The Aims of Human Factors and Their Application to Issues in Automation and Air Traffic Control

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Preamble

The primary objectives of air traffic control have been described as "the safe, orderly, and expeditious flow of air traffic" (see Hopkin, 1991). At a fundamental level, this represents the aided retention of object dispersal in four dimensional space-time. As the objects under air traffic control are not within the range of "humanscale", (Hancock & Chignell, 1990) the recognition and manipulation of such objects can only be achieved via the use of technological prosthetics. Three major constraints are imposed on this general case. First, objects are limited with respect to resources; second, they are required, at some point, each to occupy essentially a common spatial location; and third, the objects themselves are under volitional control and can act independently. Separation distance covaries with object density, as does demand on communication capability and control action. The process by which such objects are controlled itself represents a record of iterative evolution to which proposed forms of automation will add an additional layering. The impact of such automation on the human operators within such a system is the major subject of this paper.

There is considerable literature on the questions of human factors as related to air traffic control (Hopkin, 1988) and it would be of little benefit here simply to re-iterate what has been said previously. Instead, this paper examines the fundamental aims of human factors and within a general framework, identifies critical commonalities subsuming the function of many complex systems. Principal among these are questions which are central also to an understanding of human actions. These include the problem of representation, intention, and the substitution of metaphor for direct experience. In understanding such questions, the role of automation as a prosthetic is examined. The emergent and nominally "preferred" role is in stark contrast to real-world systems, whose motivation for development is primarily technical and financial in nature. In illustrating contemporary incompatibility between human and machine, the paper examines potential, preferable, and probable solutions to the question of future interaction. Particular application to the questions of air traffic control is highlighted.

Introduction

Much has been made recently about the concepts of chaos and non-linear systems, and how an understanding of the patterns intrinsic to such systems provide a rich and varied

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understanding of multiple phenomena, ranging from the weather to human cognitive activity (Gleick, 1987). It has been asserted that the behavior of such systems, while not completely random, is also not completely predictable due to the acute sensitivity to minor variations in initial conditions, where the establishment of initial conditions is constrained by Heisenberg's principle of uncertainty (Thompson & Stewart, 1986). While the latter may be the subject of philosophical contention, the present status of practical knowledge confirms that predictability cannot as yet be achieved. Order opposes chaos, and stability is the enemy of uncertainty. Hence, when a system is designed, it is purposely created for stable states of operation.

Like nature, the design engineer is faced with a dilemma. How can a system be constructed so that it is able to oppose the vagaries of an uncertain environment while continuing to perform its desired function?

The history of technology is a handbook of the ways in which engineers have attempted to solve this question. Examples abound of strategies such as surrounding the system with layers of protection, or making the system itself partially adaptive, both of which are taken from nature's own solutions. Many systems require that the unique capabilities of a human be employed, and this is one unpredictable element that the engineer may view as "the enemy within."

To eliminate the undesired component of human spontaneity and unpredictability, the engineer of the past disenfranchised the worker, emphasizing repetitive motions and tasks of essentially negligible cognitive content. Problem solving endeavors such as breakdown and maintenance were separated from the line worker and were the province of a different group of individuals.

Both time and engineers themselves have defeated this sterile conception of the human operator. Any task as mindless as that described above has already become a prime target for automation. However, the role of the human in current systems retains much ambiguity. The changing nature of this role has been observed ad nauseam, but what actually emerges as the primary role for the human is still unclear. Are we further along the path toward an automated utopia, where the engineer can finally, and thankfully, usher out the last human operator from the system, close the door, press the on switch and retire?

For those with that form of vision the answer is still no. Humans retain a vital role in the vast majority of contemporary systems, at least on the basis of their abilities to respond to the uncertainties noted above. But the role the human operator is constrained to adopt today is often anathema to a variety of human performance characteristics. Operators are regularly required to sit for several hours watching the condition of a system which varies little in status, a task at which humans are notoriously poor (Parasuraman & Davies, 1976; Mackworth, 1950/1961; Warm, 1984). Further, in many complex operations, operators are required to change from a passive monitoring mode to assume active control of a system of whose contemporary status they may have little fundamental conception. Essentially reverting from audience to action.

