducing organisations as biological systems and therefore, systems biology could essentially be used to study organisations and in particular, the robustness of coordinated response to disasters, for example, where we would assume a higher degree of uncertainty and unpredictability in the environment leading to organisational behaviour, which can be explore by foundations of systems biology. Secondly, if we establish the ground for classifying the organisation as a biological system which is organic, adaptive and self organised, we could then put forward theoretical predictions for analysing, evaluating and improving coordinated response to disasters by applying immune systems modelling which deals with coordinated response to infections / aberrant behaviour in a biological networks. Thirdly, we intend to explore a large email communications corpus for exploring organisational communications network in phases such as stable, during crisis, and at collapse. Fourthly, we would superimpose the immune systems model of our biological systems on the visualised communications network to suggest theoretical predictions leading to some empirical generalisations about robustness of coordinated response and resilience to shocks / disasters from a system biological perspective.

References

Anderson AMF. (2009) Classes of socio-technical hazards: Microscopic and macroscopic scales of risk analysis. *Risk Management* 11: pp. 208 - 240.

Ansoff HI. (1975) Managing Strategic Surprise by Response to Weak Signals. *California Management Review* Vol. XVIII, No. 2: pp. 21-33.

Ashby R. (1957) *An Introduction to Cybernetics*, London: Chapman and Hall.

Buldyrev SV, ,2, R., Parshani, G., Paul, H.E., Stanley & S., Havlin. (2010) Catastrophic cascade of failures in interdependent networks. *Nature* 464, 15 April 2010 (Received 22 December 2009; Accepted 17 February 2010): pp. 1025-1028.

Bunge MA. (2000) Ten Modes of Individualism - None of Which Works - And Their Alternatives. *Philosophy of the Social Sciences* 30(3): pp. 384-406.

Castells M. (1996) The Information Age. Economy, Society and Culture. *Volume I The Rise of the Network Society.* Oxford: Blackwell Publishers.

CIPD. (2009) Recruitment, Retention and Turnover. *Annual survey report.* London: Chartered Institute of Personnel and Development

Coffman B. (1997) *Weak Signal Research, Part I: Introduction*. Available at: http://www.mgtaylor.com/mgtaylor/jotm/winter97/wsrintro.htm.

Cover TM, & J. A. Thomas. (1991) *Elements of Information Theory*, New York: John Wiley & Sons, Inc.

Dahl RA. (1957) The Concept of Power. *Behavioral Science* 2:3, July: 201.

Dimpfl T, & P.J., Franziska. (2012) Using transfer entropy to measure information flows between financial markets. *Humboldt-Universität zu Berlin, Forschungsgemeinschaft SFB 649 "Economic Risk": Discussion Paper*. 2012-051.

Dixon N. (1977) *The Psychology of Military Incompetence*, London: Jonathan Cape.

Donnelly CN. (2006-) A series of interviews and briefs on related subjects specific to Defence Relations, Operational Art and Strategic Thinking. . In: S. Reay Atkinson. UKDA-ARAG, CUED (ed). Learning & Adapting to Modern Insurgencies: UKDA-ARAG.

Dreyfus HL, & S.E., Dreyfus. (1987) *Mind Over Machine*, New York: The Free Press.

Easley D, M. López de Prado, & M., O'Hara. (2011) The Microstructure of the 'Flash Crash': Flow Toxicity, Liquidity Crashes and the Probability of Informed Trading. *The Journal of Portfolio Management* Vol. 37, Winter, No. 2: pp. 118-128.

Endsley MR, L., Strater. (2005) Designing to Enhance SA in the CIC. *Human Systems Integration Symposium.* Arlington, USA.

Felici M. (2007) Trust strategies and policies in complex socio-technical safety - critical domains: An analysis of the air traffic management domain In: N.

Guelfi D, Buchs (ed) *Proceedings of the 3rd International Workshop on Rapid Integration of Software Engineering techniques, RISE 2006, No. 4401 in LNCS.* Geneva, Switzerland: Springer-Verlag, pp. 51 - 65.

Foreman D. (1991) *To Reason Why*, London: Deutsch.

Frankenberger E, & P., Badke-Schaub. (1999) Information Management in Engineering Design - Empirical Results from investigations in industry. In:. *Proceedings of the International Conference on Engineering Design.* Munich, GE, pp. 911-916.

Goffman E. (1963) *Stigma: Notes on the management of Spoiled Identity,* Englewood Cliffs, NJ: Prentice-Hall.

Goodger AC, N.M.M., Caldwell & J.T., Knowles. (2012) What Does the Assurance Case Approach deliver for Critical Information Infrastructure Protection in Cybersecurity? *System Safety 2012 - The 7th International IET System Safety Conference, incorporating the Cyber Security Conference 2012.* Edinburgh, 15 Oct: IET.

