THE INTERNATIONAL
C2 JOURNAL

VOLUME 3, NUMBER 2, 2009

From Clansman to Bowman: HFI Principles for NEC System Design

Guy H. Walker
Neville A. Stanton
Dan Jenkins
Paul Salmon

CCRP
Focus
& Convergence
for Complex Endeavors

THE INTERNATIONAL C2 JOURNAL

The Editorial Board

About the Journal

The International C2 Journal was created in 2006 at the urging of an international group of command and control professionals including individuals from academia, industry, government, and the military. The Command and Control Research Program (CCRP, of the U.S. Office of the Assistant Secretary of Defense for Networks and Information Integration, or OASD-NII) responded to this need by bringing together interested professionals to shape the purpose and guide the execution of such a journal. Today, the Journal is overseen by an Editorial Board comprising representatives from many nations.

For more information

Visit us online at: www.dodccrp.org
Contact our staff at: publications@dodccrp.org

CCRP
Focus
& Convergence
for Complex Endeavors

The International C2 Journal | Vol 3, No 2

From Clansman to Bowman: HFI Principles for NEC System Design

Dr. Guy H. Walker (Heriot-Watt University, UK)

Prof. Neville A. Stanton (University of Southampton, UK)

Dr. Dan Jenkins (Sociotechnic Systems, UK)

Paul Salmon (Monash University, Australia)

Abstract

As a consumer of advanced network enabled equipment the Military (like all consumers) has probably become used to a dominant design paradigm; the closed, bureaucratic, inflexible, complex, technology laden piece of kit which, despite all that, really only permits the user to perform simple and arbitrary individual tasks and often only then with arduous training and operational effort. This paper attempts to shift that paradigm. From the evolution of military equipment to its co-evolution with human users, from a focus on what equipment 'is' to what it actually 'does,' an argument for the application of systems principles to the type of equipment now found in network enabled domains is developed. This enables a set of initial propositions posed at the beginning of the paper to be elevated to the status of actionable design principles. Drawing widely from the domains of human factors and sociotechnical systems theory a case is thus put forward for equipment (and its procurement) to be as open, flexible, agile and self-synchronizing as the net-enabled system into which it is designed to operate.

Introduction

The Proposition(s)

This paper begins by being deliberately contentious:

Proposition 1. Although it is technically convenient to see items of military equipment as stand-alone, none of it really exists in isolation.

Proposition 2. Equipment design and procurement is often based on a set of inappropriate implicit theories.

Proposition 3. It is not possible to achieve NEC's aspirations through top-down processes of design alone.

Proposition 4. It is not possible to specify all user requirements at the beginning of the design process. It is not even desirable.

Proposition 5. Design is not a one-off process and there is no clear end-product.

Proposition 6. Functionality is mostly split across artificial functional boundaries.

Proposition 7. The way that equipment should be used is often over-specified.

Proposition 8. Step changes in capability consistently fail to meet expectations.

Proposition 9. Design itself is often not designed.

Proposition 10. And the moment people start using equipment they are designing the next version of it.

These propositions could have been put forward in the delicately nuanced and heavily caveated manner which they ordinarily would deserve. We have chosen instead to frame them in deliberately contentious terms because the next task, which is to build a theoretical argument to support them, becomes considerably more challenging and meaningful. The only caveats that we do need to put in place are the following: firstly, these propositions relate to a particular class of networked, interoperable equipment that is becoming increasingly ubiquitous in 21st century military environments: they by no means relate universally to all forms of equipment. Secondly, the perceptive reader will also note that these principles are reminiscent of Chern's (1976/1987), Davis' (1977) and Clegg's (2000) classic 'principles of sociotechnical design.' This is deliberate too. Whilst we are certainly not the first to be as contentious as this we do believe that the principles are as relevant now as they always have been. With the advent of NEC, probably more so.

In the sections that follow an alternative vision of how to think about and design this specific class of military network-enabled equipment is presented. A collection of explicit concepts and theories, some of them with a substantial legacy of practical application, suggest that there are fundamentally different ways of approaching the problem. We use the British Army's digital tactical communications system, called Bowman, as an example of how and why the propositions made at the beginning are closer to valid, actionable design principles than their contentious nature might at first suggest.

The Information Age

A number of attributes qualify the assertion that the Bowman communications system represents an incipient information age system. As a product Bowman is, in some senses, less about what it 'is' (i.e., a collection of green boxes and cables) but what it is connected to and what it 'does' (Kelly, 1994). From the users point of view Bowman represents a form of mobile porthole into a military 'blogosphere' populated by other people, information and assets. It should enable personnel to extract value from this collection of interconnected artifacts, to harness the capability that this provides in order to do meaningful ‘Effects Based’ activities easily, only one of which is talking to people over the radio.

If flexibility, innovation and learning are the hallmarks of information age equipment, then for military audiences used to considerably greater degrees of determinism this brings with it the appearance of an alarming lack of control. The key issue with this kind of networked, interoperable equipment, especially when combined with greater degrees of peer-to-peer working and effects based operations under the auspices of NEC, is that it creates the conditions for people to ‘discover’ ways of usefully deploying it. The more flexibility and ease-of-use, the more ‘discovery’ potential there is. This means that many of the ways in which current and future functionality will connect to what people want to do with it, that is to say the behavior of such equipment, remains as yet undiscovered by users. Whilst the generic capability to interact and exchange information has been provided, what users decide to do with that capability, how they link it to the effects they want to achieve will be up to them: this is the essence of self-synchronisation.

From the moment users put information age equipment to use the perceptive designer will see that a form of participatory, democratic design process is already underway. Thus in some senses Bowman, and other net-enabled equipment, is not an ‘end product’ at all, at least not in the traditional sense. What has been designed is often something more akin to a set of initial conditions or ‘capabilities,’ a system that ‘becomes’ rather than a system that is frozen in time. An ongoing process of user/product evolution and co-evolution will tell exactly what. The following sections develop these basic premises further.

Design Evolution

End Products vs. Initial Conditions

Equipment is not just manufactured it is also 'designed.' Because it is designed it is subject to a range of diffuse interconnected influences, from competitive and commercial pressures to technology developments and user requirements. Equipment emerges out of a wider dynamic background and context, in a sense it too evolves, a form of natural process within which the designer plays a key role.

