From Clansman to ComBAT: HFI Principles for NEC System Design

The work described in this document has been undertaken by the Human Factors Integration Defence Technology Centre, part funded by the Human Capability Domain of the U.K. Ministry of Defence Scientific Research Programme.

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Reference HFIDTC/2/WP2.17/4

Version...2

Date..23rd July 2008

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Glossary

AM	Amplitude Modulation. Radio technology normally associated with analogue communications.
BCIP	Bowman ComBAT Infrastructure Platform. Term used to refer to the phased delivery of next generation tactical communications.
Bowman	The name of the tactical communications system currently being introduced.
CCRP	Command and Control Research Program. Part of the US Department of Defence, it deals with so-called 'out of the box' thinking in relation to Command and Control.
Clansman	The tactical communications system in use prior to Bowman.
ComBAT	The name of a software package enabling, amongst other things, command planning and force identification, using the Bowman infrastructure.
FM	Frequency Modulation. Radio technology associated with more contemporary forms of tactical communications (e.g. Clansman and Bowman).
HF	Human Factors. The use of scientific data on human performance in order to improve the design of artefacts, equipment and systems.
HFI	Human Factors Integration. The embedding of HF principles into business practices (such as design and procurement).
HTA	Hierarchical Task Analysis. Structured method for decomposing activities prior to analysis. A key method in HF.
ISO	International Standards Organisation.
Larkspur	The predecessor to both Clansman and Bowman.
NEC	Network Enabled Capability.
RS232	Recommended Standard 232. A generic name referring to a standard means of digital connection.
SST	Sociotechnical Systems Theory. The application of systems theory to the design/re-design of systems involving both humans and technology. The goal is to jointly optimise the performance of both.
SUDT	Staff User Data Terminal. A UDT tailored to the requirements of command staff.

UDT	User Data Terminal. A computer terminal that utilises the Bowman communications infrastructure and upon which the ComBAT software system runs.
USB	Universal Serial Bus. A modern equivalent to the RS232 connection.
VUDT	Vehicle User Data Terminal. A UDT tailored to use within a vehicle

1 Executive Summary

What is the report about?

The report is about how to design networked, interoperable equipment such as that found within NEC domains. Part 1 presents the theoretical rationale for Part 2, which sets out a collection of high level design principles.

Background and reasoning behind the work:

The research extends the scope of sociotechnical systems theory, firstly by relating it to the military context, and secondly by drawing down insights normally applied to large scale systems, and applying them to a growing class of networked, interoperable equipment.

What was undertaken in the research?

Part 1 takes the example of military communications hardware and shows how its development from Clansman to ComBAT can be understood in sociotechnical systems terms. The research demonstrates that not only can systems concepts be applied to ‘equipment’ but moreover, it is an entirely appropriate conceptual response in the NEC era. Part 2 distils these insights, synthesises them with key literature and presents a set of high level design principles that hint at what this may mean practically.

What was discovered?

Under the aegis of NEC, an ever expanding array of military equipment has the facility to support as yet un-thought of future capability. This brings with it profound changes in the way that equipment/systems should be designed and thought about. From the evolution of military equipment to its co-evolution with human users, from a focus on what equipment ‘is’ to what it ‘does’, in sum, a case is developed in favour of equipment (and its procurement) that is as open, flexible, agile and self-synchronising as the NEC system into which it is designed to operate. Based on experience in the commercial domain explicit design principles suggest how this might be practically achieved.

Military relevance of the work:

There is an extraordinary amount of overlap between the nascent military domain of NEC and the well established field of sociotechnical systems theory. The insights derived from this synergy can be used to re-examine the way in which equipment is designed and procured in the NEC era. The lessons learnt from ComBAT/Bowman provide a mandate to consider alternative approaches. The sociotechnical systems viewpoint currently under development is one such candidate.

2 Part 1: Networked, Interoperable Equipment

2.1 Introduction

2.1.1 Background and Context

ISO 13407 (human-centred design processes for interactive systems) sees Human Factors Integration (HFI) as the optimisation of top-down activities of systems engineering with bottom-up, iterative approaches of user centred design. The HFI DTC has consistently sought to explore and develop interdisciplinary synergies that can feed into this process. The application of Sociotechnical Systems Theory (SST) is the topic of this report and an example of one such synergy.

By definition SST is a bottom-up process. Given its fifty year legacy of successful application in the commercial world, this report asks the question of what lessons can be learnt? How can top-down and bottom-up processes be combined and traded-off? What does a bottom-up, open-systems view mean for system design, and furthermore, what does it mean for the individual pieces of equipment that reside in 'open-systems' like NEC? A set of high level design/HFI principles is derived from an analysis of relevant concepts. They represent a further step towards relating theory to practice.

2.1.2 Presentation of Material

A demilitarised version of this report forms the topic of a peer reviewed journal article in which the concepts presented have already been subject to external peer scrutiny (please see Walker et al., 2008). Having passed this test, the current report takes the same material and applies it to a military case study. This two step process provides robustness and military relevance.

A number of strategies are used to try and design this report for human use, and effectively convey what potentially could be complex and obtuse sounding concepts. These include a case study (mapping the historical development of Bowman style communications to the concepts under discussion), a set of explicit principles (adapted from the commercial arena where they have a legacy of real-world application) and a writing style that is a little more conversational than the norm. The motivation for this is nothing more than an attempt to sustain the reader's interest and provide a strong narrative flow for the ideas being expressed.

To further set the report into context is to say that it fits a wider trend in the world of NEC research. This is perhaps best exemplified currently by the Command and Control Research Program (CCRP) book series, a widely disseminated body of research within the NEC community. As such, the reader is likely to get the most benefit from this report by approaching it in much the same way. Of course, there are several key differences. Most notable is that where the current state of the art in NEC thinking is driven and written from an ostensibly military perspective, this work draws more widely.

2.1.3 Structure of the Report

The report is divided into two main parts. Part 1 deals with the theoretical background and why it is appropriate to pull down systems principles like Sociotechnical Systems Theory to the design of equipment and artefacts. It is comprised of the following:

A section describing The Information Age and The Control Revolution. Both of these highlight the problem space to which SST is an appropriate conceptual response.

There follows sections entitled: Design Evolution, Coevolution and Open Systems Behaviour, which take the NATO SAS050 conceptual model of command and control and explore each of its axes in relation to equipment design. Numerous supporting concepts and theories are drawn upon.

Part 2 is entitled Design Principles and it synthesises previous literature, and the preceding sections, in order to derive 11 principles to serve as high level guidance for achieving the objective of appropriate NEC equipment. They serve as an illustration of what the practical application of these insights might look like.

2.2 The Information Age

The word ‘capability’ crops up frequently in discussions about military equipment. As a result, is equipment increasingly exhibiting the properties of a service rather than a product? It certainly appears to be the case that it’s not what is sold to the army/the air force/the navy, it’s what is done for them, what is provided. In equipment terms, it is becoming much more the case that “It’s not what something is, it’s what it is connected to, what it does” (Kelly, 1994, p. 27). One thing appears clear: equipment design is changing.

The corollary of this change is that concepts which were once the exclusive domain of large scale entities and organisations, concepts such as Systems Theory, are now becoming applicable to individual items of equipment. This shifting paradigm has a number of interesting implications, not just in terms of how new capability expresses itself through specific bits of technology, but how this technology should be designed and thought about in the first place. Take the Bowman system as an example:

Bowman is “a communication system for tomorrow – today”, it is “more than just a radio”, according to the Army (MoD, 2008) it “provides our forces with the latest digital voice and data communications technology in a package that will significantly improve command and control”. Indeed, Bowman is central to instantiating the ‘information-infrastructure’ essential for the realization of Network Enabled Capability (NEC).

