

A Review of Sociotechnical Systems Theory: A Classic Concept for New Command and Control Paradigms

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ABSTRACT

Command and control is the management infrastructure for any large, complex, dynamic resource system (Harris & White, 1987). Traditional military command and control is increasingly challenged by a host of modern problems, namely environmental complexity, dynamism, new technology, and competition that is able to exploit the weaknesses of an organisational paradigm that has been dominant since the industrial revolution. The conceptual response to these challenges is a new type of command and control organisation called Network Enabled Capability (NEC). Although developed independently, NEC exhibits a high degree of overlap with concepts derived from sociotechnical systems theory, a fact that this paper aims to explore more fully. Uniquely, what sociotechnical theory brings to NEC research is a successful fifty year legacy in the application of open systems principles to commercial organisations. This track record is something that NEC research currently lacks. The paper reviews the twin concepts of NEC and sociotechnical systems theory, the underlying motivation behind the adoption of open systems thinking, a review of classic sociotechnical studies and the current state of the art. It is argued that 'classic' sociotechnical systems theory has much to offer 'new'

command and control paradigms.

Keywords: Sociotechnical Systems Theory, NEC, NCW, C2

DEFINITION

Socio (of people and society) and technical (of machines and technology) is combined to give 'sociotechnical' (all one word) and/or 'socio-technical' (with a hyphen). Both variations mean the same thing but should it be Sociotechnical Theory, Sociotechnical System or Sociotechnical Systems Theory? Certainly, all of these terms, hyphens or otherwise, appear ubiquitously in ergonomics literature. For example: "purposeful interacting socio-technical systems..." (Wilson, 2000, p. 557) or "complex Sociotechnical Systems ..." (Woo & Vicente, 2003, p. 253) or "sociotechnical work systems..." (Waterson, Older Gray & Clegg, 2002, p. 376). In use the actual meaning of the term sociotechnical can be inferred but its precise meaning can often remain unclear. The danger is that this devalues the phrase to that of a buzzword.

Sociotechnical refers to the interrelatedness of 'social' and 'technical'.

Sociotechnical 'theory' is founded on two main principles. One is that the interaction of social and technical factors creates the conditions for successful (or unsuccessful) system performance. These interactions are comprised partly of linear 'cause and effect' relationships, the relationships that are normally 'designed', and partly from 'non-linear', complex, even unpredictable relationships, which are those that are often unexpected. An inevitable consequence of mixing 'socio' with 'technical' is that the socio does not necessarily behave like the technical, people are not machines, paradoxically, with growing complexity and interdependence even the 'technical' can start to exhibit non-linear behaviour. Inevitably, both types of interaction occur when a sociotechnical system is put to work. The corollary of this, and the second of the

two main principles, is that optimisation of either socio, or far more commonly the technical, tends to increase not only the quantity of unpredictable, 'un-designed', non-linear relationships, but those relationships that are actually injurious to the system's performance. Sociotechnical 'Theory', therefore, is all about 'joint optimisation'.

A sociotechnical 'system', as well as being the descriptive term given to any practical instantiation of socio and technical elements engaged in purposeful goal directed behaviour, is a particular expression of Sociotechnical Theory. Sociotechnical systems take the concepts and metaphors of general systems theory, in particular the notion of 'open systems' (e.g. Bertalanffy, 1950), as a way of describing, analysing and designing systems with joint optimisation in mind, particularly those that embody some degree of non-linearity within themselves as well as the environment they reside in. Sociotechnical systems theory, the term used throughout the current article (and seemingly the term in most widespread use at the present time) reflects certain specific methods of joint optimisation in order to design organisations that exhibit open systems properties and can thus cope better with environmental complexity, dynamism, new technology, and competition.

The current article reviews the extant knowledge in this area and argues that the parallel world of military command and control is experiencing the same organisational design challenges that sociotechnical systems theory was originally developed to answer. The argument is developed pursuant of two aims, firstly, to expand and define the underlying motivation, principles and theories that sociotechnical systems theory is founded upon, and secondly, to explore the linkages

that exist between it and the emerging command and control paradigm labelled Network Enabled Capability (NEC). The overriding purpose of this endeavour is to explore the potential of sociotechnical systems theory as a way of confronting the as yet unanswered challenges that now face NEC. To understand fully where such challenges have arisen from some historical background is required.

RATIONALITY AND INDUSTRIAL AGE THINKING

“Formal organisation design, or deliberate as opposed to informal or evolved organisation design, is part of the evolution of both Western and Eastern civilisations” (Davis, 1977, p. 261). Organisations of one sort or another are ubiquitous and the specific case of military command and control is but one example. In virtually all developed civilisations the recent history in organisational design is wedded to a shared ‘industrial age’ mindset (Beringer, 1986), one that forms the backdrop to both sociotechnical systems and NEC, and one that can be explained with reference to a deeper, more fundamental concept.

Formal rationality (Weber, 2007; Ritzer, 1993; Trist, 1978) lends weight to the opinion of many eminent observers over the years who have been exercised not by the apparent mastery of human endeavour but instead the various maladies that accompanied the modern industrial age. Elton Mayo (1949) for one wrote that, “To the artist’s eye, some-thing was decidedly eschew in the actual Victorian progress; and that something continues to this day.” (p. 4). Because in spite of all the time, effort and expense that feeds into the design of organizations (e.g. Ritzer, 1993; Davis, 1977), systems (e.g. Bar-Yam, 2003), major projects (e.g. Morris & Hough,

1987) consumer products (e.g. Green & Jordan, 1999) and now NEC (e.g. Baxter, 2005), what consistently emerges is something that is often substantially less effective than intended (Clegg, 2000). More than that, these entities and artefacts are occasionally injurious to human well being (although technically effective they are often criticised for being ‘dehumanising’; Ritzer, 1993) and may, in extreme cases, become ‘anti-human’. In military command and control the organisational aetiology of friendly fire incidents seems to be a case in point.