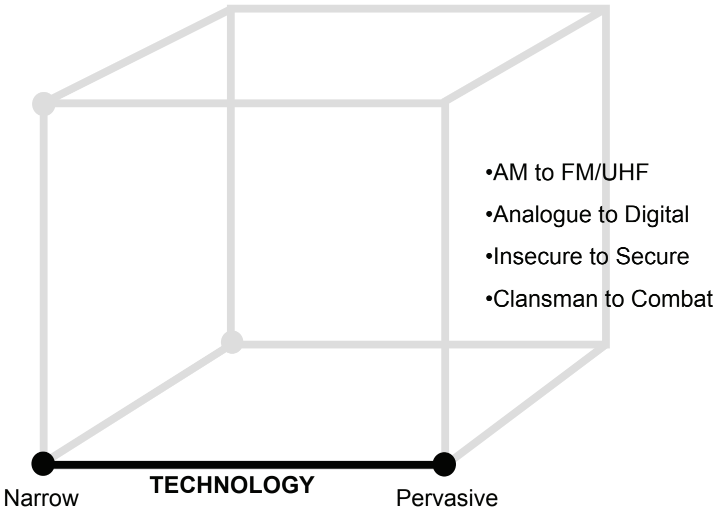

Figure 1. Bowman's (simplified) evolutionary timeline.

Like any system, Bowman has its own evolutionary timeline (Figure 1), its own inherited traits, its own 'equipment DNA' and its own adapted state vis-à-vis its environment; at least conceptually. Natural evolution, as distinct from the artificial evolution of equipment, is a bottom up process. There is no 'control' or 'design' as such and complexity emerges out of simplicity. Implicit in bottom-up processes like natural evolution is a subsumption architecture in which higher (complex) levels subsume lower (simple) levels. The rules of subsumption proposed by Brooks (1986) are instructive for equipment designers because they seem to map well onto the verb or capability-like properties of information age equipment such as Bowman:

- Step 1: Get the equipment doing simple things first and get them working perfectly.
- Step 2: Add new layers of activity over the results of the simple tasks.
- Step 3: Don't alter the simple things.
- Step 4: Make the new layer(s) work as perfectly as the layer below.
- Step 5: Repeat…

Bottom-up processes like these are not ideal in every circumstance. Neither are top-down processes. As Table 1 shows, design is contingent on the context of use and the type of problem a piece of equipment is meant to be solving.

Table 1. Matrix of 'Approach' vs. 'Problem'

		Problem	
		Deterministic: i.e. stand-alone equipment	Complex: i.e. networked systems
Approach	Top Down	Matched	Rational systems start to behave irrationally…
	Bottom Up	Too slow and lacks scale…	Matched

The sort of artificial ecology that equipment normally resides in, and emerges from, exhibits a recognizable form of evolution but there is a combination of bottom up and top down processes. Achieving a balance between the two lies at the heart of Human Factors Integration (HFI) processes such as ISO 13407 (ISO, 1999). Achieving a balance is easier said than done and the more typical situation is a design ecology which is out of balance. Most common seems to be the application of long-standing top-down processes of design being used to solve complex non-deterministic problems. What typically arises from this mismatch are the technologically intensive pieces of equipment representative of the dominant paradigm (bureaucratic, inflexible, difficult to use, fails to meet aspirations etc.).

Opaque vs. Transparent Capability

Let us now examine the bottom-up processes implicit in Bowman's evolutionary pre-history. This can be traced back as far as Morse code and the Crimean War. This was the first campaign to use electric telegraph and where it is sobering to learn that even then, the Commander in Chief received so many administrative queries from London that he was quickly overwhelmed with information. Morse Code was gradually superseded by voice telephony (e.g., the Boer War), voice telephony eventually led to radio-telephony (used to some extent in WWI) and onwards to the recognizably modern Larkspur radio system. This in turn was superseded by the lightweight, modern, but still ostensibly analogue Clansman system until the limitations of that created the conditions for voice and data communications under the aegis of Bowman.

Expressed in terms of subsumption there is an argument to suggest that Morse Code first demonstrated the principle of electronic communications on any meaningful scale. This led to the nascent beginnings of a telecommunications equipment infrastructure. This infrastructure, and the capability it afforded, created new uses and new aspirations for the system, which in turn paved the way for the next layer; voice telephony. This took the proven technology (of electrical signals carried by copper conductors) to the next level, enabling voice modulated signals to be carried rather than just dots and dashes. Again, this layer worked and served to create new affordances, affordances that helped the principle of voice telephony to break free from its wires through the use of radio, firstly AM (amplitude modulated and the bulky WWII era wireless sets) then VHF/FM and the post-war Larkspur and Clansman radios. In each case, communications spread further outwards from a 'strategic' mode of communication (e.g., the Crimean War and London communicating with field HQ) to 'tactical' (e.g., the Boer War, where field HQ used it to direct artillery fire). Presented in this way Bowman's developmental pre-history is of course grossly overly simplified. It is intended merely as an illustration (not a detailed historical critique). The key point is that the continued outward spread of communications technology from strategic to tactical meant that the technology changed from being narrow, with specific users and highly defined uses, to pervasive, used by nearly every one for all manner of purposes.

This process continues. Some of the technology which is now a familiar part of military operations is itself becoming subsumed, a side effect of which is that it becomes increasingly transparent, "weaving itself into the fabric of everyday life until indistinguishable from it" (Weiser, 1990, 94). Of course, the technology has not become 'literally' invisible, the point is that whilst it would be possible to point to and isolate the function that a specific cable or antenna serves, from the users perspective there is little point (Weiser, 1990). From the users point of view the behavior of the Bowman system has become largely disconnected from the specific technological artifacts that support it. It is the behavior that counts. Despite its heterogeneous parts the system as a whole not only works satisfactorily (as per Brook's subsumption rules above) but more importantly it behaves coherently (as per Actor Network Theory; Law, 2003). Only when the system breaks down does it dissolve into its constituent electronic components and human interventions, but even then this lack of coherency has more meaning for the signals engineer than it does for most Bowman users (Law, 2003).