Bowman is a significant development, not necessarily in itself or how it was specifically designed, but in what it seems to signify. Bowman, and the equipment that resides under its aegis, shows that a particular point within a wider equipment design paradigm shift has been reached. This is equipment that is located firmly within the transformation from ‘industrial age’ notions of what military kit should be like, to something much more relevant to the ‘information age’.

A number of attributes qualify the assertion that Bowman is 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) and more about what it's connected to and what it does (Kelly, 1994). Bowman is indeed more than just a radio, conceptually it is more than just a computer, and it is also more than just a communications network. For the users it is a type of mobile porthole into a form of military 'blogosphere' populated by other people, information and assets. It should enable personnel to extract value from this collection of interconnected artefacts, to harness the power of the capability that this provides, to do meaningful 'Effects Based' activities easily, only one of which is talking to people over the radio.

2.3 The Control Revolution

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 (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 behaviour 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 arguably, and to greater extents, be up to them: this is the essence of self-synchronisation. What it means is that how networked, interoperable equipment is actually going to be used is to some extent unanticipated by its designers, not to mention its procurers. At first glance, it is tempting to see elements of the design as being out of control.

Is it truly out of control or is it merely a different type of control? The latter is argued to be the case. The new vocabulary of 'firmware upgrades', plug-ins and add-ons is emblematic of information age equipment lending itself to a form of 'through life capability' (to use a popular systems engineering term) making it able to take advantage of current as well as future developments. Instead of a product life-cycle characterised by 'design', 'deliver' and 'maintain', design occurs 'through-life', and often with the end user's participation. It may not be active participation, in so far as the user may not explicitly request an enhancement which the maker then provides, but in an increasingly networked world emerging needs can be sensed and increasingly supported. Thus in some senses Bowman, and other NEC-era equipment, is not an 'end product' at all, at least not in the traditional sense. What has been designed is to some extent 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 'coevolution' will tell exactly what.

There can be little doubt that military equipment is changing, admittedly not all equipment but at least some of it, and in growing numbers. Arguably, military equipment is just beginning its shift away from "the linear, predictable, causal attributes" of something like the relatively simple Clansman radio system, "to the crisscrossing, unpredictable, and fuzzy attributes" of something like Bowman (Kelly, 1994, p. 24). The conundrum facing equipment designers is how to cope with the transition from the noun like qualities of equipment being 'something' to the verb like properties of it being a 'process' (e.g. Law, 2003).

The military world is far from alone in facing this dilemma. The effects of the information age have already been felt acutely in numerous 'large scale' domains such as the design of commercial organisations (e.g. from traditional organisational hierarchies to 'open' business models; e.g. PriceWaterhouseCoopers, 2008), systems engineering (from requirements capture to 'I'll know it when I see it'; John, 2007) even human sciences is showing an interest beyond individuals to 'networks' of individuals (e.g. Actor Network Theory; Czarniawska & Hernes, 2005). Whilst representing a major paradigm shift in the military arena, in a wider sense NEC and Bowman merely herald a new era in the increasingly widespread domestication of 'systems' ideas. This report will attempt to draw down the considerable experience of similar information age transformations in non-military domains and apply it to this specific and growing class of military system and the equipment it comprises.

2.4 Design Evolution

According to Green and Jordan (1999) it is becoming increasingly difficult for equipment manufacturers to compete on functionality, reliability or manufacturing costs. They argue that technology alone is not enough anymore, to some extent equipment design may be about to reach a ceiling, if it hasn't already. Interestingly, the ceiling is dictated not by technology per se, but by the ability of human users to access its potential.

Functionality, technical reliability and manufacturing costs do share one fact in common. They can be seen as industrial age concepts that relate more to what a piece of equipment 'is'. This is not necessarily the same as the information age concept of what a piece of equipment 'does', especially in the hands of an experienced member of armed forces personnel. This paradox warrants further examination.

2.4.1 End Products versus Initial Conditions

The dictionary definition of equipment is "…necessary outfit, tools, apparatus, etc." (Allen, 1984, p. 247). By definition it is also "… a thing or substance produced by natural processes or manufacture" (p.588). Equipment is self evidently manufactured but the idea of it being produced by 'natural processes' has a certain resonance in 'systems' terms. Equipment is not just manufactured it is also 'designed'. Because is it designed it is subject to a range of diffuse interconnected influences, from competitive and commercial pressures to technology developments and user requirements. Equipment, therefore, emerges out of a wider dynamic background and context, it too evolves, a form of natural process within which the designer plays a key role.

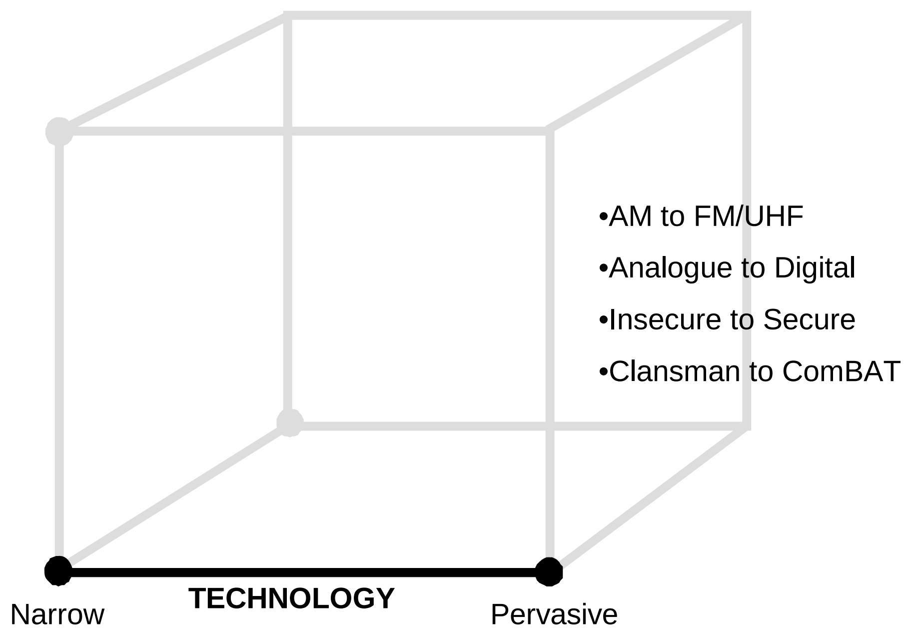

Figure 1 - Bowman's (simplified) evolutionary timeline

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 an essentially 'bottom-up' process. There is no 'control' or 'design' as such and complexity emerges out of simplicity.

Implicit in natural evolution is a subsumption architecture. Higher (complex) levels subsume lower (simple) levels, like building blocks (Brooks, 1986). 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 like Bowman:

- Step 1: Get the equipment doing simple things first and get them working perfectly (in the case of Bowman it does everything that legacy systems like Larkspur and Clansman did and appears to do them very well indeed).

- Step 2: Add new layers of activity over the results of the simple tasks (in the case of Bowman the new layers include 'secure' voice and high capacity data radio).

- Step 3: Don't alter the simple things (the voice capabilities of Bowman remain virtually unchanged from the users' point of view, in that they still pick up a handset and speak into it).