Harmaakorpi V, I., Kauranen, & A., Haikonen. (2003) The Shift in the Techno-socio-economic Paradigm and Regional Competitiveness. *The 43rd Conference of European Regional Sciences Association (ERSA), 27-31 Aug.* Lahti Center, Jyväskylä, Finland: Helsinki University of Technology.

He Z-L, & P-K Wong. (2004) Exploration vs. Exploitation: An Empirical Test of the Ambidexterity Hypothesis. *Organization Science* Vol. 15, No. 4, July-August: pp. 481-494.

Hickson DJ, C. R., Hinings, C. A., Lee, R. E., Schneck & J. M., Pennings. (1971) A Strategic Contingencies' Theory of Intraorganizational Power. *Administrative Science Quarterly* Vol. 16, No. 2, (Jun): pp. 216-229.

Hiltunen E. (2008) Good sources of weak signals: a global study of where futurists look for weak signals. *Journal of Futures Studies* Vol. 12 No. 4: pp. 21-44.

Hiltunen E. (2010) Weak Signals in Organizational Futures Learning. Helsinki School of Economics A-365.

Hossain L, S., Reay Atkinson, M., D'Eredita, & Rolf.T., Wigand. (2013) Towards a Mech-Organic Perspective for Knowledge Sharing Networks in Organizations. *UK Academy for Information Systems.* Worcester College University of Oxford, 8-20th March 2013.

Jacoby A, D. Snape, & A. Baker. (2005) Epilepsy and social identity: the stigma of a chronic neurological disorder. *The Lancet - Neurology* 4(3), Mar.

Juarrero-Roqué A. (1991) Fail-safe versus safe-fail: Suggestions toward an evolutionary model of justice. *Texas Law Review* 69(7): pp. 1745-1777.

Juarrero A. (1999) *Dynamics in Action: Intentional Behavior as a Complex System,* Cambridge, MA.: MIT Press.

Keller R, N., Carrigan, S., Reay Atkinson, P., Johnson & P.J. Clarkson. (2008) Collaboration and Information Sharing in NEC Networks. *NECTISE, Oct.* Leeds: NECTISE.

Kullback S, & R. A., Leibler. (1951) On information and sufficiency. *The Annals of Mathematical Statistics* 1: pp. 79-86.

Leach J. (2004) Why people freeze in an emergency: temporal and cognitive constraints on survival responses. *Aviation, Space and Environmental Medicine*: pp. 539-542.

Longstaff PH. (2010) Is the blame game making us less resilient? *Oxford Martin School, Lecture Paper.* Oxford: University of Oxford.

Marsay DJ. (2013) Which mathematics for financial resilience? *IMA Conference on Mathematics in Finance.* Heriot-Watt, Edinburgh 8 Apr: Institute of Mathematics and its Applications (IMA).

McKnight DH, & N. L., Chervany. (2001) Trust and distrust definitions: One bite at a time. In: R. Falcone M, Singh, & Y.-H., Tan (ed) *Trust in Cyber-societies. No. 2246 in LNA.* Berlin: Springer-Verlag.

McOwat D. (2001) Enterprise Modelling. London: MoD, Defence Technology Centre, DERA.

McOwat D. (2007) A series of interviews and briefs on related subjects specific to Defence, systems, strategy and designs. In: S. Reay Atkinson. UKDA-ARAG, CUED (ed).

Modis T. (1994) Fractal Aspects of Natural Growth. *Techno-logical Forecasting & Social Change* Vol. 47: pp. 63-73.

Modis T, & A. Debecker. (1992) Chaoslike States Can Be Expected Before and After Logistic Growth. *Techno-logical Forecasting & Social Change* Vol 41(1): pp. 111-120.

Nembhard DA, & M.V. Uzumeri. (2000) Experiential learning and forgetting for manual and cognitive tasks. *International Journal of Industrial Ergonomics* 25: pp. 315-326.

Oliver P, G. Marwell, and R. Teixeira. (1985) A Theory of Critical Mass: I. Interdependence, Group Heterogeneity, and the Production of Collective Action. *American Journal of Sociology* 9.3: pp. 552-556.

Peirce CS. (([1878] 1931)) How to make our ideas clear. *Popular Science Monthly* Ristampato on Peirce CS 1959: 286-302., vol. 12.

Reay Atkinson S, & M Sharma. (2007) Learning and Adapting to Modern Insurgencies. In: Marshall-Centre (ed) *The Comprehensive Approach to Modern Conflicts Conference,.* Munich 26-27th March: UKDA, ARAG.

Reay Atkinson S, S. Lesher & D. Shoupe. (2009) Information Capture and Knowledge Exchange: The Gathering Testing and assessment of Information and Knowledge through Exploration and Exploitation. *14th ICCRTS: C2 and Agility.* Washington: CCRP.