Formal rationality is a prominent part of the ‘implicit theory’ that has guided modern organisational design since the industrial revolution. A formally rational organisation is labelled a bureaucracy, in the scientific rather than pejorative sense, and the stereotypical case of so-called ‘classic’ hierarchical command and control (C2) fits into this category well. Rationalising organisations exhibit a tendency towards hierarchies, reductionism and the maximisation of the following:

1. Efficiency: A rational organisation is “...the most efficient structure for handling large numbers of tasks...no other structure could handle the massive quantity of work as efficiently” (Ritzer, 1993, p.20),
2. Predictability: “Outsiders who receive the services the bureaucracies dispense know with a high degree of confidence what they will receive and when they will receive it” (Ritzer, 1993, p. 21),
3. Quantification: “The performance of the incumbents of positions within the bureaucracies is reduced to a series of quantifiable tasks...handling less than that number is

unsatisfactory; handling more is viewed as excellence” (Ritzer, 1993, p. 21)

4. Control: “...the bureaucracy itself may be seen as one huge nonhuman technology. Its nearly automatic functioning may be seen as an effort to replace human judgement with the dictates of rules, regulations and structures” (Ritzer, 1993, p. 21).

Like all bureaucracies so-called ‘classic C2’ rests on “tried and true assumptions: that the whole will be equal to the sum of the parts; that the outputs will be proportionate to the inputs; that the results will be the same from one application to the next; and most fundamentally, that there is a repeatable, predictable chain of causes and effects.” (Smith, 2006, p. 40). As a result, one metaphor for a bureaucracy is as a type of ‘organisational machine’ (Arnold, Cooper & Robertson, 1995). In other words, “When all the incumbents have, in order, handled the required task, the goal is attained. Furthermore, in handling the task in this way, the bureaucracy has utilized what its past history has shown to be the optimum means to the desired end” which is the nub of what formal rationality is really all about (Ritzer, 1993, p.20). In summary, then, organisations designed along bureaucratic lines can be seen as a way of imposing control theoretic behaviour on a large scale, and in so doing, trying to make inputs, processes, outputs, and even humans, behave deterministically.

The core tenets of formal rationality, efficiency, predictability, quantification and control, in turn link to a much more recent model of command and control developed by NATO working group SAS-050 (NATO, 2006). This model provides three major

axes (and a three dimensional space) within which various instantiations of command and control can be plotted. The purpose of defining the problem space in terms of these three dimensions is to explore alternative paradigms for command and control, one's that are becoming increasingly tractable with the growth in networked technologies. The formally rational instance of classic C2 can be positioned in the NATO SAS model as shown in Figure 1. This type of organisation might be characterised by unitary decision rights (in which optimum means to ends are specified at the top of, or at higher levels of a vertical hierarchy); tightly constrained patterns of interaction (due to rules, standard operating procedures and other means by which the bureaucracy embodies its past experience and specifies optimum means to ends) and tight control (in which performance can be quantified and controlled through intermediate echelons of management). It is these features, and their formally rationalistic backdrop, that together make up the diffuse zeitgeist referred to in contemporary literature as 'industrial age thinking' (e.g. Smith, 2006; Alberts, 2003; Alberts, Garstka & Stein, 1999; Alberts & Hayes, 2006; Alberts, 1996).

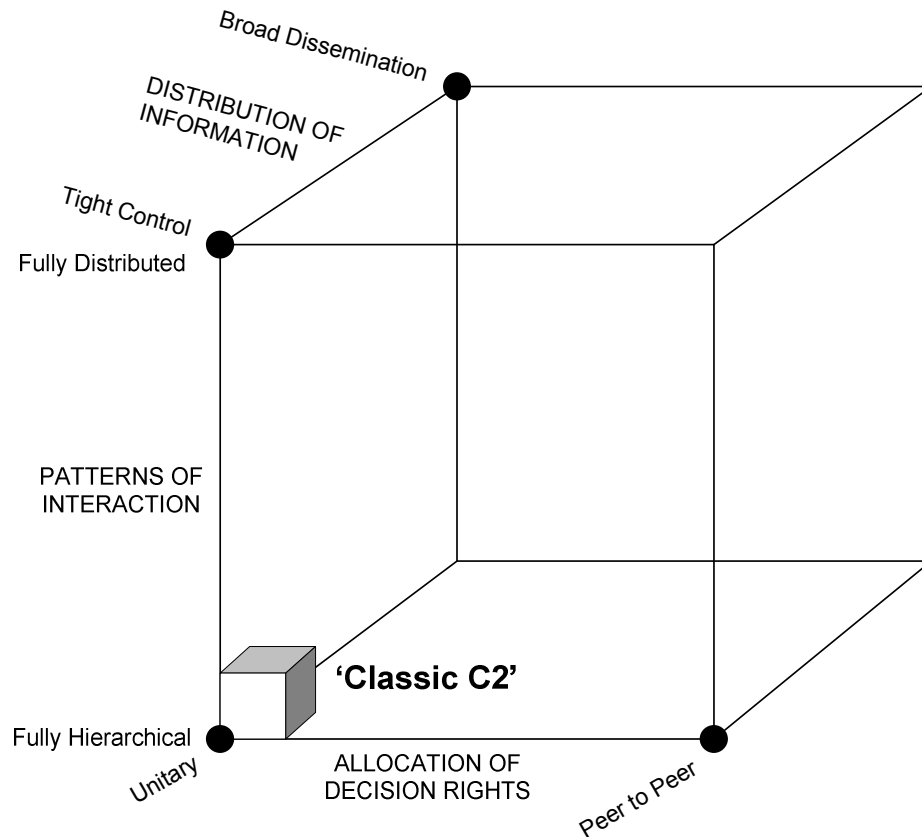


Figure 1 – The NATO C2 conceptual model situates traditional hierarchical command and control in a three dimensional space defined by unitary decision rights, hierarchical patterns of interaction and tight control of information.

THE IRRATIONALITY OF RATIONALITY

The tension created by this prevailing climate of industrial age thinking emerges from “...the observation that Rational systems, contrary to their promise, often end up being quite inefficient” (Ritzer, 1993, p.122). As Ritzer (1993) goes on to explain: “Instead of remaining efficient, bureaucracies can degenerate into inefficiency as a result of ‘red tape’ and the other pathologies we usually associate with them. Bureaucracies often become unpredictable as employees grow unclear about what

they are supposed to do and clients do not get the services they expect. The emphasis on quantification often leads to large amounts of poor-quality work...All in all, what were designed to be highly Rational operations often end up growing quite irrational” (Ritzer, 1993, p.22). Experience over centuries of conflict (e.g. Regan, 1991) make it possible to go further to say that in some cases classic C2 can actively create inefficiency (instead of efficiency), unpredictability (instead of predictability), incalculability (instead of calculability) and complete loss of control (Ritzer, 1993; Trist & Bamforth, 1951). These are the antithetical problems, ironies and productivity paradoxes that, when all else fails, fall into the lap of ergonomics.