In short, the human is new and will be required to act specifically in non-stable conditions. The processes of problem-solving, and error identification and correction are emphasized in these transient phases rather than steady-state modes of operation. Such conditions are often time-restricted and are attended by high levels of stress. How human operators respond under such conditions is a critical question (see Hancock & Warm, 1989; Tattersall, 1990).

Human Factors: Definition and Aims

Typically, definitions through historical references to human factors start with the first human use of tools and quickly skate several millennia to the late twentieth century and the nascent efforts of systems integration stimulated by the necessities of global conflict. However, it is important to examine this putative foundation more closely.

First, to constrain the use of tools to humanity alone is incorrect. Many animals use naturally occurring prosthetics to accomplish tasks, and some even modify such primitive tools to suit their required function. The human is certainly not the only animal or organism which orders its environment to promote self-welfare. Although Louis B. Leakey named a branch of the human family tree (Homo Habilis) after this tool-wielding capacity, it cannot be legitimately used as the differentiate for human factors, unless we choose to include all such tool users.

The essence of the difference lies not in the local and constrained manipulation of nature but in two fundamental ideas which also underlie the foundations of science itself, namely, the conception that nature can be controlled, and further, that there are principles that allow control by transcending individually-specific conditions. It is this affirmation of control, the expectation of progressively greater control, and the use of induction through reality-matching that lies at the very heart of Bacon's conception of the scientific method (Eiseley, 1973). In essence, the better differentiation is not as wielders of tools, but as wielders of what has become formalized as science. It is more than worth noting here, that the scientific method as conceived by Bacon was vitally, and "above all things, for the uses of life." While much of technology extends knowledge, it is human factors that critically focuses on science for the uses of life. In the long search for the leitmotif of human factors, the observation by Bronowski (1978) typifies the frustration of the user with an unknown and arcane technology, supposedly designed to assist, but which in reality resists. He noted that:

> Science and society are out of joint. Science has given to no one in particular a power which no one in particular knows how to use. Why do not scientists invent something sensible? Wives say it every time they stub their toe on the waste bin, and husbands say it whenever a fuse blows. Why is it the business of no one in particular to stop fitting science for death and to begin fitting it into our lives?

Although Bronowski's comment was voiced over technology of the 1950's, we hear continued and equally strident cries for help over four decades later. The following is taken from a newspaper, earlier this year, it reads:

> Infuriating gadgets:
> Sir, May I add my own "design" complaints to those of Geoffrey Wheatcroft. The off-set control panel on moderm cars is a maddening example of overdesign leading to front seat passengers having to crane necks and thrust elbows to operate the radio: a flurishing gear change by the driver produces a set of grazed knuckles.
>
> Infuriating in the home is the grill pan with the "easily detachable handle" - especially when tilting the pan to remove excess fat. But my most recent cause for despair was the attempt to buy a comfortable garden chair with hinged foot rest. There were dozens of them in all makes. But the foot rest can be raised only when the chair tips backward so that to read a newspaper with your feet up you have to be

lying on your back. When challenged, shop assistants say feebly: "They're all made like that now." Why?

Such comments reinforce the necessity for human factors and ergonomics, while simultaneously reflecting their importance in percolating into everyday society.

A Descriptive Structure

The question of the definition and aims of human factors is inextricably linked with the basic motivations of human action. To understand this primary linkage, we have to understand the changing scales of human capability. This can be accomplished by plotting a representation of the scales of time and space. In Cartesian coordinates, we can view our environment as ranging spatially from the very small to the very large, and temporally from the very brief to the very prolonged.