- Step 4: Make the new layer(s) work as perfectly as the layer below (to some extent this is still the subject of test and evaluation with Bowman).

- Step 5: Repeat…

The sort of artificial ecology that equipment normally resides in, and emerges from, exhibits a recognisable yet peculiar form of evolution in which these rules become distorted. In equipment design there is a combination of bottom-up and top-down processes (a fact that HFI explicitly recognises), there are varying degrees of control, in fact, the so-called ‘blind watchmaker’ (e.g. Dawkins, 2006) is not necessarily blind at all, there is a plan and the designer acts as a creator.

This distorted design ecology typically gives rise to a particular type of equipment, a technologically intensive item like, for example, the User Data Terminals (UDT) that plug into the Bowman infrastructure. It is easy to be critical from the current ‘theoretical’ perspective and the intention is not to be. On the contrary, early experience with this device provides information that can be learnt from and in this case serves as an interesting exemplar of what happens when the rules of subsumption are distorted.

As an example of Brooks’ rules of subsumption it is possible to argue that the UDT is limited in its ability to do some of the simple things well enough. The central processing unit, for one, has a modest clock speed of 700MHz and the rubber keypad renders typing extremely difficult. Despite these difficulties new layers have been added (a data encryption system that operates in the background consuming yet more of the limited processing resources) and/or the simple things that may have worked were changed (in responding to specific capability issues, the ComBAT software has, or is, becoming increasingly complex, not less).

All of this is not to be especially critical of a piece of equipment that probably more than most had to negotiate a particularly challenging and tortuous set of requirements, far from it, because despite any individual shortcomings it may yet succeed in a different, somewhat less predictable way. If nothing else it may help to create certain ‘initial conditions’ from which progressively more well evolved and developed layers can be built based on what is being learnt currently.

Figure 2 - Bowman User Data Terminals (like most items of complex equipment) result from a distorted design ecology. Despite issues, it may still create the conditions for increasingly more refined iterations of the system

Based on this analysis, what is the key to equipment design in the information age? The question to ask might be: what if, instead of designing 'end products' (something that is made), favourable 'initial conditions' are created (so that something can 'become')? What if hierarchical control ('we, the designers, are designing something for you, the users') is substituted for a different kind of 'distributed control'? One in which the boundary between designers and users "is highly blurred, highly permeable, or non-existent" (Scacchi, 2004, p. 6-7), or to use Toffler's (1981) or Tapscott and William's (2007) phraseology, consumers become 'prosumers'? What if the focus of equipment design shifts, at least conceptually in some way, from 'manufacture' to something more like 'natural process'? Embedded within Bowman's developmental timeline are several key themes which suggest that insights into these 'what if' questions may be available.

2.4.2 Opaque versus Transparent Capability

The evolutionary pre-history of Bowman can probably be traced as far back as Morse code and the Crimean War, the first campaign to use electric telegraph (perhaps tellingly, the Commander in Chief received so many administrative queries from London that he was quickly overwhelmed with information). This was gradually superseded by voice telephony (e.g. the Boer War), voice telephony eventually led to radio-telephony (used to some extent in WW1) and the recognisably modern Larkspur system. This was superseded by the lightweight, sealed 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 in turn 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 created new affordances, affordances that helped the principle of voice telephony to break free from its wires through the use of radio, first 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 it being a 'strategic' mode of communication (e.g. 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, intended more as an illustration rather than a detailed historical critique. However, 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 everyone for all manner of purposes, as exemplified today by Bowman.

A major trend in the transition from the industrial to the information age is that some of the technology which is now a familiar part of military operations is itself becoming subsumed, which means that it is becoming transparent, "weaving itself into the fabric of everyday life until indistinguishable from it" (Weiser, 1991, p. 94). Of course, the technology has not become 'literally' invisible. Whilst it would be possible to point to and isolate the function that a specific cable or antenna serves, the key point is that from the users' perspective there is little point (Weiser, 1991). Indeed, from the users' point of view the behaviour of the Bowman system has become largely disconnected from the specific technological artefacts that support it. It's the behaviour that is important, not the device.

Despite its heterogeneous parts, Bowman as a whole not only works satisfactorily (as per Brook's subsumption rules above) it behaves coherently (Law, 2003). Only when the system breaks down does it dissolve into its constituent electronic components and human interventions, even then this lack of coherency has more meaning for the signals engineer than it does for most Bowman users (Law, 2003).

2.4.3 Centralised versus Distributed Equipment

Technological invisibility goes hand in hand with another of Weiser's concepts: ubiquity. Ubiquity means "present everywhere or in several places simultaneously" (Allen, 1984, p. 817). What it means is that what a system like Bowman 'does' has been largely 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, p. 61). As a result, information age equipment, whether it be something overtly ‘radio-like’ or something more complex like the various Data Terminals, is equipment that can increasingly be plugged in anywhere, from a tank to a tent.

In the case of Bowman’s ancillary equipment, although the user is still tied to a specific item of kit, that device is no longer tied quite so tightly to any one location, neither is it quite so tightly constrained in terms of what it does, at least compared to the Clansman radios of old. Moving from left to right along Bowman’s evolutionary axis, the difference in innovation and learning now potentially available to the user can be illustrated by likening it 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.

2.4.4 Summary

To sum up this section, whether going from analogue to digital, from electricity power grids to computer ‘grids’, from telephone networks to the Internet, the information age is characterized by changes that are occurring at the boundaries of materialism (‘is’ versus ‘does’) and place (‘somewhere’ versus ‘everywhere’). Behaviour is becoming detached from the places and technology required to support it. More than that, networked, interoperable equipment, through systems like Bowman, are in the process of ‘becoming’ the system that is required. To put it another way, the ‘servitisation’ of battlefield effectiveness (to use another systems engineering term) appears well underway, technology is evolving and so are users to it. The whole system, then, is ‘co-evolving’.

2.5 Design Coevolution

2.5.1 Structured Capability

According to researchers in the field of Cognitive Systems Engineering (e.g. Hollnagel & Woods, 2005) technology and complexity are intertwined. Received wisdom describes in broad terms that 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, p.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 is often one that is more complex to drive on; Hollnagel & Woods, 2005). The Law of Stretched Systems explains this self-reinforcing evolutionary cycle.

The cycle begins with an identified deficiency, a lack of capability, which is answered by expanding the equipment’s functionality. Functionality is expanded by capitalising on the extra capability afforded by new technology, thus creating a new product, albeit a more complex one. Consider for a moment the functionality/ease of use afforded by the venerable Clansman system (in which a curly cord to the handset was considered an innovation) and the functionality/ease of use afforded by a Bowman UDT. An attempt has been made to push the equipment “back to the edge of the performance envelope”, to make the most of what technology now affords (Woods & Cook, 2002, p.141). With extra capability has clearly come greater task complexity, which 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 capitalising 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, p. 151). In other words, the solution may be technically effective but not 'jointly optimised' with its human users. Human adaptability is then required in order for equipment like this 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, p. 5). The typical response to this situation, one exemplified by ComBAT's sometimes faltering progress through its phased capability release (BCIP4, 5, etc.) is to change the functionality of the system again. This completes the self-reinforcing cycle of complexity shown in Figure 3, which does not merely cause difficulties, rather it represents an optimum strategy for maximising them (e.g. Norman, 1990).