Centralized vs. Distributed Equipment

Technological invisibility goes hand in hand with another of Weiser's concepts: ubiquity. In practice what this means is that what a system like Bowman 'does' has not only been set free from the technology that supports it (i.e., the technology is transparent), equally important is that it has also been set free from the boundaries of space and location. Through systems like Bowman, information is becoming as "dependable, consistent, and pervasive" as an electricity power grid (Chetty & Buyya, 2002, 61). As a result, information age equipment, whether it be something overtly 'radio-like' or something more complex like the various Bowman data terminals, all of it can be plugged in wherever this increasingly pervasive information infrastructure is present, from tanks to tents. Moving from left to right along Bowman's evolutionary axis, the difference in innovation and learning now potentially available to the user is akin to the kind of step change difference in the power of a product that runs off a battery compared to one that plugs into a mains supply.

Design Co-Evolution

Stretched Capability

If technology is evolving then so to are the users of it. The sociotechnical system, then, is 'co-evolving.' According to researchers in the field of Cognitive Systems Engineering (e.g., Hollnagel & Woods, 2005) technology and complexity are intertwined in precisely this way. In broad terms the extra utility afforded by some form of technological advance is usually seized thus "pushing the system back to the edge of the performance envelope," rather like the motorway that is being continually widened and just as continually filled (Woods & Cook, 2002, 141). As a result, equipment tends to be run to its limits with all that that entails for reliability, stability and complexity (a bigger, wider motorway, at the level of the total system, is a more complex one; Hollnagel & Woods, 2005). The Law of Stretched Systems explains this self-reinforcing evolutionary cycle in relation to artifacts such as military equipment.

The cycle begins with an identified deficiency, a lack of capability, which is answered by expanding the equipment's functionality. Functionality is expanded by capitalizing on the extra capability afforded by new technology, thus creating a new product which, like the wider motorway, is now a more complex one. Consider for a moment the functionality/ease of use afforded by the venerable Clansman radio (in which a curly cord to the handset was considered an innovation) and the functionality/ease of use afforded by a Bowman data terminal? An attempt has been made to push the equipment "back to the edge of the performance envelope" and to make the most of what technology now affords (Woods & Cook, 2002, 141). With extra capability has come greater task complexity which in turn creates new opportunities for problems and new deficiencies in capability, thus the cycle repeats.

An undesirable characteristic of this self-reinforcing cycle is that in capitalizing on technology potential the user can often be left "with an arbitrary collection of tasks and little thought may have been given to providing support for them" (Bainbridge, 1982, 151). In other words, the solution may be technically effective but not 'jointly optimized' with its human users. Because of this, human adaptability becomes required for equipment to work as intended which, in turn, creates new 'opportunities for malfunction.' Hollnagel and Woods clarify that "by this we do not mean just more opportunities for humans to make mistakes but rather more cases where actions have unexpected and adverse consequences" (2005, 5). The typical response to this situation is to change the functionality of the system again. This completes the self-reinforcing cycle shown in Figure 2, which does not merely cause difficulties but represents an optimum strategy for maximizing them (e.g., Norman, 1990).

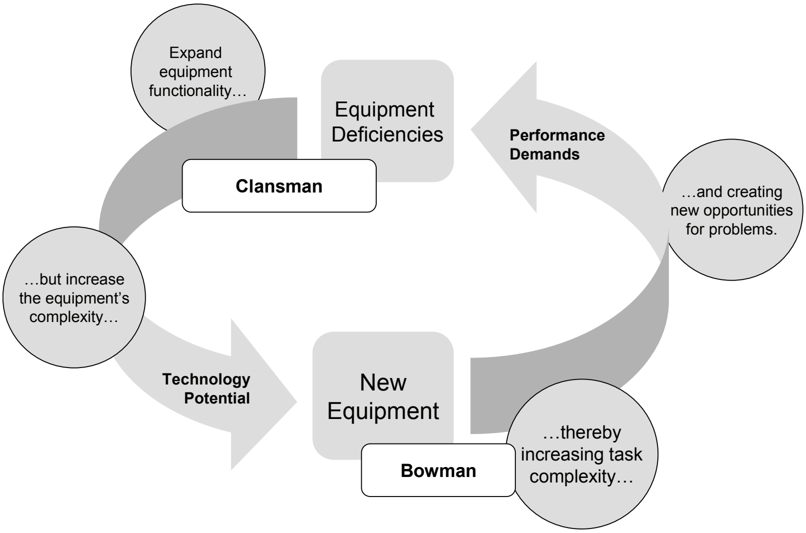

Figure 2. Hirshhorn's Law of Stretched 'Equipment' (Hollnagel & Woods, 2005).

Co-Evolution

A well known maxim in Human Factors is that 'it is easier to twist metal than it is to twist arms' (e.g., Sanders & McCormick, 1992). In other words, it is easier to adapt equipment to its user than to rely on them adapting to it. When interpreted literally, it tends to presuppose that users do not readily change and that items of equipment can be seen in isolation from their environment.

Another way of looking at this twisting metal vs. arms dialectic is to see it as an almost necessarily antagonistic process, such that there is "reciprocal evolutionary change" or a little of both metal and arm twisting (Kelly, 1994, 74). Users have their arms twisted by having to adapt to new equipment, in turn, the equipment has a little more of its metal bent to suit new needs that arise from this adaptation, which creates more new needs, more arm twisting and more metal bending, on and on in a spiraling co-evolutionary fashion until the original piece of equipment becomes almost unrecognizable. As such, Bowman's evolutionary timeline says as much about what the technology has done to users as the users have done to the technology. Users and equipment have become locked more and more into a single system, "each step of co-evolutionary advance winds the two antagonists more inseparably, until each other is wholly dependant on the other's antagonism. The two become one" (Kelly, 1994, 74; Licklider, 1960). Bowman's evolutionary pre-history provides an interesting example of this process in action.