The overarching source of these problems, simply stated, is that despite attempts to impose deterministic behaviour on an organisation and its environment, the resultant interlinked entities, or ‘system’, is actually very hard to maintain in a fixed state (or as a ‘closed system’). All the more so when such systems are subject to a large range of external disturbances. The greater the scale and extent of determinism that is trying to be imposed the worse the problem actually becomes. As these systems grow larger and more interlinked the more this process spirals and the bigger the effect that such organisations have on their environment. In fact, they end up becoming the environment and a prime cause of non-linear change and complexity within it (Emery & Trist, 1965).

The evolution of military command and control is particularly instructive. The apotheosis of classic C2 was seemingly reached in the large scale techno-centric style of attrition seen in the cold war era (Smith, 2006). Technically effective hardly seems

an adequate term for the sheer destructive might of the opposing military forces in question. Their evolution, for many lesser organisations with militaristic ambitions, served to fundamentally change the environment within which such activities took place. A new paradigm emerged, so called asymmetric warfare, of the sort grimly revealed in current theatres of conflict. Asymmetric warfare is characterised by largely urban operations, an opposing force that co-exists with a civilian population, one that does not adhere to 'rules of engagement' of the sort that classic C2 is adapted. Ironically, the type of organisation that classic C2 now faces is altogether more swarm-like, agile and self-synchronising. In other words, it is an organisation that exhibits open systems properties to a far greater extent than the supposedly technically effective organisation to which these activities are directed. Is the current situation a case of closed versus open systems? Perhaps. Either way, military organisations around the world, to paraphrase Trist and Bamforth (1951), are now ready to question a method which they have previously taken for granted.

NETWORK ENABLED CAPABILITY

Sitter, Hertog and Dankbaar (1997) offer two solutions for organisations confronted with such difficulties. With an environment of increased (and increasing) complexity: "The first option is to restore the fit with the external complexity by an increasing internal complexity. [...] This usually means the creation of more staff functions or the enlargement of staff-functions and/or the investment in vertical information systems" (p. 498). And the second option: "...the organisation tries to deal with the external complexity by 'reducing' the internal control and coordination needs. [...] This option might be called the strategy of 'simple organisations and

complex jobs””. This provides a neat characterisation for the current state of affairs in closed versus open systems, asymmetric style warfare. One way of putting it is that a traditional military organisation, a complex organisation with simple jobs, is facing a simple organisation with complex jobs and is, despite a gross imbalance in numbers and resources, quite frankly struggling.

The purist vision of NEC is congruent with the second option. The techno-organisational vision of NEC runs along the following lines: “...self-synchronizing forces that can work together to adapt to a changing environment, and to develop a shared view of how best to employ force and effect to defeat the enemy. This vision removes traditional command hierarchies and empowers individual units to interpret the broad command intent and evolve a flexible execution strategy with their peers” (Ferbrache, 2005, p. 104). Referring back to the NATO SAS-050 model of command and control presented earlier, it can be seen that NEC, unlike classic C2, is characterised by broad dissemination of information and shared awareness. This “includes the sharing not only of information on the immediate environment and intentions of our own enemy and neutral forces, but also the development of shared combat intent and understanding” (Ferbrache, 2005, p. 104). NEC is further characterized by distributed patterns of interaction and agility. This is the “ability to reconfigure forces and structures rapidly, building on this shared awareness, exploiting effective mission planning methods, and enabled by an information environment that allows rapid reconfiguration of the underlying network and knowledge bases” (Ferbrache, 2005, p. 104). NEC is also characterised by peer-to-peer interaction and synchronization, which is the “ability to plan for and execute a

campaign in which we can ensure all elements of the force work together to maximum military effect by synchronizing the execution of their missions to mass forces or generate coordinated effects on target” (Ferbrache, 2005, p. 104). Although there is little evidence of overt cross-referencing, this vision is shared almost exactly with the ‘simple organisations and complex jobs’ concept, in other words, those organisations designed according to sociotechnical principles.

Sociotechnical theory brings with it a decisive advantage that NEC currently lacks: a fifty year pedigree of organizations in which such a vision has been realized in practice and with considerable success (e.g. Pasmore et al., 1982; Beekun, 1989; Cummings, Molloy & Glen, 1977). In the remainder of the paper our primary task will be to explore the domain of sociotechnical systems theory and to review exactly how it could bestow open systems behaviour, in practice, on NEC. This task will be conducted against a backdrop of continually trying to establish synergies between these two apparently highly compatible domains.

SOCIOTECHNICAL THEORY

Sociotechnical theory offers a theoretical basis from which to design organisations and, moreover, to harness the advantages that NEC-like command and control promises. This section goes back to first principles and the now seminal work of Trist and Bamforth (1951) entitled, “Some social and psychological consequences of the longwall method of coal getting”. This is an interesting case study which, like most of the work in Sociotechnical Theory, is focused on a particular type of ‘production system’, in this case coal mining. It was motivated by the following irrationality:

“Faced with low productivity despite improved equipment, and with drift from the pits despite both higher wages and better amenities [...] a point seems to have been reached where the [coal] industry is in a mood to question a method it has taken for granted” (Trist & Bamforth, 1951, p. 5). The so-called ‘longwall’ method of coal mining reflects a number of rationalistic principles:

- Large scale coal cutting machinery led to a simplification and specialisation of the miners tasks.
- The method of working became driven by the needs of the mechanised method with the pattern of the shift and its social organisation changing as a result.
- This new organisation required an intermediate level of supervision and management that was previously absent.

The NATO SAS-050 conceptual model would characterise the ‘longwall method of coal getting’ by its hierarchical pattern of interaction, its unitary allocation of decision rights and its relatively tight control over the distribution of information. All of this is conceptually very similar to classic C2 despite the vast differences in task type and domain. The new mechanised longwall method of mining is actually something of a retrograde step, in sociotechnical terms, compared to the previous ‘hand got method’. This method, despite its arcane outward appearance, was nevertheless characterised by a broader dissemination of information, more distributed patterns of interaction and more devolved decision rights. Trist and Bamforth explain that, “the longwall

method [can be] regarded as a technological system expressive of the prevailing outlook of mass-production engineering and as a social structure consisting of the occupational roles that have been institutionalized in its use” (1951, p, 5). The prevailing outlook that they refer to is the industrial age, rationalising method of the ‘factory system’ (the Fordist production line) to coal mining. They continue: “These interactive technological and sociological patterns will be assumed to exist as forces having psychological effects in the life-space of the face worker, who must either take a role and perform a task in the system they compose or abandon his attempt to work at the coal face” (p. 5). As mentioned earlier, the psychological effects of the interacting socio and technical ‘forces’ (to use the author’s term) was leading to reduced productivity and absenteeism. The notion of ‘interactive technological and sociological patterns’ quickly evolved to become the term ‘sociotechnical’.