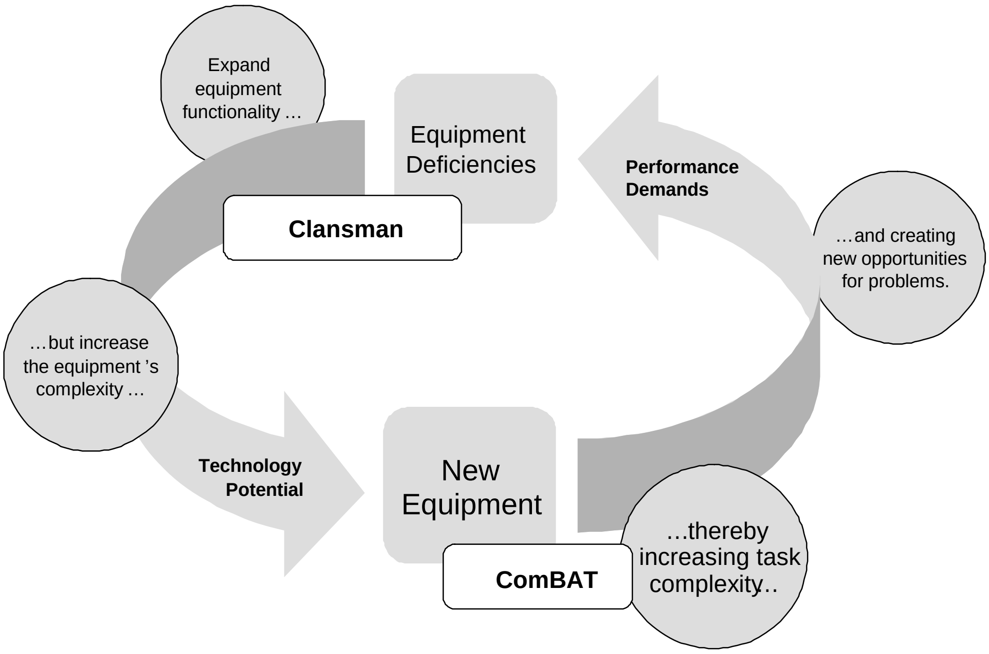

Figure 3 - Hirshhorn's Law of Stretched 'Equipment' (Hollnagel & Woods, 2005)

2.5.2 Coevolution

A well known maxim in Human Factors is that 'it is easier to twist metal than 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 adapt and that items of equipment can be seen in isolation from their environment.

Another way of looking at this twisting metal versus arms dialectic is to see it as an almost necessarily antagonistic process, such that there is "reciprocal evolutionary change" (Kelly, 1994, p. 74), a little of both metal and arm twisting. 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 spiralling coevolutionary fashion until the original piece of equipment becomes almost unrecognisable. Indeed, 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 coevolutionary advance winds the two antagonists more inseparably, until each other is wholly dependant on the other's antagonism. The two become one" (Kelly, 1994, p. 74; Licklider, 1960). It is an interesting notion that warrants further scrutiny.

At the birth of recognisably modern military communications technology, who actually 'needed it'? The question sounds faintly ludicrous but the answer to it is surprising. At the outset, and for many years hence, relatively few people 'needed it' and it remained the more or less exclusive province of Headquarters.

Its use as a tactical communications medium derived from being able to direct flank formations and artillery fire. This requirement was further 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 further, equipment became more mobile, like Clansman.

The key point is that these improvements did not fundamentally alter the nature of the communications task. It altered the context, setting and 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). The old subsumed layer had worked perfectly, the new layer merely required some subtle metal twisting as a new technology was adapted to a new context, and new users adapted themselves to it.

As Clansman became more widespread and ubiquitous, users and technology became increasingly locked into a single system, the metaphorical twisting of arms required some more metal to be twisted. Enter Bowman. The step change in capability provided by Bowman derives from three areas of functionality: secure tactical communications (with Bowman there is no longer a requirement to encode and decode radio messages using paper code), enhanced situational awareness (through global positioning technology) and a reliable data network. All of this is designed to support the kind of interaction and service that users of Clansman and the Internet were coming to expect as they passed the 'performance demands' phase of the self-reinforcing complexity cycle.

An interesting example of reciprocal human/technological change emerged from direct (field) observations of ComBAT. Within the generally heavily prescribed method of working embodied by the ComBAT software suite (which resides on various Bowman User Data Terminals), a facility called Free Text is provided. This was 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 a facility that is part of a wider 'Publish and Subscribe' function). Because every communications eventuality seems to have been incorporated into ComBAT, giving rise to an almost 'extreme' level of functionality, it seems unlikely that this 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 adapted to the technology in surprising ways. The effect of the simple Free Text facility, therefore, became magnified out of all proportion to its almost incidental nature. During a full-scale operational trial of the system, it was observed that out of all the data communications events, a not insubstantial 9% were accounted for by Free Text. This represents 73% of all 'user initiated' data communications (those non-automatic system generated data comms events such as positional data reports and so forth). This is surprising for a feature that wasn't even 'designed' this way.

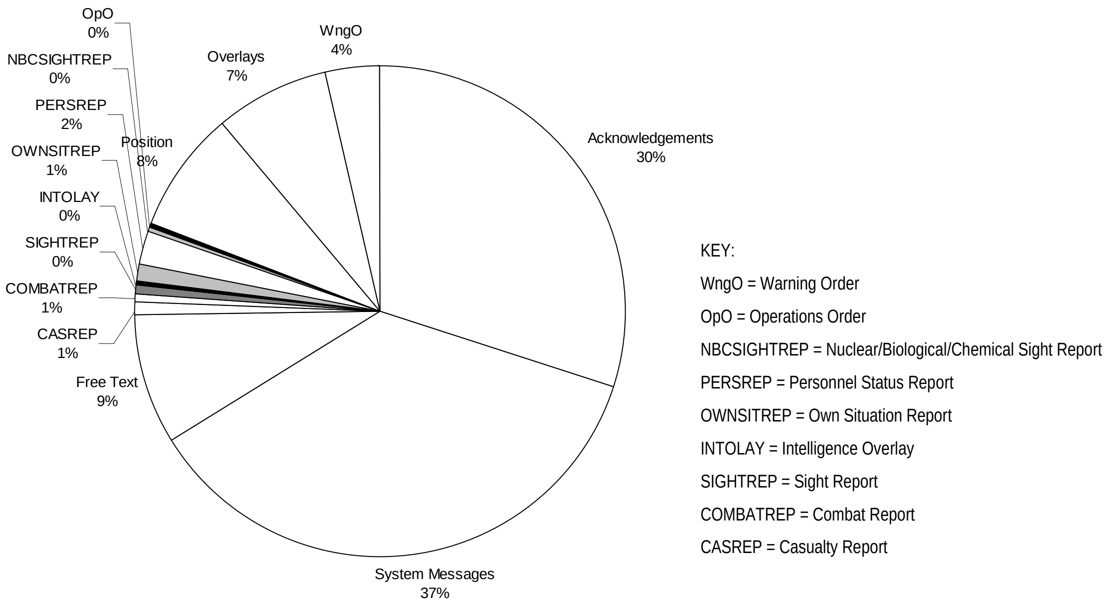

Figure 4 - Users adapted to Bowman in surprising ways with the simple Free Text facility becoming magnified out of all proportion to its largely incidental presence on the requirements list (narrow segments of the pie chart shaded for the purposes of legibility)

Arising from the mutually antagonistic relationship between evolving user needs and evolving technology is coevolution, a potentially powerful force. So, whereas evolution describes Bowman's own individual technological adaptation, coevolution is a form of bottom-up optimisation of both user needs and technological capability (e.g. Brand, 1974). Coevolution binds user needs and technology potential together; neither force existing in isolation. This is a crucial point.