The question to ask is at the birth of recognizably modern military communications technology, who actually 'needed' it? The historical answer is surprising. At the outset, and for many years following, relatively few people 'needed it' and it remained the more or less exclusive province of strategic communications at headquarters level. Its use as a tactical communications medium sprung from being able to direct flank formations and artillery fire, with this requirement in turn driven by the ability to undertake this sort of battlefield coordination without the use of wires. As radio technology improved, so did its reliability and resilience, and with it, the requirement for wired communications diminished. As technology improved still further, equipment became even more mobile, like Clansman. The interesting point is that none of these improvements fundamentally altered the nature of the communications task. It altered the context, the setting and the capability but the task of speaking into a receiver remained ostensibly the same. In equipment design terms Clansman was not a radical departure or paradigm shift from the antiquated field telephones and wireless sets that preceded it. It was not like Bowman, for example, that needs a critical mass of other Bowmanised bits of equipment in order to extract its full capability. It was merely a new layer of enhanced technology overlain on top of a proven method of working (i.e., radio communications).

As Clansman became more widespread and ubiquitous, as users and technology became increasingly locked into a single system, the metaphorical twisting of arms required more metal to be twisted. Enter Bowman. The step change in capability provided by Bowman derives from three areas of functionality: secure tactical communications, enhanced situational awareness [*sic*] (through global positioning technology) and a reliable data network. All this is designed to support the kind of interaction that users of Clansman (not to mention the Internet, an interacting non-military trend) were coming to expect as they passed through the 'performance demands' phase of the self-reinforcing complexity cycle.

Reciprocal human/technological change continues. Within the heavily prescribed method of working embodied by the software suite (which resides on the various Bowman data terminals) a facility called Free Text is provided. This is nothing more or less than the ability for users to type text, then to send it across the data network to any other data terminal user (it is actually a secondary function embedded within a much larger super-ordinate capability). Because every communication eventuality seems to have been anticipated and subsequently incorporated into the software, giving rise to a highly specified method of working and an almost extreme level of functionality, it seems unlikely that the simplistic Free Text facility would be used all that often. After all, every template and pro-forma was provided so no-one really 'needed to?'

The technological metal of Clansman was bent into Bowman in response to new aspirations, users in turn are adapting Bowman technology in surprising ways. During a large scale field trial (see Stanton et al., 2009) the effect of the simple Free Text facility became magnified out of all proportion. In a situation reminiscent of the explosion in SMS Text Messaging it was observed that out of all the data communications events, 73% of those initiated by the user were Free Text. This is surprising for a function that no one anticipated being used very often, if at all.

Complexity

To paraphrase the classic sociotechnical systems literature: *"The single most descriptive term for* [military] *environments is change. This characteristic in itself is the basis for innovation of alternative* [equipment], *since the implicit assumption of* [industrial age equipment] *was high stability or placidity of the environment"* (Davis, 1977, 263). The Larkspur radio handset, at one end of the evolutionary spectrum, has a simple well defined capability designed for an enduring context of use. It is an end product. Bowman, on the other hand, has the potential for through-life capability. Whether it's innate flexibility and adaptiveness is seen explicitly as this or not, Bowman is designed for an altogether more dynamic environment, as "a system designed to keep pace with technology" (MoD, 2008).

The problem with complex entities and environments is that they begin not to "…function in the linear ways in which we are used to thinking and analyzing" (Smith, 2006, 40). "[A]ctions are both persistent and strong enough to induce autochthonous processes in the environment" (Emery & Trist, 1965, 29). The self-reinforcing co-evolutionary cycle is one such autochthonous process, a type of positive feedback loop which means that "the consequences which flow from…actions lead off in ways that become increasingly unpredictable: they do not necessarily fall off with distance, but may at any point be amplified beyond all expectation [like Free Text]; similarly, lines of action that are strongly pursued may find themselves attenuated by emergent field forces [like overall system performance]" (Emery & Trist, 1965, 29). As a result, step changes in capability of the sort represented by Bowman are embarked upon with extreme caution. If the resultant system is not jointly optimized with users then the inevitable adaptations that they will perform will normally lead to the latter outcome rather than the former.

Interaction Pull and Technology Push

The graphical depiction of coevolution and the shift to information age equipment shown in Figure 3, which is adapted from the work of Alberts, Gartska & Stein, (1999), represents a good summary for this section. Here it can be seen that an interactional y-axis has been added to Bowman's evolutionary timeline and the effect of co-evolutionary arm and metal twisting, of interaction and technology push, spirals forward in time. The interesting fact about this co-evolutionary spiral is that whilst it does indeed lead to complexity it does not necessarily lead to chaos: "By incrementally extending new structure beyond the bounds of its initial state, [an information age system] can build its own scaffolding to build further structure… with no bounds in sight" (Kelly, 1994, 22-23).

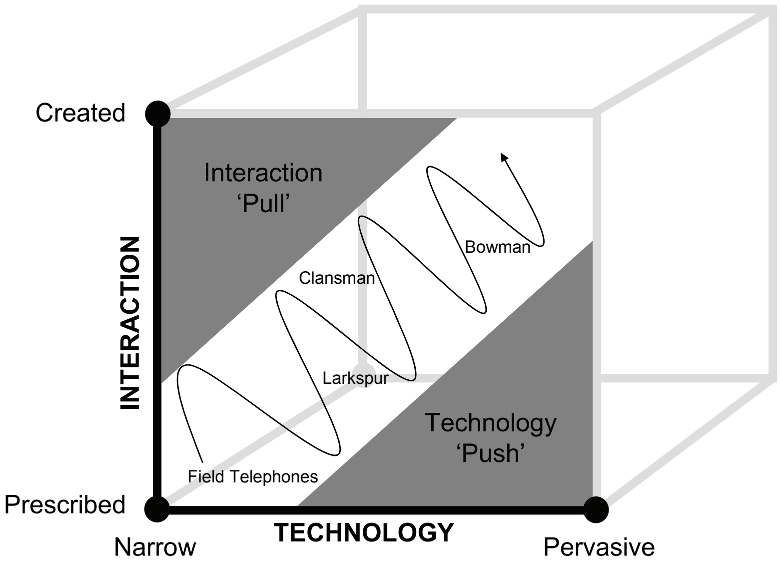

Figure 3. Interaction pull, technology push and equipment co-evolution (adapted from Alberts, Gartska & Stein, 1999).