In order to explore this productivity paradox twenty miners with varied experience of the work domain were interviewed at length, along with various management and training roles. Trist and Bamforth’s paper is thus based on ethnographic techniques, the outcomes of which led to the elaboration of a number of enduring sociotechnical principles which are as follows:

Responsible Autonomy

“The outstanding feature of the social pattern with which the pre-mechanized equilibrium was associated is its emphasis on small group organisation at the coal face”. Indeed, “under these conditions there is no possibility of continuous supervision, in the factory sense, from any individual external to the primary work

group” (Trist & Bamforth, 1951, p. 7). Physical constraints simply prevented the task from being carried out ‘rationally’, so instead of a larger ‘whole of shift’ based organisation accountable to intermediate layers of management, the hand-got method embodied internal supervision and leadership at the level of the ‘group’ resulting in so-called ‘responsible autonomy’ (Trist & Bamforth, 1951, p.6). Sociotechnical theory was pioneering for its focus on the group as the primary unit of analysis.

A facet of this method of working that is somewhat unique to the dangers of the underground situation, yet with ready parallels to military operations, is “the strong need in the underground worker for a role in a small primary group” (Trist & Bamforth, 1951, p. 7). It is argued that such a need arises in hazardous circumstances, especially in cases where the means for effective communication are limited. As Carvalho (2006) states, operators use this proximity and group membership “...to produce continuous, redundant and recursive interactions to successfully construct and maintain individual and mutual awareness...” (p. 51). The immediacy and proximity of trusted team members makes it possible for this need to be met with favourable consequences for team cohesion and overall system performance. The field of NEC is preoccupied with varied issues of trust and team cohesion (e.g. Siebold, 2000; Oliver, et al., 2000; Mael & Alderks, 2002) and whilst the principles of sociotechnical systems theory may not be a panacea they do at least admit the possibility of creating favourable conditions for these varied aspects to emerge.

Adaptability

As Trist and Bamforth put it, “though his equipment was simple, his tasks were

multiple”, the miner “...had craft pride and artisan independence” (1951, p. 6). The ‘hand-got method’ is an example of a simple organisation (and equipment) ‘doing’ complex tasks. The longwall method, on the other hand, is an example of a complex organisation (and technological infrastructure) ‘doing’ simple tasks. Job simplification has long been associated with lower moral and diminished job satisfaction (e.g. Hackman & Oldman, 1980; Arnold, Cooper & Robertson, 1995). In the former case a type of ‘human redundancy’ was created (e.g. Clarke, 2005) in which “groups of this kind were free to set their own targets, so that aspiration levels with respect to production could be adjusted to the age and stamina of the individuals concerned” (Trist & Bamforth, 1951, p. 7). In other words, outcomes or ‘effects’ were more important than activities or the precise means by which those effects were achieved.

Trist & Bamforth (1951) go on to note that “A very large variety of unfavourable and changing environmental conditions is encountered at the coal-face, many of which are impossible to predict. Others, though predictable, are impossible to alter.” (p.20). The longwall method is clearly inspired by the appealing industrial age, rational principles of ‘factory production’ wherein “a comparatively high degree of control can be exercised over the complex and moving ‘figure’ of a production sequence, since it is possible to maintain the ‘ground’ in a comparatively passive and constant state” (Trist & Bamforth, 1951, p. 20). In many contexts, coal mining and military operations being just two, there is little in the way of opportunity for maintaining the ‘ground’ in such a state, thus limiting “the applicability [...] of methods derived from the factory” (Trist & Bamforth, 1951, p. 20). This rather emphasises the point that

NEC is just as much about shifting underlying modes of thought as it is about networked technology per se.

Meaningfulness of Tasks

Sociotechnical theory is as concerned for the experience of humans within systems as it is with the system's ultimate performance. Sociotechnical systems theory sees the two as isomorphic under the terms of reference of joint optimisation. Trist and Bamforth (1951) go into detail as to how this was realised in their mining example. They identify the hand-got method as having "the advantage of placing responsibility for the complete coal-getting task squarely on the shoulders of a single, small, face-to-face group which experiences the entire cycle of operations within the compass of its membership." Furthermore, "for each participant the task has total significance and dynamic closure" (Trist & Bamforth, 1951, p. 6). It is a meaningful task. Meaningfulness arises out of a focus on the group, from responsible autonomy and from adaptability, linking jointly optimised sociotechnical systems to a number of 'core job characteristics' (Hackman & Oldman, 1980):

- Skill variety (e.g. simple organisations but complex varied jobs that rely on a multiplicity of skills; Sitter et al., 1997).
- Task Identity (e.g. "entire cycle of operations" or whole tasks; Trist & Bamforth, 1951).
- Task Significance (e.g. "dynamic closure" and meaningful tasks; Trist & Bamforth, 1951).

- Autonomy (e.g. human redundancy, adaptability, semi-autonomous work groups; Trist & Bamforth, 1951).
- Feedback (e.g. continuous, redundant and recursive interactions; Carvalho, 2006).

The pioneering work of Trist and Bamforth was motivated by the most prominent irrationality of rationality, namely that it is dehumanizing. It elaborated on the central themes that would form a fully fledged sociotechnical school of thought, as well as the features that would bestow open systems characteristics on organisations. There are ready parallels between this and the dynamic, uncertain and often dangerous world of military operations. Sociotechnical systems theory provides a detailed conceptual language with direct links to NEC system design. Perhaps the major influence of Trist and Bamforth's pioneering sociotechnical work, however, was to change the prevailing viewpoint in which organisations were considered: from a purely technical perspective (industrial age thinking) or as purely social entities (an organisational or industrial relations perspective) to instead "...relate the social and technological systems together" (Trist, 1978, p. 43). In the world of NEC a similar shift is far from complete.