The inseparability of human and technical coevolutionary partners means that 'step changes in capability' (of the sort boasted by Bowman) are embarked upon with extreme caution because just as aspects of system performance like Free Text can become magnified out of all proportion, anticipated modes of operation and system behaviour can also become sharply attenuated. The public and Parliamentary accounts of Bowman's often painful gestation show this to be the case in several important respects (House of Commons, 2007).

From a systems perspective there emerges a clear imperative to consider the causes of coevolutionary change, both interaction pull (twisting arms) as well as technology push (twisting metal), the processes of change (e.g. the Law of Stretched Systems) as well as the presence of change itself. The biggest imperative of all is that both the human and the technical aspects of a system have to be jointly optimised for these systems processes to work in favourable ways and for the power of the Network in NEC to be realized. It is also important to consider that a likely consequence of the information age is that coevolutionary processes like these will accelerate.

2.5.3 Complexity

To paraphrase the 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, p. 263). The Larkspur handset, for example, has a simple, well defined capability designed for an enduring context of use. It is an end product in all senses of the word. Bowman, on the other hand, has the potential for through-life capability. Whether its innate flexibility and adaptiveness is seen explicitly as this or not, Bowman is designed for an altogether more dynamic environment.

It is possible to go even further to say that information age equipment itself exhibits the NEC-like property of 'agility' (e.g. Ferbrache, 2003, p. 104). This sort of equipment is, or should be, able to reconfigure (or be reconfigured) in response to the evolving demands of the environment. Bowman is certainly publicised not only as "A communication system for tomorrow-today" but as "A system designed to keep pace with technology" (MoD, 2008).

A piece of equipment's agility in response to environmental change is one aspect, but because equipment and users are increasingly inseparable coevolutionary partners, agility serves to create further change. Not just an increasing rate of change but also change in terms of what it is ultimately changing towards; greater order but also greater complexity (e.g. Emery & Trist, 1965, p. 13).

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, p. 40). "Actions are both persistent and strong enough to induce autochthonous processes in the environment" (Emery & Trist, 1965, p. 29). The self-reinforcing coevolutionary 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, p. 29).

As a result of all this, equipment design in the information age presents itself as a daunting prospect. Fortunately there is good news. The significant equipment design opportunities embedded within complexity arise “paradoxically from the same conditions because it is exactly this nonlinearity that presents the possibility of obtaining a disproportionate leverage from a given action” (Smith, 2006, p. 40). Evolution and coevolution appear as the watchwords for realising this aim. The example of Free Text appears as a pertinent case in point.

2.5.4 Summary

The graphical depiction of coevolution and the shift to information age equipment shown in Figure 5, 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 coevolutionary arm and metal twisting, of interaction and technology push, spirals forward in time. The interesting fact about this coevolutionary spiral is that it leads not to chaos but to order: “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. Spontaneous order helps create more order.” (Kelly, 1994, p. 22-23). Information age design therefore becomes much more like a service, one that matches the ongoing provision of a ‘capability’ and the evolving and co-evolving nature of developing sociotechnical systems.

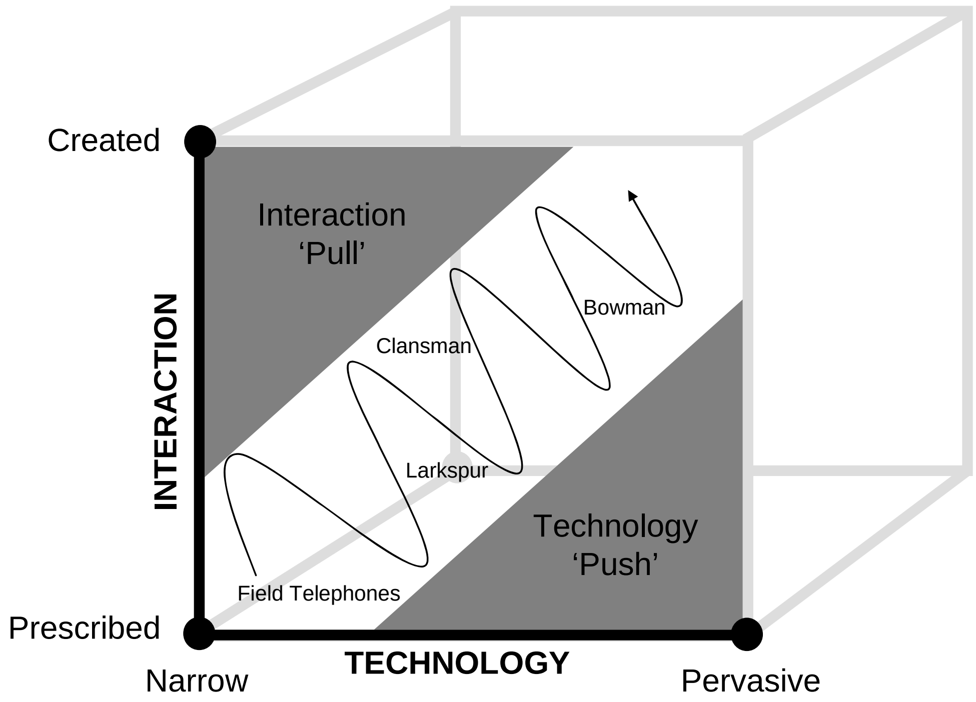

Figure 5 - Interaction pull, technology push and equipment coevolution

2.6 Open Systems Behaviour

2.6.1 Object or System? Equipment or Capability?

Systems thinking is "…a framework for conceptualizing or viewing the world" (Carvajal, 1983, p.230). In this regard military equipment need not be conceptually different to any large scale system to which 'systems thinking' is normally applied. Although rarely 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, 2007).

Let us assume that Bowman is an interacting group that forms a unified whole. UDTs (User Data Terminals), VUDTs (Vehicle UDTs), not to mention their human users, all of these heterogeneous parts link together to create the Bowman 'system' proper. This structural definition of a system combines vertical and horizontal axes, which means that systems can be analysed at several levels (Molina, 1995). Moving downwards different layers of interconnectivity are traversed, from the links between VUDTs and vehicle systems, to the links between this and other local devices, to the links established within a much wider telecommunications infrastructure involving battlegroup and brigade headquarters. In each case the system becomes an ever larger group of interacting parts. Thus artefacts like local UDTs/VUDTs are often simultaneously part of a super-system (i.e. a system of systems) or micro-systems in themselves. Super-systems subsume micro-systems; subsumption being what this vertical axis is really concerned with (Figure 6).