Reay Atkinson S. (2010) Returning Science to the Social. *The Shrivenham Papers, UK Defence Academy* Number 10, July.

Reay Atkinson S. (2011) Engineering Design Adaptation Fitness in Complex Adaptive Systems. *CUED EDC.* Cambridge University Engineering Department: Cambridge, UK.

Reay Atkinson S, A. Goodger, N.H.M Caldwell, L. Hossain. (2012a) How lean the machine: how agile the mind. *The Learning Organization* Vol. 19 Iss: 3: pp. 183 - 206.

Reay Atkinson S, S., Feczak, A., Goodger, N.H.M., Caldwell & L. Hossain. (2012b) Cyber-internet: a potential eco-system for innovation and adaptation. *European Alliance for Innovation: Internet as Innovation Eco-System Summit and Exhibition 2012, 4-6 Oct.* Riva del Garda: Italy: EAI.

Reay Atkinson S. (2013a) Complex Designs Workshop, DSTO Adelaide. In: Reay Atkinson S (ed) *Managing Complex Projects & Programmes Cooperative Research Centre (CRC).* Sydney & Canberra: Unpublished: University of Sydney & International Centre for Complex Project Managment (ICCPM), 7 Feb.

Reay Atkinson S, S., Tavakolitabaezavareh, D., Walker, L., Liu, & L., Hossain. (2013b) Securing the bolts before the horse has bolted: A new perspective on

Managing Collaborative Assurance. *The IEEE 2013 Conference on Security Management, Aug.* Las Vegas.

Reay Atkinson S, S.,Tavakoli Taba, A.M.C, Goodger, N.H.M., Caldwell & L., Hossain. (2013c) The Need for Synthetic Standards in Managing Cyber Relationships. *The Third International Conference on Social Eco-Informatics (SOTICS 2013), Nov 18-20.* Lisbon: International Academy, Research and Industry Association (IARIA).

Rowland D. (2006) *The Stress of Battle,* London: HM Stationary Office.

Schreiber T. (2000) Measuring Information Transfer. *Physical Review Letters* 85: pp. 461-464.

Simpson ID, P.D. Tanwar, Chittaranjan Andrade, D.K. Kochar and R. L. Norris. (2008) The Ebbinghaus retention curve: training does not increase the ability to apply pressure immobilisation in simulated snake bite - implications for snake bite first aid in the developing world. *Transactions of the Royal Society of Tropical Medicine and Hygiene* 102,: pp. 451-459.

Sokol M. (2003) The 'Knowledge Economy': a critical view". *paper presented at the Regional Studies Association International Conference,12-15 April.* Pisa.

Sternin J, & R. Choo. (2000) The Power of Positive Deviance. *Harvard Business Review* January-February: pp.14-15.

Sullivan PF. (1991) On Falsificationist Interpretations of Peirce. *Transactions of the Charles S. Peirce Society* 27: 197-219.

Szilard L. (1964 (1929)) On the Increase of Entropy in a Thermodynamic System by the intervention of Intelligent Beings - the Critique (Rapoport A. and M. Knoller trans.). *Behavioral Science* 9: pp. 302-310.

Tenkanen A. (2008) Transfer Entropy. *A presentation in the information theory seminar.* Department of Information Technology, University of Turku: Finland.

Thibaut JW, & H.H., Kelley. (1959) *The Social Phsychology of Groups,* New York, London: John Wiley, Chapman Hall.

UK-PASC. (2010) Who Does UK National Strategy? . *Public Administration Select Committee (PASC),12 Oct.* London: House of Commons

Verhulst P-F. (1838) Notice sur la poursuit dans son accroissement. *Correspondence Mathematique et Physique* Vol. 10: pp. 113-121.

Walker D, S., Reay Atkinson, & L., Hossain. (2012) Collaboration Without Rules - A New Perspective on Stability Operations. *Presented at IEEE Cyber Conference, 14-16 Dec.* Washington: IEEE.

Warren RB, & D.I, Warren. (1977) *The Neighborhood Organizer's Handbook,* South Bend, Ind: University of Notre Dame Press.

Wozniak RH. (1999) Introduction to Memory: Hermann Ebbinghaus (1885 / 1913). *Classics in Psychology, Historical Essays.* Vol 20. Bristol: Thoemmes Press.

Wrong DH. (1968) Some Problems in Defining Social Power. *The American Journal of Sociology* Vol. 73, No. 6 (May): pp. 673-681.

Yin RK. (2009) *Case Study Research: Design and Methods,* Los Angeles: 4th Edition, Sage Publications.

Yu CH. (1994) *Abduction?: Deduction? Induction? Is There a Logic of Exploratory Data Analysis?*: ERIC Clearinghouse.