SOCIOTECHNICAL SYSTEMS

Systems thinking created the conceptual language from which notions of 'networks' and 'distributed systems' and, indeed, NEC itself ultimately derive. Its application to sociotechnical theory came in 1959 with a paper by Emery, expanding the field by drawing on the specific case of open systems theory (Kelly, 1978, p. 1075). Open

systems theory gave sociotechnical theory a more tightly defined grounding as well as a unifying conceptual language.

The characteristics of systems thinking are the twin notions of “a complex whole” formed from a “set of connected things or parts” (Allen, 1984). Part of the appeal of industrial age thinking is that the ‘set of connected things or parts’ can be tightly defined. A visual metaphor for such a deterministic system might be an electrical circuit diagram, an artefact with components that have known input/output properties connected by electrical pathways with similarly known properties and flows. Such an artefact, in systems terms, would be called a closed system or an ‘object’ or a rational system. In organisational terms a closed system is concerned with the attainment of a specific goal and there is a high degree of formalization (Scott, 1992), in other words, an archetypal bureaucracy. An open system is different.

Import and Export

Open systems are acknowledged to have boundaries with other systems and some form of exchange that exists between them: “A system is closed if no material enters or leaves it; it is open if there is import and export and, therefore, change of the components” (Bertalanffy, 1950, p. 23). In the original biological conception of open systems this exchange would be ‘matter’ such as haemoglobin or oxygen. As systems theory has expanded, the inviolable characteristic of all such exchanges is now seen as essentially informational (e.g. Kelly, 1994; Ciborra, Migliarese & Romano, 1984). Exchange between system elements is input, which causes state changes, outputs of which become further inputs for other elements. An appropriate visual metaphor for

such a system might be a block or venn diagram in which the properties of the components and the links between them are not as well defined and subject to change. A system exhibiting these properties is also referred to as a network, expanding somewhat the definition of 'network' in NEC.

Steady States

“A closed system must, according to the second law of thermodynamics, eventually attain a time-independent equilibrium state, with maximum entropy and minimum free energy [...] An open system may attain (certain conditions presupposed) a time-independent state where the system remains constant as a whole...though there is a constant flow of the component materials. This is called a steady state” (Bertalanffy, 1950, p. 23). If sociotechnical systems are open systems then organisations become analogous to a 'vitalistic' (i.e. living) entity. The idea of a 'vitalistic entity' strikes a chord in organisational psychology. At least one metaphor for an organisation is 'organismic', meaning it is able to adapt and evolve to environmental changes and behave more like an ecology than a machine (e.g. Morgan, 1986). This is something that NEC is undoubtedly striving for. By comparison, a closed system is, or becomes, locked or frozen in a particular state and requires no further import or export of information to maintain that state. A closed system (or industrial age organisation taken to its extreme) is therefore unresponsive to environmental change, matched to an optimum means to an end within a defined context and slow to change or adapt. To use a computer science metaphor, a closed system is an entity that is 'programmed' while an open system is something that 'learns' (or programmes itself).

Equifinality

Related to these ideas of dynamism and adaptability is the notion of equifinality, described by Von Bertalanffy thus: “A profound difference between most inanimate and living systems can be expressed by the concept of equifinality. In most physical systems, the final state is determined by the initial conditions...Vital phenomena show a different behaviour. Here, to a wide extent, the final state may be reached from different initial conditions and in different ways” (p. 25). This is exactly what NEC desires when it speaks of self-synchronisation and what sociotechnical theory offers in terms of adaptability and semi-autonomy. Equifinality grants open systems a certain ‘paradoxical behaviour’, “as if the system “knew” of the final state which it has to attain in the future” (p. 25), which of course it does not, merely that sociotechnical principles permit it to rapidly adapt and evolve one. Trist (1978) could have been describing NEC when saying that open systems grow “by processes of internal elaboration. They manage to achieve a steady state while doing work. They achieve a quasi-stationary equilibrium in which the enterprise as a whole remains constant, with a continuous ‘throughput’, despite a considerable range of external changes.” (p. 45).

To sum up, sociotechnical systems theory is wedded to ideas about open systems. The principles first elaborated by Trist and Bamforth (1951) are framed in terms of endowing favourable open systems behaviour on organisations.

PROGRESS IN SOCIOTECHNICAL SYSTEMS

Since the pioneering work of Trist and Bamforth in 1951 there has been considerable

effort undertaken in organisational design using sociotechnical principles. We begin this section by providing a case study from the ‘classic’ sociotechnical school. The intention is to provide a grounding and contextualisation, describing what an organisation re-designed according to these principles actually ‘looks like’, and importantly, what it achieves when it is subject to live commercial pressures. Given the synergies already alluded to, the ambitions of NEC would seem intimately tied to the apparent successes of ‘real-life’ sociotechnical interventions.

A ‘classic’ sociotechnical analysis

One of the earliest accounts of a comprehensive organisational re-design according to sociotechnical principles was that undertaken by Rice (1958) in textile mills in Ahmedabad, India. Here, as elsewhere, the sociotechnical re-design led to a radically different organisation which, it was argued, was now jointly optimised. Indeed, the “reorganization was reflected in a significant and sustained improvement in mean percentage efficiency and a decrease in mean percentage damage [to goods]...the improvements were consistently maintained through-out a long period of follow up” (Trist, 1978, p. 53). No doubt encouraged by a growing body of similar findings, sociotechnical systems theory, for a time at least, experienced the same kind of commercial buy-in currently enjoyed by business process re-engineering, lean production and six sigma.

The most famous example of sociotechnical design is undoubtedly that undertaken at Volvo’s Kalmar and Uddevalla car plants (e.g. Hammerstrom & Lansbury, 1991; Knights & McCabe, 2000; Sandberg, 1995). Whilst many commercial instantiations

of sociotechnical systems theory are criticised for their limited degree of 'technological' change (choosing to focus instead on the altogether less expensive aspects of 'socio' and 'organisational' change; Pasmore et al 1982) the Volvo case study embraced the principles based on a clean slate approach and on a scale heretofore not yet experienced. The defining feature of the Kalmar plant's design was a shift from a rationalistic style of hierarchical organisation to one based on smaller groups, conceptually very similar to NEC. In Volvo's case the change was radical. The production line, the mainstay of automobile manufacture since the days of Henry Ford, literally disappeared. It was replaced by autonomous groupwork undertaken by well qualified personnel, "advanced automation in the handling of production material; co-determination in the planning and a minimum of levels in the organisation" (Sandberg, 1995, p. 147).