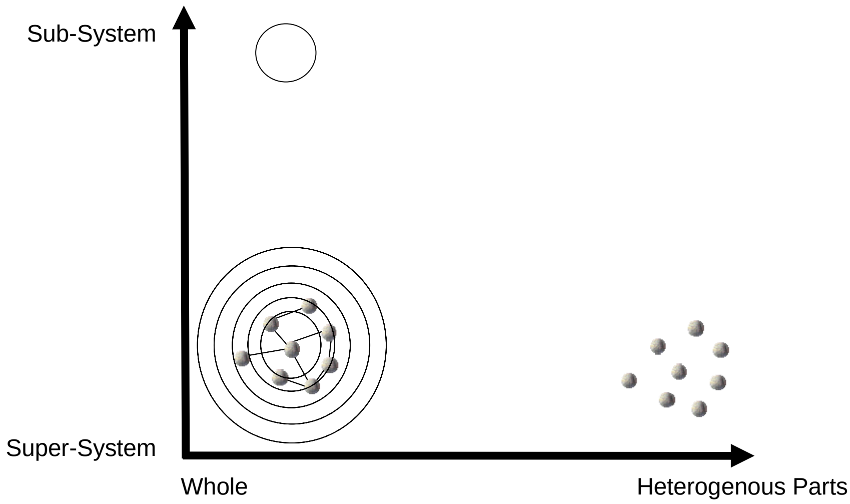

Figure 6 - Sub-Systems, Super-Systems, Systems of Systems

The horizontal axis, on the other hand, is more about the heterogeneity of the parts that go towards making up the uniformity of the 'whole'. Whereas the vertical axis is comprised of horizontal layers of building blocks, the horizontal axis is comprised of vertical slices, meaning that the building blocks are different shapes and sizes. In Figure 6, running from left ('whole') to right (heterogeneous parts) the point is made that, whether subsumed or otherwise, individual parts differ in all manner of ways. For example, UDTs serve a different purpose than VUDTs and both are different from SUDTs (Staff User Data Terminal). The role that each of these data terminals plays (not to mention the panoply of other networked, interoperable devices floating around the Bowman 'blogosphere') within a larger super-system or whole is quite different. This diversity is an important determinate of the systems' behaviour.

The structural perspective considers systems from a very 'real-life' perspective (for example, of real-life data terminals disposed geographically and linked through a real-life telecommunications network). It is possible to divide up the systems theoretic cake according to more abstract 'functional' criteria as well. A system can be divided up according to purpose, location, behaviour, in fact to almost anything. In each case the end result is a quite different sort of system, one that does not necessarily conform to any kind of physical correlate. The key point in all of this metaphorical cake slicing are the twin notions of "a complex whole" formed from a "set of connected things or parts" (Allen, 1984). Without trying to gloss over the practical implications of bringing real-life systems into being (which is undeniably complex), conceptually at least, the 'things' or 'parts' of a system can be almost literally anything. These systems can be "composed not only of people but also of machines, animals, texts, money, architectures – any material that you care to mention" (Law, 2003, p. 2). Systems thinking is simply a way of enabling such diverse phenomena to be linked together to form a kind of heterogeneous network, which can then be described with a universal language.

Equipment design is traditionally very good at doing the 'parts' of a system, yet the Aristotelian axiom that "the whole is characterized not only by its parts, but by the relations between the parts…" (Ropohl, 1999) is just as relevant. Networking innovations like Bowman, and any piece of networkable equipment that has a connection to it and/or to other devices, bring with them the added imperative to consider these ‘interconnections’ between parts, as well as the ‘whole’ that arises when parts are linked in this way. In a sense the information age raises the systemic level at which networked, interoperable equipment needs to be considered. In other words, the designer needs to include more of the world in their design. Because of this, networkable equipment can become greater than the sum of its parts as “…above all, the set of relations determines the very character of the system…[and]…the structure of the system determines its function” (Ropohl, 1999, p. 4).

Metcalfe’s Law brings home the point that lies behind even looking at information age equipment in this way. It states that, “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 this potential.

2.6.2 Objects versus Networks

Just as the concepts and metaphors of systems theory have been successfully applied to large systems and organisations it is possible to argue that the same insights are becoming increasingly relevant to individual items of networkable equipment as well. Thus it is possible to proceed from a more general characterisation of what systems thinking is to what it might mean.

The term ‘network’ has a very different meaning in systems theory than it might do in the world of NEC (where it is often, arguably erroneously, attributed to the networked technology underlying it). In systems theoretic terms the extent to which a product’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 ‘simple contraption’ like the legacy Clansman radio handset. The characteristics of a ‘network’ are better aligned with the flexible, adaptable, information age attributes of the various Bowman data terminals (ignoring the manifold and often handicapping usability issues for the moment). Looking at Bowman’s evolutionary timeline it can be noted that the equipment on the left of the axis seem to exhibit object-like properties. They are:

- concerned with the attainment of a relatively specific goal,
- have well specified criteria for deciding on optimum means to ends and
- a “high degree of formalization” (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 is a visual metaphor for a closed system, the outputs of one component form the input for another, the behaviour of the component being similarly well defined. Interestingly, it is not just the technical parts of a product that conform to closed systems thinking. The original Clansman handset, for example, has other well definable 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 10 tasks in such an analysis whereas the HTA for the ComBAT system comfortably exceeds 300 (not including an increasingly elaborate and expanding array of complex work-arounds). Not only are there more tasks, there are more 'plans' that cue their enactment, which connotes considerably more skill being required. In addition, the extent to which the external environment is referred to within these plans is considerable.

For all practical purposes normal use of the Clansman system 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). The machine-like closed system metaphor extends outwards from the technical parts of the equipment to include the user's interaction with it. This is not such a disadvantage with the mono-functional Clansman handset but raises interesting questions for the 'multi-functional' Bowman system. The "logic of the machines" (Kelly, 1994, p. 2) runs something like this:

- *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 rationally 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, p. 40). This applies equally to both the human 'socio' elements of a system and the 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.

Equipment that exhibits the characteristics of an 'object' seems to make certain underlying machine-like assumptions about the nature of human users. By only offering limited and simple functionality these assumptions are to some extent made tenable. The more complex the equipment becomes, if it remains as a form of closed system, the more it will have to rely on a prescribed and correspondingly complex form of human adaptability in order to make it work as the designer intended. Of course, such a prescribed form of adaptability sits uncomfortably with NEC as it is the antithesis of self-synchronisation and adaptability.

The real-world consequences that arise from this situation are that what start out as highly rational products quite often degenerate into irrationality. From an equipment design perspective: "*Instead of remaining efficient*, [systems] *can degenerate into inefficiency as a result of* [the bureaucratic design of their interfaces] *and the other pathologies we usually associate with them.* [Systems] *often 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, p.22). This is arguably what has occurred in the case of ComBAT, which in many senses meets all of its design criteria yet exhibits 'anti-synergistic' behaviour.

Information age systems are different. Users can often 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 unspecified ones, ones for which an interconnection between product and user must surely exist but its precise nature is more difficult to define in advance. 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 coevolutionary needs rather than an artificial prescribed form of adaptability and a need to find 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, whose 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. This type of equipment is open, flexible, easy, yet as a result of this; powerful.

2.6.3 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, p. 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, p. 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, p. 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 as if 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 army had to withdraw them and update its equipment 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, p. 23). Steady state behaviour 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, p. 45). The behaviour and capability inherent in the various UDTs, VUDTs and other Bowman equipment is, to a significant degree, dependent upon the live, dynamic, informational 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 kind of "stable instability" (Kelly, 1994, p. 78). Without labouring the deep theoretical concerns of open systems thinking too heavily, a new implicit theory seems to apply to information age systems and it is this:

- 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, p. 467). They will adapt themselves and the product to suit their needs and preferences, which creates new and unexpected goals that although useful for users, are quite often divergent from the normative, rational behaviour anticipated by designers (Hollnagel & Woods, 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, that is to say that they can be more than the sum of their parts, capability can be emergent, not traceable to any one cause or individual. To use Johnson's (2005) definition, these emergent properties are "unexpected behaviours that stem from the interaction between the components [people] …and their environment" (p. 1). This is a bottom-up approach to capability and to design.

- 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.