For anyone who has seen the spatial representation of size in *Powers of Ten*, this range effect is clearly illustrated (Morrison, Morrison, Eames, & Eames, 1982). In the center of the axes at 10° and 10°, we establish an arbitrary intersection. This is an arbitrary choice of location, as scales must always be specified relative to alternative entities. Here, and in common with human observers throughout the ages, we have put ourselves at the center and referenced everything else with respect to our own size and perception of immediate duration. From this perspective, at the center of these axes we have humanscale or the ecological scale, as it has been termed by Shaw (see Shaw & Kinsella-Shaw, 1988). We may visualize humanscale as an envelope centered at the intersection of these axes whose boundary connotes the region over which humans can exercise unaided influence.

For example, on the spatial scale of the very small, unaided, we may perceive and manipulate objects some millimeters in size. On the time scale, the lower boundary is represented by events that are separated by fifty to one hundred milliseconds (Stroud, 1955), a period that is projected to represent the "now," the perceptual moment, or in the terms given by Minkowski (1908), the specious present.

The boundaries at the upper end are somewhat more ambiguous. For simplicity, if we consider actions which occur with a brief time duration, a human might throw a spear or javelin and exercise unaided influence over an area of approximately one hundred meters in radius. However, with the aid of prosthetics, it is clear that the range over which a human may exert unaided action is vastly increased.

Therefore, surrounding this tiny region of humanscale is the vast expanse of space and time over which we exert influence when we act in conjunction with the technology we have created. This latter region is labeled prostheticscale. Spatially contemporary boundary markers to this prostheticscale are represented by elementary particle manipulation, at the lower spatial bound to Voyager and its physical presence beyond the edge of the solar system, at the upper end of the spatial scale. It might be argued that humankind has exercised influence over a much larger range when we consider the information intrinsic to radiowaves that have left this planet within the last century. Our choice of physical manipulation as a criterion is on this basis one that may be challenged; however, as this simply extends the envelope by some multiple, it is not a question of particular moment.

On the temporal scale, we have become familiar with nanosecond-based measures

(Rifkin, 1988) at the lower boundary, while storage and dynamic knowledge representation of expert systems promises the use of technology to preserve at least a small portion of our personal selves beyond our actual lifetime. Further, according to allometric scaling, humans should live on average to 23 years of age (Schroots & Birren, 1990; Yates, 1990). Already, our use of technology prolongs our expected life-span more than three-fold. Also, there is a trend with improvements in medical facilities for individuals to live longer.

Outside prosthetic scale, is perceptualscale. This represents the boundaries of what we may perceive. We could, as with action, differentiate perceptual scale into aided and unaided perception. Unaided, the human observer can see objects down to quite small sizes and from their actions infer the presence of even smaller particles, as for example in observing Brownian motion. However, it is the unaided eye directed toward the night sky that perceives the vastness of large scale spatial representation.

We should not neglect at this juncture, to point out that an individual looking out into space is also looking back in time. The interdependence of space and time has been recognized by philosophers and physicists for over two centuries, and more recently combination (space-time) has been explored with respect to human behavior (Hancock & Newell, 1984). With the aid of contemporary technology, our range of perception is vastly increased. The resolution of the Hubble telescope promises to expand our perceptions close to the boundaries of the known Universe, and our "perceptions" of smaller and smaller particles of matter is further expanded by tools such as the superconducting supercollider.

One of the major rationales for exploration is the desire to exercise influence over the things we are able to perceive. Words are small substitute for the illustration of William Blake. In his woodcut "I want, I want," he expresses the quintessence of the human desire to reach beyond such continual restrictions. We should note that Blake's example is taken from the large scale of space, where our manifest inability to exercise influence over far distant objects has been clear for some millennia.

Nor should we ignore the cultural bias of such desire, in that many cultures beyond the Occidental World express little interest in physically manipulating elements beyond their immediate reach.