Open Systems Behavior

Object or System?

Formal systems thinking is "…a framework for conceptualizing or viewing the world" (Carvajal, 1983, 230). Although not always seen in this way, the special case of networked, interoperable equipment can be seen as "…a set of interrelated elements" (Hall & Fagen, 1956 cited in Carvajal, 1983) and a "regularly interacting or interdependent group of items forming a unified whole" (Merriam-Webster, 2003). Metcalfe's Law brings home the point behind looking at information age equipment in this way: "as the number of [parts in a system] increases linearly the potential 'value or effectiveness' of the [system] increases exponentially" (Alberts et al., 1999). Information age systems like Bowman have more parts (not just Clansman-esque handsets but data terminals and more), more interconnections and potentially more value. The point of applying systems thinking to the type of equipment that lives in this networked environment is to try and harness such potential.

Objects vs. Networks

The term 'network' has a very different meaning in systems theory than it might in the world of NEC (where it is often attributed to the networked technology underlying it). In systems theoretic terms the extent to which a piece of equipment's 'parts' and 'interconnections' can be specified determines whether it has the systemic properties of an 'object' or a 'network.' The characteristics of an object bring to mind a relatively simple device such as the legacy Clansman radio handset. The characteristics of a 'network' are better aligned with the flexible, adaptable, information age attributes that technology like Bowman should offer. Looking at Bowman's evolutionary timeline it can be noted that the equipment on the left of the axis seems to exhibit object-like properties. They are, or tend to be:

- concerned with the attainment of a relatively specific goal,
- have well specified criteria for deciding on optimum means to ends, and
- have a "high degree of formalization" (Scott, 1992).

According to Scott (1992) this is the definition of a closed or rational system. This is a system containing parts that have well specified input/output characteristics and interconnections with known properties and flows. An electrical circuit diagram would be a good visual metaphor for such a system. The outputs of one component form the input to another, the behavior of the component and the connection itself being well defined. It is often not just the technical parts of a product that are made to yield to closed systems thinking. The original Clansman handset, for example, has other well defined input characteristics. Users lift the handset from its cradle, enter a number on the keypad and speak into the mouthpiece when they hear someone on the other end. The output characteristics are also definable, in so far as they are represented by the sound of a voice coming out of the earpiece. The first user is linked to the second user, functionally, by a simple two way informational link. Obviously, it is possible to delve into greater detail but this is the essential essence of a Hierarchical Task Analysis (HTA) for this piece of equipment. A domestic telephone of similar design has around ten goals/operations in its HTA, which means for all practical purposes the use of a Clansman radio exploits the full, albeit limited capabilities of the equipment and there is only one way to achieve an end state (which is the way the designer has provided). Equipment like this seems to make certain tacit assumptions about human users. The logic runs as follows:

- Rationality – the user, like the equipment, can be assumed to behave rationally. There is a well defined end state and optimum prescribed ways of reaching those end states, which the user will follow logically and consistently.

- Linearity – “the whole will be equal to the sum of the parts; … the outputs will be proportionate to the inputs; …the results will be the same from one application to the next; …there is a repeatable, predictable chain of causes and effects.” (Smith, 2006, 40). This applies equally to both the human ‘socio’ elements of a system and its technical parts.

- Stability – end states, routes to end states, the context of use, the needs and preferences of users and the human system interaction remain static and enduring.

By only offering limited and simple functionality these assumptions are to some extent made tenable. It is certainly appropriate for the mono-functional Clansman handset but raises important questions for the 'multi-functional' Bowman system. The HTA for the software system residing on Bowman's data terminals, for example, comfortably exceeds 300 goals/operations, not including an increasingly elaborate and expanding array of complex work-arounds. Not only are there considerably more tasks but there are also more 'plans' that cue their enactment which, according to Annett's second principle of human performance, requires considerably more skill on the part of human users (e.g., Annett et al., 1971). However, the more complex the equipment becomes, and if it still adheres to the logic of simple machines, then the more it will have to rely on a prescribed form of human interaction. In practice, of course, it often yields a complex form of human adaptability in order to make it work as the designer intended. The real-world consequences of this are that what start out as highly rational products quite often degenerate into irrationality. From an equipment design perspective, instead of remaining efficient equipment rapidly degenerates into inefficiency as a result of its bureaucratic top-down design and poor usability. Systems then become unpredictable as users grow unclear about what they are supposed to do and do not get the outcome they expect. "All in all, what were designed to be highly Rational [systems] often end up growing quite irrational" (Ritzer, 1993, 22). The hallmark of this can be seen in many large-scale projects, all of which meet their contractually enshrined requirements yet still exhibit paradoxical 'anti-synergistic' behavior (e.g., Morris & Hough, 1987).

Information age systems are different, or at least they should be. Here, users can do many things with the same piece of equipment, reaching the same end states from different initial conditions and in different ways. Information age equipment is not concerned merely with the attainment of specific goals but also as yet unspecified ones. Information age products should link users more closely to the kind of real-life 'effects based' tasks they want to perform, which means that if human adaptability is required then it is because of co-evolutionary needs rather than an artificial prescribed form of adaptability and work-arounds. Rather than a circuit diagram, with known properties, moving up the vertical/structural axis from micro-systems to systems of systems, a more appropriate visual metaphor might be a block, Venn or influence diagram, one in which the properties and links are no less extant but more loosely specified. This type of equipment exhibits the systemic property of a network rather than an object.

Open Systems, Steady States and Equifinality

The idea of a network brings along with it several useful concepts, the first of which is that of the 'open system.' "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, 23). "The 'open' perspective implies that the social and technological dimensions of [equipment] must be designed not only in relation to each other, but also with reference to evolving environmental demands" (Mitchell & Nault, 2003, 2). Open systems have boundaries with other systems and there is some form of meaningful exchange between them. An exchange that is not constrained by machine-like assumptions imposed upon human users.

"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" (Bertalanffy, 1950, 23). A Clansman radio can exhibit 'time-independent states' with 'maximum entropy,' at least conceptually. These high-level systems concepts make such a device look like it is developmentally frozen; it performs one simple task in one simple environment, it cannot be changed or updated, there are no 'firmware upgrades,' no plug-ins and no add-ons. With a real-life change in the environment from analogue to high capacity digital communications the Clansman system couldn't inherently adapt so the British Army had to withdraw them and undertake a step-change to Bowman.