2.6.4 Summary

It may still be difficult to perceive the link between systems thinking and military equipment and to be fair, military equipment in general, and Bowman specifically, are by no means the purest expression of information age principles. It is not an either/or situation. The challenges of NEC 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). To the perceptive designer, though, there appears to be enough about many current military systems to argue that at least some of their characteristics lend themselves to this alternative way of thinking. Some practical questions to ask might simply be: Does my bit of equipment have the Plessey equivalent of a USB or RS232 port; is it connected to something or can it be? Is it the sort of kit where users can explore and discover its more wide-ranging functionality? Is there a defined end state and route to that end state or is the kit more flexible than that? Does it perform a task or confer a 'capability'? If the answer to any of these questions is in the affirmative then it has attributes that can be exploited by the principles of information age equipment design.

The enduring dialectic throughout this report 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 7). 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 kit like it, is heading towards.

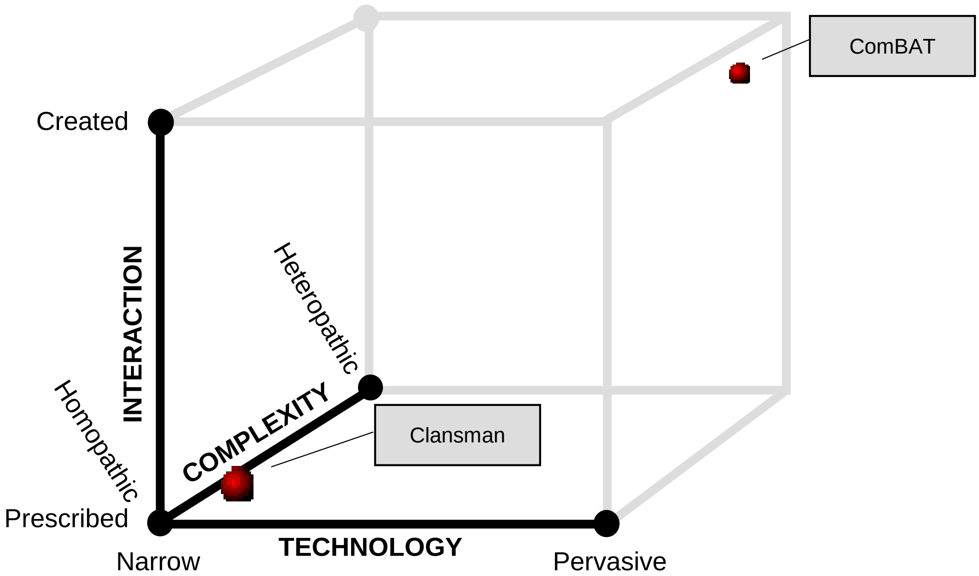

Figure 7 - From Industrial to Information Age products (based loosely on NATO, 2006)

3 Part 2: Design Principles

3.1 Background

Design principles are the first step in turning the theoretically orientated ideas presented above into something more practice orientated. This section owes a great deal to previous work in the domain of Sociotechnical Systems, most notably Cherns' (1976) paper (updated in 1987) entitled 'The Principles of Sociotechnical Design', the work of Davis (1977) and the work of Clegg (2000) entitled 'Sociotechnical principles for system design'. These examples of prior work represent experience of applying the principles and ideas discussed above in non-military domains. A first attempt is made now to relate these concepts not just to a military context, but to draw them down from the study of large scale organisations to the altogether more 'local' case of designing individual pieces of military equipment.

Design principles act as heuristic devices for design, they describe a set of intended outcomes with the choice of methods (Human Factors or otherwise) required to meet those objectives being left to the designer. Note that future work is aimed at mapping principles to specific methods/practices.

Heuristics represent possibly the simplest class of design method and their use is widespread (Stanton & Young, 1999; Nielsen & Molich, 1990). Interestingly, despite their simplicity this generic approach lends itself to the high level analysis of complex systems (Pejtersen & Rasmussen, 1997). In the present case, the principles are not focused on telling the designer what to do but what to try and achieve; the focus is on 'characteristics' rather than specific features. Clegg (2000) highlights the benefits of such principles as:

- Encouraging an 'interconnected perspective' on design, thereby encouraging the designer to consider the overall coherency of the equipment as well as its relationship to its wider context (Clegg, 2000).
- "The principles also provide a potential framework for evaluation purposes" (Clegg, 2000, p. 464).
- The principles are argued as having some predictive validity. Equipment that fares poorly in being evaluated against these principles may be one that fares poorly in the face of information age challenges like environmental complexity and dynamism (Clegg, 2000).

That is the good news. The principles of information age equipment design also come with several caveats attached. Firstly, the principles are as interconnected as the information age design environment to which they are applied ("it would be bizarre if they were not"; Clegg, 2000, p. 464-465). Similarly, they are subject to the same evolutionary and coevolutionary forces that information age products are subject to, thus they themselves represent a set of initial conditions from which coevolutionary scaffolding can be continually built. As a result, not only are they likely to express any current gaps in our understanding, they make no assumptions about the future either. With all of this in mind the principles come with the following more succinct health warning. Put simply, information age design is not "rendered non-problematic" (Clegg, 2000, p. 464) through their application, they, like the equipment and systems to which they are directed, are not an end product. In some senses the 'process' is more important than 'the principle'. The aim is to try and help the perceptive designer and/or procurer to leverage the disproportionately favourable outcome that non-linearity and complexity allows. Having put in place these caveats it is right to point out that similar outcomes appear to be increasingly unlikely to emerge from the implicit theories underlying the dominant 'industrial age' equipment design paradigm.

3.2 Principles

3.2.1 Principle 1 – Equipment does not exist in isolation

Although sometimes technically convenient to see certain types of equipment as stand alone (a closed system), in the NEC era this viewpoint is becoming increasingly outdated; the behaviour of information age equipment relies on open systems characteristics, whereby there is constant import and export of information between it and a wider informational infrastructure of other users, devices, equipment etc. From a design point of view the structure and type of these interactions is as much of a determinate of the equipment's purpose and function as the bit of kit itself.

Equipment can become more than the sum of its parts (becoming a capability rather than just a function), thus a focus on technology to the exclusion of other factors is unlikely to meet the objectives, or indeed the potential of NEC system design. Equipment can become not just more than the sum of its parts but more than the sum of its users, its technology and even its original design. It is apparent that HF and HFI take on a new meaning in information age design.

In summary, this principle is about a shift in thinking from design being good at 'doing the parts' to design becoming good at 'doing the interconnections' as well.

3.2.2 Principle 2 – Implicit theories

Why do rationally designed systems behave irrationally? Why has a technology ceiling been reached? Why don't users use equipment in the way intended? Should we be creating 'end products' or 'initial conditions'? There are numerous paradoxes and ironies in systems design. Arguably, an insular approach that focuses on the 'differences' between the military domain to the exclusion of readily apparent 'similarities' presents the danger of creating an artificial barrier between hard-won experience in other domains that can be exploited in 'essence' if not in 'detail' within the military arena.

In summary, this principle reflects the shift from industrial to information age design. This shift requires a flexible, questioning approach that includes self awareness of wider movements and trends.

3.2.3 Principle 3 – Bottom-up system design

"…design choices are contingent and do not necessarily have universal application" (Clegg, 2000, p. 468). In other words, the same outcome can be achieved from different initial conditions and different processes. What works in one situation and context may not work in another. Thus design choices may themselves have unintended consequences, creating effects that can become magnified or attenuated out of all proportion.