With respect to this endeavor, technological innovation serves to expand the envelope of aided actions and so enlarge the area we have labeled prostheticscale. In so doing, however, technology often and purposefully serves to expand the region of perceptual scale. It is suggested that there is a continual tension between these two regions, as humankind seeks to physically control what they can perceive. It is indeed the purpose of technology to expand these envelopes.

However, in addition to the tension created by the dissonance between regions of perception and action, the further the envelopes expand away from the relatively fixed humanscale, the further divorced are actions from everyday experience. As we progress in our efforts to influence the very large and the very small, we begin to rely more on metaphorical representations of entities which we cannot sense directly and with which we have no direct empathy on a spatial and temporal basis. Time provides us with a most pertinent example here, as indicated by Rifkin (1988). Supposing two supercomputers of the near future are exchanging information and a user interrupts them with a line code of ASCII such as the enquiry "what are you doing?" In the time taken to enter such an enquiry, such computers can exchange more information than is contained in the sum total of spoken language for all time. Similar examples abound on the spatial scale. The point is simply that we are progressively operating more and more with metaphor, and the metaphors are becoming clearly more inadequate as technology progresses.

Technology is driven by forces which require that the boundaries we have identified are progressively enlarged. For market purposes, systems must be faster, they proliferate in physical size, and when connected with other units they grow in complexity. Often such progress is relatively "mindless," that is, driven by forces with few concerns whether such "progress" is beneficial.

One fundamental rationale for human factors is the dissipation of tension between ranges of perception and action, but a further one is to assume a leadership role in directing technological innovation. Often human factors is characterized as facilitating human interaction with machine systems; however, a more fundamental role is in the active direction of systems technology. The price of this dissonance is the spectacular system failures which adorn the news media. Recent insights suggest that micro-ergonomic manipulations can have only a limited effect in ameliorating the tension created. It is at the level of organizational structure that a more profound impact may be effected.

Yet the paradox remains that organizations are assemblages of individuals who each have disparate and sometimes opposing goals. The systems approach may be a vehicle through which to integrate the concept of adaptability in reconciling the internal pressures with the external tensions mandated by my above stated premise. Briefly, both individual and organization seek to increase their range of functional influence to reach desired goals, set future goals, and expand the horizon of future feasible goals. Each employs adaptive strategies to reconcile possible goal paths with imposed constraints. The critical role of macro-ergonomics is in harmonizing individual and organizational goals, by generating a functional synchronization between each, so that composite task and goal solution paths can be readily recognized and pursued as dynamic constraints act to continually change both personal and organizational solution spaces.

Vast efforts in all societies are given over to the pursuit of greater and greater technological capability. By comparison, efforts to harmonize and integrate such advances with existing human capabilities are virtually non-existent. Micro-ergonomic manipulations facilitate individual interaction with particular machine systems and hence, at one level, act to ease local dysfunction. However, it is clear that such changes are, in and of themselves, insufficient and potentially impotent with respect to organizations. Our failures are marked by the increasingly spectacular breakdown of systems of larger scale and energy. Yet we have already constructed systems that cannot be shut down and systems that must not fail. Our inability to recognize these progressive symptoms may be reprehensible, but our failure to act upon them will certainly prove fatal. Hence, human factors in all its forms is not merely a cosmetic appendage to system design and operation, nor is it an advertising or marketing ploy to boost sales and acceptability. It is the decisive factor in our future ability to explore our environment and one key to collective survival.

The Problem of Representation

I have identified a number of problems. One of the more important, but least tractable is the question of representation. Essentially, the question of representation is a "how" question. How can any entity hold, in a finite storage space, information about potentially infinite combinations of instantaneous conditions and combine these with all previously stored information and expectation about future conditions? Further recognition that the storage medium itself is in a constant state of flux has proved an additional stumbling block for theoreticians. However, concerning human capabilities we have two important clues. Representation is necessary for successful behavior, and complete representation is probably beyond any limited entity. But we are both limited and successful entities, and therefore, there is a solution to the problem.