An open system, on the other hand, "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, 23). Steady state behavior is an attribute of information age equipment and systems: "They 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" (Trist, 1978, 45). The behavior and capability inherent in the various data terminals and other Bowman equipment is, to a significant degree, dependent upon the live, dynamic, information infrastructure that they are connected to. If Bowman was suddenly turned off, and with it the constant import and export of information, then all the data terminals would become closed systems and to all intents and purposes frozen and of limited use. Their capability exists as a steady state, a form of "stable instability" (Kelly, 1994, 78) for which the following represents a new implicit design theory:

- Irrationality – "people using the new [system] interpret it, amend it, massage it and make such adjustments as they see fit and/or are able to undertake" (Clegg, 2000, 467). They will adapt themselves and the equipment to suit their needs and preferences, which creates behavior that is divergent from the normative, rational behavior anticipated by designers (Hollnagel, 2005).

- Non-linearity – Industrial age closed systems are often designed from the top down. In systems terms, parts and interconnections are well defined and they are thus designed to be 'homopathic,' that is, the 'whole' is designed to be equal to the sum of the 'parts.' Information age products can exhibit heteropathic effects which means that they can become more than the sum of their parts. Capability, therefore, can be emergent and not traceable to any one cause or individual. To use Johnson's (2003, 1) definition, these emergent properties are "unexpected behaviors that stem from the interaction between the components [people] …and their environment."

- Equifinality – end states, routes to end states, the context of use and the needs and preferences of users are dynamic and changeable. "There are different ways of achieving the same purpose" (Majchrzak, 1997) from different initial conditions and by different means.

What information-age design is confronted with is not an either/or situation. The challenges of network-enabled system design can be partly explained by *both* the deterministic, industrial-age techniques of old just as much as they can by the probabilistic, information-age techniques of today (and the future). The key is ensuring that human factors approaches match the extant nature of problems.

The enduring dialectic throughout this paper has been 'from' something 'to' something else. From 'is' to 'does,' from 'simplicity' to 'complexity,' from 'linearity' to 'non-linearity.' If each of these transitions are ascribed an intersecting axis then a three dimensional space is created that describes in more detail where the Army's tactical communications has come from and where it is heading to (Figure 4). One set of implicit theories, dominant design paradigms and conceptual languages applies to where tactical comms has been. The purpose so far has been to establish a foothold into the new implicit theories, emergent paradigms and conceptual languages applicable to where Bowman, and all information age equipment like it, is heading towards.

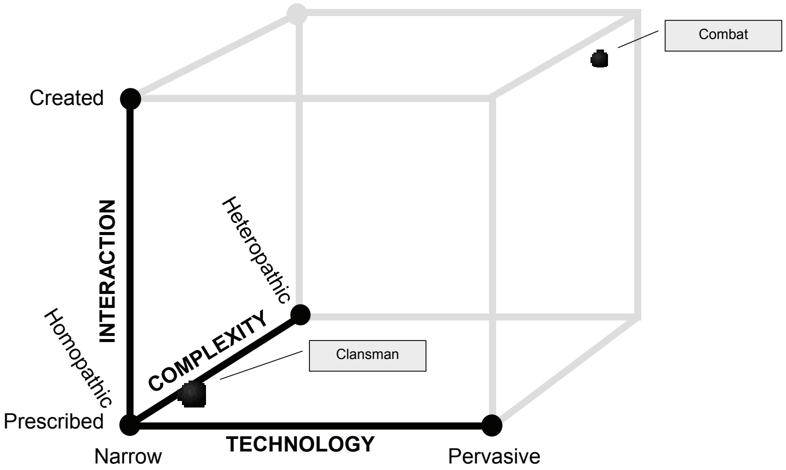

Figure 4. From Industrial to Information Age products (based loosely on NATO, 2006).

Conclusions

This paper began with a deliberately contentious set of propositions which, given the arguments and evidence just presented, are perhaps rendered a little less contentious than they might have seemed at the beginning. The polemic tone of this paper continues, however, with an observation that perhaps many readers will recognize: the presence of an almost perverse form of isolationism which looks upon military equipment as a special case. That may be true, and if it is it certainly brings with it some special problems. Here we have equipment that is most often built from scratch by specialist military suppliers, technically optimized through top-down processes of requirements capture, which themselves are rendered acutely necessary because it is against these that the highly complex legal relationship between supplier and customer (i.e., the tax payer) is enshrined.

The prevailing climate is one in which there is nothing whatsoever in common with civilian equipment (i.e., products). Military equipment is serious.

Despite that, problems do arise and in this respect the military really is unique. Here problems can be 'trained out.' This provides an artificially soft landing for many non-jointly optimized pieces of equipment, with military personnel 'bludgeoning it into submission' (in the words of front-line personnel) and thereby masking the fact that they are not jointly optimized in the first place. The military is unique because that sort of luxury is not afforded to parallel technology in civilian domains, for which professionalism, perseverance and 'training it out' are simply not an option. For military users when will the limits of this adaptation be reached? When does the need to bludgeon a piece of equipment into submission and 'train it out' outstrip the capability a new piece of equipment provides? The introduction of networked, interoperable equipment under the aegis of network enabled capability seems to be pushing this adaptation to its limits.

What might a good information age piece of equipment look like? Unfortunately, it would probably not look like many examples of equipment currently finding its way into NEC, all of which is a far cry from most contemporary PC based computers which themselves are far from perfect. But at least they have been allowed to co-evolve with their users to some extent, which means they rely on a lot of hard-won usage conventions (standardized left and right mouse button clicks are one example). A lot of NEC equipment is a far cry indeed from some of the more pioneering consumer electronic devices that manage to combine similarly extreme levels of functionality with extreme usability, not all of them by any means, but a lack of joint optimization is quickly punished by a hard landing and better competition. Consider mobile phones, the civilian tactical communications equivalent. The example might sound trivial but behind the brand attributes are serious pieces of technology with similar sized HTA's to Bowman's data terminals. And all this contained in a highly portable device with a fraction of the button count and no opportunity (let alone desire) to train anything out. The new iPhone is a particularly trivial sounding example, but here is an even more powerful device which dispenses with a keypad altogether and only has one button: on/off.