This principle reflects a need to manage interdependency between and among design choices, a challenging task if conducted using a top-down approach for which large scale complexity has to be managed by decomposition. The bottom up approach might suggest that a piece of equipment's design should be grown according to the rules of subsumption and modularity (Kelly, 1994). Each small aspect made to work 'perfectly' before being subsumed by a more complex layer. The 'build a little test a little' maxim is one example of a strategy for managing complexity in equipment design.

In summary, best practice in HFI should embody iterative, circular design strategies that focus on experimentation.

3.2.4 Principle 4 – System behaviour

The traditional conception of design is to respond to "some articulated need" (e.g. Clegg, 2000, p. 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. So, in addition to stated needs and anticipated users, there is a requirement to consider an alternative position: what 'behaviour' is the equipment/system capable of?

In summary, more complex behaviours, behaviours that enable users to do more useful meaningful things, are likely to create more emergent user needs than those pieces of equipment whose behaviour is constrained, prescriptive, targeted and ultimately simple minded.

3.2.5 Principle 5 – The stability myth

As Clegg (2000) rightly states: "…design is extended over lengthy periods of time. It is not a one-off that has a clear end." (p. 467). The assumption that user needs, behaviour and preferences are not only stable but enduring is no doubt reassuring and technically convenient but, in the information age, often flawed. The only constant is change.

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, p. 467). Information age equipment increases the opportunities for this adaptation as well as the speed with which this adaptation creates new coevolutionary requirements.

In summary, the ‘tempo’ of information age equipment design increases, making the traditional conception of a ‘linear design lifecycle’ less appropriate and ‘through life capability’ more so.

3.2.6 Principle 6 – Design useful, whole tasks

Quite often equipment is designed from a functional perspective, with functions arranged vertically. Systems like ComBAT, for example, typically present the user with ‘functions’ (e.g. “what task do you want to undertake”) rather than purpose (“what one of the seven questions Combat Estimate process do you want to answer?”). 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, p. 6).

This principle states that design should avoid splitting such tasks across artificial functional boundaries (e.g. Clegg, 2000). Flexible human-centeredness is key to exploiting this systemic artefact.

3.2.7 Principle 7 – Minimal critical specification

“…one should not over-specify how a [product] will work […] Whilst the ends should be agreed and specified, the means should not” (Clegg, 2000, p. 472). Here we are talking about an open, democratic, flexible technology that users can tailor to suit their own needs and preferences. This principle is the practical manifestation of the open-systems concept of equifinality. Users should be able to reach the same end states from different initial conditions and by different means.

In summary, equipment should incorporate “scope for learning and innovation” (Clegg, 2000, p. 472).

3.2.8 Principle 8 – Hard won coevolution

If design is evolutionary then the designer plays a key role in natural selection. Favourable adaptations need to be preserved (or ‘selected’). Recognise, then use, the best of previous designs, preserve a piece of equipment’s DNA. In practical terms ‘design should be congruent’ with existing practices (which may on occasion appear archaic compared to what technology now offers) but which, in actual fact, arise out of hard won coevolution. This principle is about subsumption; use the simple things that work perfectly as building blocks for future layers of complexity.

In summary, hybrid systems rather than ‘step-changes’ are an appropriate strategy for managing complexity and change.

3.2.9 Principle 9 – Design is itself an information age system

“This principle simply states that systems that under-take design also need designing” (Clegg, 2000, p. 472). Equipment and system design is itself an information age entity and, therefore, no doubt amenable to the same information age insights. Indeed, there is clearly a paradox if NEC capability is being designed and procured according to ‘industrial age’ principles.

3.2.10 Principle 10 – Devolved, democratic, participatory design

Open, flexible, information age equipment that permits innovation and learning implicitly involves the users in designing what the equipment ultimately ‘becomes’ from the initial conditions/capabilities that designers provide. In other words: “We, the users of the new product, are finding ways of exploiting the product’s capabilities and thus helping you, the designers, to provide us with new capabilities”. This is a reversal from the ‘implicit argument’ Clegg (2000) proposes that, “we, the designers of a new system, are trying to find ways of getting you, the users, to participate in its design”.

In summary, from the moment users set information age equipment on the road to coevolution, the perceptive designer will see that the design of future capabilities is already underway.

3.2.11 Principle 11 – Multidisciplinary input

To paraphrase Clegg (2000), there is a danger that equipment designed according to industrial age principles will only be, at best, ‘technically’ effective. Increasing complexity and interconnectedness brings with it the requirement for pluralism and multidisciplinary input. The systems perspective regards equipment not just in its closed system sense (for which technologists would be required) but also the device’s interaction with its user (human factors expertise) its wider informational infrastructure (expertise in communications networks and the Internet) the social (social psychological) and cultural (anthropological), to name a few.

In summary, interconnections between the equipment and its various systems levels bring with them a requirement for more diverse knowledge and expertise.

4 Conclusions

As a consumer of advanced electronic equipment, the Military (like all consumers) has probably become used to a dominant design paradigm, that of the closed, bureaucratic, inflexible, complex, technology laden bit of kit which, despite all that, really only permits the user to perform relatively simple and arbitrary individual tasks and often only with arduous training and operational effort. So what might a ‘good’ information age product look like? Unfortunately, it would probably not look like BCIP6 and ComBAT. Indeed, Bowman’s UDTs/ComBAT are a far cry from most contemporary PC based computers, which themselves are far from perfect, however, they do at least rely on a lot of hard-won usage conventions (standardised left and right mouse button clicks are one example). ComBAT is a far cry indeed from some of the more pioneering consumer electronic devices that manage to combine ‘extreme functionality’ with ‘extreme usability’. The new iPhone is a good example, it dispenses with a keypad altogether and only has one button: on/off. This 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. Rather it is the design of the equipment that goes with it. 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). A bold assertion perhaps, but with equipment that is facing up to the challenges of the information age, Sitter, Hertog and Dankbaar (1997) offer two broad strategies:

“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 functionalities 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 sociotechnical 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 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 and features. 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 that in some senses can become as ‘self-synchronising’ as the system within which it resides. This is the goal to which the principles above apply.

5 Note

This report remarks on a number of benefits and drawbacks of the Bowman system. Aside from the specific example quoted in Section 2.5.2 above, this judgement is based entirely on information available in the public domain.

The authors wish to acknowledge the resources and information available at the Royal Signals Museum located at Blandford Camp, Dorset.

6 References and Bibliography

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.

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.

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.

House of Commons (2007). Ministry of Defence: Delivering digital tactical communications through the Bowman CIP programme. London: Stationary Office.

ISO13407 (1999). Human-centred 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 February 2007.

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.

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

Neilsen, J. & Molich, R. (1990). Heuristic evaluation of user interfaces, in Chew, J. C. and Whiteside, J. (eds) Empowering People: CHI '90 Conference Proceedings, Monterey, CA: ACM Press, pp. 249-56.

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.

Pejtersen, A. M. & Rasmussen, J. (1997). Effectiveness testing of complex systems, in Salvendy, G. (ed.) Handbook of Human Factors and Ergonomics, 2nd edn, New York: John Wiley, pp. 1514-42.

PriceWaterhouseCoopers (2008). Meeting the challenges. Available at: www.pwc.com

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.

Stanton, N. A. & Young, M. S. (1999). A guide to methodology in ergonomics: designing for human use. London: Taylor and Francis.

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.

Walker, G. H., Stanton, N. A., Jenkins, D. P. & Salmon, P. M. (2008). From telephones to iPhones: Applying systems thinking to networked, interoperable products. Applied Ergonomics. In Press (Available On-Line 19th May 2008).

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

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

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