From a systems perspective, according to Dekker's more contemporary work on network structures (e.g. 2002), this new configuration has something of a 'hybrid' feel to it. In structural terms there is a mixture of hierarchical subdivision (albeit to a far lesser extent than before) and peer to peer interaction (within groups rather than everybody literally interacting with everyone else). Hierarchical interaction is still required so that task complexity at the level of the entire system can be managed but peer to peer interaction allows rapid response to local conditions without the need for lengthy vertical interaction and effort on the part of higher management. In fact, "the learning in this work organisation is impressive. Being engaged in all aspects of work makes the production comprehensible and the employees become, as part of their job, involved in the customer's demands and in striving after constant improvement.

Work intensity is high” (Sandberg, 1995, p. 148). Another major effect of this network structure, as Trist (1978) notes, is that “whereas the former organisation had been maintained in a steady state only by the constant and arduous efforts of management, the new one proved to be inherently stable and self correcting” (p. 53). To put this into the language of systems theory, the organisation started to behave like an open system, one that could achieve a steady state based on a constant throughput of inputs and outputs, and maintaining this steady state despite considerable changes in the environment. In the language of NEC this phenomenon would be referred to as ‘self-synchronisation’ (e.g. Ferbrache, 2004).

The specific mechanisms that support this open systems behaviour are varied and interconnected. Principle among them are natural task groupings that bestow a form of autonomous responsibility on the group, there was a ‘whole task’ to be undertaken and the requisite skills within the group to undertake it from beginning to end. In Volvo’s case the parts for the cars were organised as if they were kits, with each member of the team completing a proportion of the kit and the team as a whole effectively building a whole car (independently of other teams). In terms of agility it was quickly observed that “model changes [...] needed less time and less costs in tools and training” compared to a similar plant that was organised around the traditional factory principle (Sandberg, 1995, p. 149).

Obviously, such teams still needed to be related to the wider system, which required someone to work at the system boundaries in order to “perceive what is needed of him and to take appropriate measures” (Teram, 1991, p. 53). In command and control

terms this new organisation shifts the primary task of commanders (or managers) away from processes of internal regulation to instead being more outwardly focused (Trist, 1978). At Volvo, not only had the assembly line disappeared but so to had the role of supervisor. In its place was a roving post called a “lagombud” (or ‘group ombudsman’) “who relates to other groups and to the product shop manager” (Sandberg, 1995, p. 148). This is an important conceptual difference. Managers and commanders now become a form of executive, coordinating function, ‘designing behaviours’ rather than arduously ‘scripting tasks’ (e.g. Reynolds, 1987).

This classic case study of organisational design appears to have many appealing analogues with contemporary visions of NEC, particularly in regard to network structures and the effects of them on the human actors they contain. We can also see rendered in this classic study some key attributes of sociotechnical system design made explicit in the later work of Davis (1977). The following fourteen attributes are reproduced and summarised below. They show what a jointly optimised sociotechnical system should ‘look like’, indeed, how similar systems such as NEC could potentially be evaluated:

INSERT TABLE 1 HERE

Review of Sociotechnical Studies from the ‘Classic’ Sociotechnical School

In order to provide a wider characterisation of the extant work in ‘classic’ sociotechnical systems theory a number of large meta-analyses have been identified. The first analysis is contained in a paper by Cummings, Molloy and Glen (1977), which reviewed 58 studies, the second in a paper by Pasmore et al., (1982), which

reviewed 134 studies, and the third is by Beekun (1989) covering a further 17. Between them they provide a substantial overview of the first thirty eight years worth of experimental work in this domain.

If this large body of work can be characterised at all then it can be done so with reference to the overwhelming predominance of positive study outcomes. There is no doubt that the combined results “support most of the claims that [sociotechnical] researchers have been making for three decades concerning the beneficial nature of this organizational redesign strategy” (Beekun, 1989, p. 893). The down side is that: “Experimenters have tended to report on successful projects almost exclusively, leaving the literature almost void of data concerning the potential pitfalls of the socio-technical approach” (Pasmore et al., 1982, p. 1197). Cummings et al., (1977) note that “There have undoubtedly been unsuccessful experiments in this field”. Pasmore et al. (1982) also note that “...because successes tend to be more widely published than failures, we would expect that the general experience with sociotechnical system designs is much less positive than will be reflected in this [current analysis of 134 studies]” (p. 1190). Despite the predominance of positive outcomes, which are nonetheless difficult to ignore, it remains the case that with so little in the way of variance it becomes difficult to judge the effect of any specific sociotechnical independent variable (Cummings et al, 1977). Yet perhaps that is the whole point. In systems thinking it is not generally possible, or even desirable, to trace a specific cause to a generalised effect. The point seems to be that sociotechnical principles and interventions are as systemic and equifinal as the system to which they are applied (e.g. Clegg, 2000). Perhaps they too become more than the sum of their parts.

From the literature, then, it would seem that implementing an ostensibly ‘technical’ system like NEC is on a scale considerably in excess of many study domains analysed previously, at least within the so-called ‘classic’ sociotechnical school. What singles out NEC as a somewhat unique case is its distributed nature, for example, the idea of a roving ombudsman figure is perhaps something of an anathema in cases where teams are distributed nationally and even internationally. This kind of distribution, the separation of information from physical artefacts and locations, is an inherent part of the ‘information age’ itself. Some of the lessons to be learnt from the commercial arena will, therefore, require further work in order to realise an equivalent in the domain of NEC. Another factor unique to NEC is the degree of non-linearity and complexity inherent in it. Despite the open systems principles created by sociotechnical systems theory the vast majority of the application domains are considerably more deterministic than the military arena, which has the unique property of entities in the environment that are not just dynamic but deliberately and adaptively trying to thwart your activities. There is a need to draw inspiration not only from successful classic sociotechnical studies but to also examine more contemporary developments which seek to move sociotechnical systems theory from its roots in the industrial age to a new information age context.