No one is suggesting that military equipment needs to literally look like this, but the trend towards convergence, towards outward simplicity (built on subsumed and transparent inner complexity) rests on the idea that for all its vicissitudes the information age is not really, in itself, the problem. It is the design of the equipment that goes with it. This is because the rate "at which uncertainty overwhelms [a piece of equipment] is related more to its internal structure than to the amount of environmental uncertainty" (e.g., Carvajal, 1983). Sitter, Hertog and Dankbaar (1997) offer two strategies that can be applied to networked, interoperable military equipment:

"The first option is to restore the fit with the external complexity by an increasing internal complexity." This is an acknowledged fact of Bowman. It is "an extremely complex system that brings together a range of software functionality in a number of different hardware configurations. All of this in turn needs to be integrated with an array of platforms" (MoD, 2008). The alternative offered by a socio-technical perspective is to: "…deal with the external complexity by *reducing* the internal control and coordination needs." This option might be called the strategy of simple equipment that enables people to do complex, real-life, effects-based tasks. The paradox, then, is that a good information age system is one that deals with external complexity *not* by a corresponding increase in *its* complexity (at least as far as the user is concerned) but by actually *reducing* complexity. All that has been discussed up until this point now comes to bear. The hallmark of information age design is subsumption, transparent, ubiquitous and flexible technology, in a word, the application of open-systems principles to equipment which should be as 'self-synchronizing' as the system within which it resides. To achieve this, design itself requires designing and thus we return to the propositions made at the start of this paper which we now recast as a set of overlapping, non-orthogonal 'principles' which draw inspiration from Cherns (1976/1987), Davis (1977) and Clegg (2000):

Principle 1. Information age equipment relies on open systems characteristics. There is constant import and export of information between it and a wider informational infrastructure of other users, devices, equipment etc. The structure and type of these interactions is as much of a determinate of the equipment's purpose and function as the piece of equipment itself. This principle, therefore, is all about a shift in thinking from design being good at 'doing the parts' to design becoming good at 'doing the interconnections.' This in turn relies on MULTI-DISCIPLINARY INPUT and a recognition that EQUIPMENT DOES NOT EXIST IN ISOLATION.

Principle 2. There is a requirement to match design approaches/ methods/techniques to the fundamental nature of the problem/ environment within which equipment will reside: IMPLICIT THEORIES NEED TO BE TESTED.

Principle 3. "…design choices are contingent and do not necessarily have universal application" (Clegg, 2000, 468). What works in one situation and context may not work in another. Design choices may themselves have unintended consequences, creating effects that can become magnified or attenuated out of all proportion. In complex systems, one strategy for dealing with this is to use BOTTOM-UP PROCESSES BASED ON SUBSUMPTION (although see Principle 2).

Principle 4. The traditional conception of design is to respond to "some articulated need" (e.g., Clegg, 2000, 466) yet, as we have argued, information age equipment may embody 'needs' that will be subsequently discovered by users, users that may not even be the anticipated benefactors of the equipment. USER REQUIREMENTS CO-EVOLVE and will only unpack themselves over time as the equipment is put to use.

Principle 5. Users of equipment "interpret it, amend it, massage it and make such adjustments as they see fit and/or are able to undertake" (Clegg, 2000, 467). Information age equipment increases the opportunities for this adaptation as well as the speed with which this adaptation creates new co-evolutionary requirements. As such: DESIGN FOR ADAPTABILITY AND HIGH TEMPO.

Principle 6. A meaningful real-life task is one in which the user experiences a full and coherent cycle of activities, a task that has 'total significance' and 'dynamic closure' (Trist & Bamforth, 1951, 6). DESIGN USEFUL, MEANINGFUL, EFFECTS-BASED WHOLE TASKS.

Principle 7. "…one should not over-specify how a [product] will work… . Whilst the ends should be agreed and specified, the means should not" (Clegg, 2000, 472). Here we are talking about an open, democratic, flexible type of technology that users can tailor to suit their own needs and preferences, in other words: MINIMAL CRITICAL SPECIFICATION.

Principle 8. Equipment should be congruent with existing practices which may on occasion appear archaic compared to what technology now offers. Congruence capitalizes on HARD WON CO-EVOLUTION AND EQUIPMENT DNA.

Principle 9. DESIGN IS ITSELF AN INFORMATION-AGE ENTITY and just as amenable to the same information age insights. There is clearly a paradox if NEC capability is being designed and procured according to 'industrial age' principles.

Principle 10. USERS OR 'PROSUMERS': "We, the users of the new equipment, are finding ways of exploiting its capabilities and thus helping you, the designers, to provide us with new capabilities." From the moment users set information age equipment on the road to co-evolution, the perceptive designer will see that the design of future capabilities is already underway.

Note

This paper remarks on a number of benefits and drawbacks of the Bowman system. This judgement is based entirely on information available in the public domain (specifically, the MoD website). The authors also wish to acknowledge the resources and information available at the Royal Signals Museum located at Blandford Camp in Dorset, UK.

References

Alberts, D. S. 2003. *Network centric warfare: current status and way ahead.* Journal of Defence Science, 8(3), 117-119.

Alberts, D. S., Garstka, J. J. & Stein, F. P. 1999. *Network centric warfare: Developing and leveraging information superiority*. CCRP.

Allen, R. E. 1984. *The Pocket Oxford Dictionary of Current English*. Oxford: Clarendon.

Annett, J., Duncan, K. D., Stammers, R. B., & Gray, M. J. 1971. Task analysis. Department of employment training information paper no. 6. London, UK: Her Majesty's Stationary Office (HMSO).

Bar-Yam, Y. 2003. When systems engineering fails - toward complex systems engineering. International Conference on Systems, Man & Cybernetics, (2)2021- 2028, Piscataway, NJ: IEEE Press.

Bainbridge, L. 1982. Ironies of automation. In J. Rasmussen, K. Duncan, & J. Neplat (Eds), *New Technology and Human Error*. New York: Wiley.