CONTEMPORARY DEVELOPMENTS AND EXTENSIONS

Faced with problems that are increasingly framed in terms of non-linearity and/or complexity, macro ergonomics (e.g. Kleiner, 2006; Kirwan, 2000), cognitive systems engineering (e.g. Hollnagel, 1983; Hollnagel & Woods, 2005) and other nascent systems based developments attest to a growing shift in ergonomics

methods and modes of thought. It is perhaps a shame, then, that sociotechnical systems theory has declined somewhat from its previous position as darling of organisational redesign. Particularly telling was that in November 1992 Volvo closed down its innovative plant in Kalmar. The reasons for this are complex but on balance they appear not to be due to a failure of the sociotechnical paradigm, rather it was more to do with a resurgence of neo-Taylorism inspired by the manufacturing excellence then evident in Japan and the methods and practices used to achieve it (Dankbaar, 1993). For Volvo, sociotechnical systems theory has given way to lean production which has a rather different value base and assumptions about human workers (Niepce & Molleman, 1998). There is no doubt that the subsequent character of sociotechnical research has been affected. Certainly, the days of ambitious large scale implementations of sociotechnical principles have largely given way to work of a much smaller and somewhat more self-effacing theoretical nature, some of which is surveyed below. Current sociotechnical thinking, however, does share with NEC an interest in the opportunities and issues raised by information technology and the internet although this transition appears far from smooth.

Hirschhorn, Noble & Rankin (2001) complain that sociotechnical approaches are, to their ongoing detriment, often rooted in notions of mass production and labour use and are not always well attuned to the contemporary concerns of industry (see also Pava, 1986). Indeed, the primary focus of modern organisations, NEC included, is to be highly responsive to the needs of the recipients of the services which the organisation dispenses, that is to say organisations should be able to learn: the quicker and more adaptively the better (Adler & Docherty, 1998). Hirschhorn et al (2001)

refer to this as ‘mass-customisation’ in which the real value of joint optimisation is not in the production and dissemination of ‘things’ (e.g. physical goods or ‘actions’) but in the production and dissemination of information (e.g. informational commodities like ‘effects’). They present the following table to show the difference between these two conceptual worlds:

INSERT TABLE 2 HERE

Table 2 clearly shows that “as a consequence of the dominant emphasis of the traditional [Sociotechnical] model on the micro level of organizational design, its relevance for modern open system organisation theory is diminishing.” (Heller, 1997, p. 606). A stark warning perhaps, hence the currently expanding array of more contemporary sociotechnical concepts. Examples of these include ‘open sociotechnical systems’ (e.g. Beuscart, 2005) and sociotechnical capital (e.g. Kazmar, 2006) to name but two. Open sociotechnical systems is an apparent contradiction in terms but actually refers to the nature of the group and to its flexible open membership thereof. The shift is from relatively enduring semi-autonomous groups towards comparatively transient ad-hoc groups. Sociotechnical capital is drawn from research in the world of the internet and a growing fascination with emergent phenomena that arises from ‘mass collaboration’ (e.g. Tapscott & Williams, 2007) and on-line communities. Sociotechnical capital deals with the formation and regulation of such groups and the characteristics of network systems required to support them (e.g. Resnick, 2002).

What of the future? Scacchi (2004) provides a contemporary summary of future

research directions which, if anything, seem to be aligning the world of sociotechnical systems theory ever more closely with the concerns of NEC. They are as follows:

1. “First, the focus of STS design research is evolving towards attention to [sociotechnical interaction networks (STINs)] of people, resources, organisational policies, and institutional rules that embed and surround an information system” (p. 5). The question of where socio and technical boundaries lie is becoming ambiguous as is ‘who’ the user of a system is (and the panoply of values, perspectives, demands etc., that they require and/or impose).
2. Second is “recognition that a large set of information systems in complex organisational settings generally have user requirements that are situated in space (organisational, resource configuration, markets, and social worlds) and time (immediate, near-term, and long term), meaning that user requirements are continuously evolving, rather than fixed” (p. 6). This prompts a need to decide how to access and respond to these shifting informational requirements.
3. Third, it is unclear how best to “visualise, represent, or depict (via text, graphics, or multi-media) an STS” (p. 6). So called ‘Rich Pictures (e.g. Monk & Howard, 1998) social network diagrams (e.g. Driskell & Mullen, 2005), soft systems methodologies (e.g. Checkland & Poulter, 2006) and the Event Analysis for Systemic Teamwork methodology (e.g. Stanton, Baber & Harris, 2007; Walker et al., 2006) already

reflect work underway to try and address this issue.

4. Fourth, “the practice of the design of STS will evolve away from prescriptive remedies to embodied and collective work practices” (p. 7). An example is given of “free/open source software development projects or communities. In this sociotechnical world, the boundary between software system developers and users is highly blurred, highly permeable, or non-existent” (p. 6-7). For example, in adapting and modifying NEC to suit local needs and preferences (as is inevitably the case; e.g. Verrall, 2006) users of NEC play as much a part in the design of the final system/organisation as the designers themselves; whether they like it or not.

Clearly this is not an exhaustive list but it is, we believe, a characterisation, one that is expressive of the changing nature of Sociotechnical Theory, the changing nature of the systems (and their boundaries) and the changing nature of the environment to which they are applied.

SUMMARY

Despite its ubiquity within ergonomics literature the term ‘sociotechnical’ is clearly much more than merely a buzzword. It is a set of explicit concepts, inspired by general systems theory, aimed at jointly optimizing people, technology, organisations and all manner of other systemic elements. This review paper has highlighted a key set of basic sociotechnical principles (responsible autonomy, adaptability and meaningfulness of tasks) which seem to offer favourable initial conditions for

effective NEC systems. Sociotechnical principles create shared awareness (through peer to peer interaction) and agility (through effects based operations, semi-autonomous groups and increased tempo) and self-synchronization (joint optimisation and synergy). As Table 3 illustrates, the extent of overlap between the classic concept of sociotechnical systems theory and the new command and control paradigm heralded by NEC is starkly manifest.