Brand, S. 1974. *Cybernetic Frontiers*. New York: Random House.

Beniger, J. R. 1986. *The control revolution: technological and economic origins of the information society*. Cambridge, MA: Harvard University Press.

Berman, M. 1983. *All that is solid melts into air: the experience of modernity*. London: Verso.

Bertalanffy, L. v. 1950. The theory of open systems in physics and biology. *Science*, 111, 23-29.

Brooks, R. A. 1986. A robust layered control system for a mobile robot, *IEEE Journal Of Robotics And Automation*, RA-2, April. pp. 14-23.

Carvajal, R. 1983. Systemic netfields: the systems' paradigm crises. Part I. *Human Relations*, 36(3), 227-246.

Cherns, A. 1976. The principles of sociotechnical design. *Human Relations*, 29(8), 783-792.

Cherns, A. 1987. Principles of sociotechnical design revisited. *Human Relations*, 40(3), 153-162.

Chetty, M. & Buyya, R. 2002. Weaving computational grids: How analogous are they with electrical grids. *Computing in Science and Engineering*, 61-71.

Clegg, C. W. 2000. Sociotechnical principles for system design. *Applied Ergonomics*, 31, 463-477.

Czarniawska, B. & Hernes, T. 2005. *Actor-network theory and organizing*. Copenhagen: Business School Press.

Davis, L. E. 1977. Evolving alternative organization designs: their sociotechnical bases. *Human Relations*, 30(3), 261-273.

Dawkins, R. 2006. *The blind watchmaker*. London. Penguin.

Emery, Fred E. and Eric L. Trist 1965. The causal texture of organizational environments. *Human Relations*, 18 (1): 21-32.

Ferbrache, D. 2003. Network enabled capability: concepts and delivery. *Journal of Defence Science*, 8(3), 104-107.

Green, W. S. & Jordan, P. W. 1999. *Human factors in product design: current practice and future trends*. London: Taylor and Francis.

Hall, A. D. & Fagen, R. E. 1956. Definition of system. General Systems, I.

Hollnagel, E. & Woods, D. D. 2005. *Joint cognitive systems: Foundations of cognitive systems engineering*. London: Taylor & Francis.

ISO 13407 1999. *Human-centered design processes for interactive systems*. London: British Standards Institute.

John, P. 2007. Contracting against requirements documents or shared models? In Network Enabled Capability Through Innovative Systems Engineering (NECTISE) Conference, Loughborough, UK 12/13th Feb.

Johnson, C. W. 2005. What are emergent properties and how do they affect the engineering of complex systems? University of Glasgow: Department of Computing Science.

Kelly, K. 1994. *Out of control: The new biology of machines, social systems, and the economic world*. New York: Purseus.

Law, J. 2003. Notes on the theory of the actor network: ordering, strategy and heterogeneity. Available at: http://comp.lancs.ac.uk/sociology/soc054jl.html.

Licklider, J. C. R 1960. Man-computer symbiosis. IRE Transactions on *Human Factors in Electronics*, HFE-1, 4-11.

Majchrzak, A. 1997. What to do when you can't have it all: toward a theory of sociotechnical dependencies. *Human Relations*, 50(5), 535-566.

Merriam-Webster 2007. System. Available at: http://www.merriam-webster.com/dictionary/system.

Mitchell, V. L. & Nault, B. R. 2003. The emergence of functional knowledge in sociotechnical systems. Haskayne School of Business, University of Calgary.

MoD, 2008. Bowman. Available at: http://www.army.mod.uk/bowman.

Molina, A. H. 1995. Sociotechnical Constituencies as processes of alignment: The rise of a large-scale European information technology initiative. *Technology in Society*, 17(4), 385-412.

Morris, P. W. G. & Hough, G. H. 1987. *The anatomy of major projects*. Chichester: John Wiley & Sons.

NATO 2006. SAS-050 conceptual model version 1.0. Available at: http://www.dodccrp.org/SAS/SAS-050%20Final%20Report.pdf.

Norman, D. A. 1990. The 'problem' with automation: inappropriate feedback and interaction, not 'over-automation.' *Philosophical Transactions of the Royal Society of London*, B 327, 585-593.

PWC, 2008. Today's Challenges. Available at: http://www.pwc.com/extweb/f.

Ritzer, G. 1993. *The McDonaldization of society*. London: Pine Forge Press.

Ropohl, G. 1999. Philosophy of socio-technical systems. *Society for Philosophy and Technology*, 4(3), 1-10.

Sanders, M. S. & McCormick, E. J. 1992. *Human factors in engineering and design*. Maidenhead, UK: McGraw-Hill.

Scacchi, W. 2004. Socio-technical design in W. S. Bainbridge (Ed), *The encyclopedia of human computer interaction*. Location: Berkshire Group.

Scott, R. 1992. *Organizations; Rational, natural, and open systems*. New Jersey: Prentice Hall.

Sitter, L. U., Hertog, J. F. & Dankbaar, B. 1997. From complex organizations with simple jobs to simple organizations with complex jobs. *Human Relations*, 50(5), 497-536.

Smith, E. A. 2006. *Complexity, networking, & effects-based approaches to operations*. CCRP Publication Series.

Tapscott, D. & Williams, A. D. 2007. *Wikinomics: how mass collaboration changes everything*. New York: Portfolio

Toffler, A. 1981. *Future shock: the third wave*. New York: Bantam.

Trist, E. L. 1978. On socio-technical systems. In, Pasmore, W. A. & Sherwood, J. J. (Eds), *Sociotechnical systems: A sourcebook*. San Diego, CA.: University Associates.

Trist, E. & Bamforth, K. 1951. Some social and psychological consequences of the longwall method of coal getting. *Human Relations*, 4, 3-38.

Weiser, M. 1991. The computer for the 21st century. *Scientific American*, Sept, 94-100.

Wikipedia 2007. Short message service. Available at: http://en.wikipedia.org/wiki/Short_message_service.

Woods, D. D. & Cook, R. I. 2002. Nine steps to move forward from error. *Cognition Technology and Work*, 4(2), 137-144.