INSERT TABLE 3 HERE

Sociotechnical systems theory speaks towards a number of ‘big issues’ in NEC research. It can be pointed out that the sociotechnical approach challenges the dominant techno-centric viewpoint, whereby NEC is seen in terms of merely data and communication networks. Instead, sociotechnical systems theory speaks towards the optimum design of networks of a different sort, those that are comprised of socio and technical elements. It also refines the notions of shared awareness (the extent to which everybody needs to know everything), peer-to-peer interaction (semi-autonomous groups are a particular form of this) and, at a more fundamental level, represents a conceptual response for dealing with complexity (which is shifted from a global level of complexity to a local view of complexity which semi-autonomous groups respond to faster and more adaptively). Perhaps above all the sociotechnical approach is innately human centred. It is concerned as much with the optimization of ‘effectiveness’ as it is with the experiences of people working within command and control organizations. Arguably, the most adaptable components of all within NEC are the human actors. Sociotechnical theory, therefore, brings with it a humanistic

value base and set of non-Tayloristic assumptions. It is not being offered as a panacea, but sociotechnical systems theory seems to offer considerable promise in terms of at least creating the conditions for cohesive, expert, flexible teams that relate well to a wider system. Indeed, all of this would be mere conjecture were it not for sociotechnical systems theory's fifty year legacy of applying open systems principles to commercial organisations. Whether, and by what means, the same positive outcomes can be realised in the field of NEC is something that future research and experimentation is directed.

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Table 1 - Attributes of jointly optimised sociotechnical systems and/or evaluation criteria for NEC systems (from Davis, 1977, p. 265-266)

Systemic	“...all aspects of organisational functioning are interrelated”.
Open System	“...continuous adaptation to requirements flowing from environments”.
Joint Optimization	The principle that socio and technical elements of an organisation should be jointly considered and maximised.
Organisational Uniqueness	“...Structure of the organisation...suits the specific individual organisation’s situation” (relates back to adaptation above).
Organisational Philosophy	The design of structures and roles is “congruent with agreed organisational values” (In other words, not a ‘bolt-on’ solution but pervasive and ubiquitous).
Quality of Working Life	“...integrity, values, and needs of individual members are reflected in the roles, structure, operations, and rewards of the organisation.” The intrinsic nature of work is enhanced (e.g. Hackman & Oldman, 1980).
Comprehensive Roles for Individuals or Groups	The content of work and the people used to carry it out (and their organisation into teams or groups) should reflect the principles of ‘meaningful’ and ‘whole tasks’.
Self-Maintaining Social Systems	“...social systems are such that organisational units can carry on without external coercion...i.e. they are to become self-regulating”. This attribute relates well to Effects Based Operations as well as ad-hoc teams and flexible forces.
Flat Structure	Although somewhat contrary to historical notions of military hierarchy, the attribute of a Sociotechnical System (one that is jointly optimised) is that there are “fewer organisational layers or levels”.
Participation	“...democratization of the work place” with individuals able to contribute to problem solving and governance.

Minimal Status Differentials	This attribute seems to run counter to military thinking in terms of there being, “minimal differences in privileges and status” but on closer inspection it can be noted that any differences which are, “unrelated to role and organisational needs” are regarded as divergent from a sociotechnical ideal.
Make Large Small	“Organisational and physical structures provide both a smaller, more intimate organisational boundaries and a feeling of smaller physical environment for individuals or groups”. This is a point alluded to in Trist and Bamforth’s original paper where they refer to negative changes in the temporal and spatial configuration of the work; automation increased the size and duration of a task, with negative consequences.
Organisational Design Process	“...components of the organisation evolve in a participative, iterative manner, only partially determined by advance planning”.
Minimal Critical Specification	This principle is (tacitly or otherwise) at the heart of Effects Based Operations. In organisational design terms, “...designers specify (design or select) the crucial relationships, functions, and controls, leaving to role-holders the evolutionary development of the remainder”.

Table 2 – Comparison of sociotechnical contexts (adapted from Hirschhorn et al, 2001, p. 249).

Focus of Sociotechnical Systems is on:	Focus of NEC is on:
Mass production	Mass customization
Minimising down time	Minimising learning time
Producing product	Producing information
Maintaining a steady state	Finding information
Performing work sequentially during a defined 'run'	Performing work continuously and adaptively

Table 3 – Comparison of concepts: NEC versus Sociotechnical Systems.

NEC Concepts	Sociotechnical Concepts
Agility and tempo	Adaptability
Effects based operations	Minimal critical specification
Peer-to-peer interaction and ad-hoc groups	Semi-autonomous work groups
Self synchronisation	All of the above combined with whole and meaningful tasks

Figure Caption

Figure 1 – The NATO C2 conceptual model situates traditional hierarchical command and control in a three dimensional space defined by unitary decision rights, hierarchical patterns of interaction and tight control of information.

Statement indicating the relevance of the findings for ergonomics theory:

The principles of sociotechnical systems theory align it exceptionally well with the challenges of modern organisational design. It is also reflective of a wider paradigm shift in ergonomics theory away from ‘industrial age’ modes of thought to systems based ‘information age’ thinking.

Author Biographies

DR GUY WALKER gained his PhD in ergonomics in 2002 and since then has been engaged on a wide variety of human factors projects both in industry and academia. These have included safety critical train protection and warning system design, vehicle automation and feedback, air traffic control, process control and advanced driver training. Guy's current research interests are orientated around his current role as Research Fellow within the Defence Technology Centre for Human Factors Integration (DTC HFI) consortium and the application of open systems concepts to command and control. Guy is author of more than thirty journal articles and co-author of Human Factors Methods: A Practical Guide for Engineering and Design.

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Paul Salmon is a Research Fellow within the Human Factors Group at Brunel

University and holds a BSc in Sports Science and an MSc in Applied Ergonomics, (both from the University of Sunderland). Paul has over six years experience in applied human factors research in a number of domains, including the military, civil and general aviation, rail and road transport and has previously worked on a variety of research projects, both for Brunel University and the Monash University Accident Research Centre in Australia. Paul's current research interests include the areas of situation awareness in command and control, human error and the application of human factors methods in sport. Paul has authored and co-authored various scientific journal articles, conference articles, book chapters and books in the areas of human error, situation awareness, team work and human factors methods.

Dan Jenkins Graduated in 2004 from Brunel University with an M.Eng (Hons) in Mechanical Engineering and Design receiving the 'University Prize' for top student in the department. With over two years experienced as a Design Engineer in the Automotive Industry, Dan has worked in a number of roles throughout the world. This wide range of placements has developed experience encompassing; Design, Engineering, Project Management and commercial awareness. Both academically and within industry Dan has always had a strong focus on customer orientated design; design for inclusion; and human factors. Completed projects include a thesis for Ford Motor Company investigating 'Why drivers sit as they do in the modern automobile' and a Masters thesis designing and developing a system to raise driver situational awareness and reduce lateral collisions. Dan is currently a full-time research fellow on the HFI-DTC project and is studying for a PhD related to the project.