Theoretical answers to this question range from the postulation of a large storage size, or economies based on storage (e.g., plans, scripts, schemae), to more recently, postulation of a degree of information intrinsic to the environmental display. In this respect, science itself is the search for pattern in chaos and "the distinction of the possible from the actual." As suggested above, recent ecological approaches to human perception seek to reduce the dependency on internal representation and computation by fixing not simply order, but information as an environmental property.

In construction of displays for a remote sensing system, like air-traffic control, the design criteria have emanated from historical analog representations, emerging mainly from the industrial revolution, which are backed by the transformational basis of early experimental psychology and more recently the information processing paradigm. Early human factors research focused on issues such as compatibility in controls and displays, anchoring effects, and scale effects, each of which amended but never questioned the basic fundamental design. More recent displays use such contemporary technology as electronic representation but still persist largely with alpha-numeric coding for information content.

It was originally conceived that the process of sensing itself, particularly for vision, was one of information assemblage, based principally on the transformation of physical energy. Little wonder that displays founded on such a principle simply extended the concept of synthesis and expected the observer to perform the correct interpretation of the physical signals provided. However, the introduction of transformation, and particularly the use of metaphor, allows progressively greater interpretational latitude. This increase in latitude is benign in some realms such as art, where the artist may actually seek such breadth. However, in more veridical pursuits such as air-traffic control, displays are meant to represent a single unambiguous status, and thus increased latitude only increases potential misinterpretation.

In perception at humanscale, interpretation is largely unambiguous. Although we may be deceived by visual illusions, they are largely synthetic and rarely occur in our "natural" visual world. Partly as a result of this effect, the new thrust toward an "ecological" psychology refers to this effect as "direct perception." The comparative approach in human factors is the notion of direct displays. These are not simply displays that rely more on visual icons, and the desktop metaphor, as developed in the Apple® Macintosh™ interface. Rather, it is a move toward the application of ecological principles to systems in general. However, this is a global specification and does not indicate exactly how such displays might be constructed (Flach, 1989).

The Problem of Intention

If representation is a "how" question, then intention is a "why" question. What are the basic goals toward which action is directed. In reality, the question of intention or motivation for action is constrained by what can be conceived and, by inference, is an extension of what is perceived. However, due in part to reference to cause and effect, the notion of intention is often considered to precede actions.

Intrinsic to an argument of intention is the notion of control, "the acceptance of responsibility for the process and the product which results from intended actions." While we have substituted mechanical sources of energy for our own muscular efforts, and have gained in efficiency proportionally, the human has to date been the primary source of intentionality. Typically, automation is perceived as a substitute for the human in the process, but the prime source of control for intention, and the evaluation of product, is still thought to reside in the human observer.

Unfortunately, in numerous complex operations, particularly those without clear deterministic goals, the notion of intention is as much linked with process as with product. The worry of automation is then two-fold. First and foremost, it disenfranchises the human operator. Second, it becomes problematic as to whether the human can regain direct control of the operation of any system which has turned toward automation as an answer to demand.

While Hopkin (1991) examines ranges of these options, typically several such options become progressively infeasible in real-world operations. Removal of control brings numerous problems. First, lack of autonomy, "going along for the ride" as pilots put it, is a high source of stress. Indeed, the combination of low control and high demand is the most destructive working condition for the human operator (Hancock & Warm, 1989). Also, removal of control without removal of responsibility is both a dangerous and unfair eventuality. With progressive automation, not only do operators begin to lose skills, after some automated design iterations under automation, their skills become obsolete anyway.

Hence, we stand at a point of major decision. The original intention is the safe and efficient passage of aircraft in an air space. That is the predetermined goal of the system. The individual operator is then instrumental in achieving that aim, but does not alter the fundamental intentionality of the system.

Why then is there a problem in full automation? We still retain a fundamental distrust in automation. Although in suspecting that breakdown is still possible, we do need to consider that humans also breakdown and fail. The extension of this concern is what happens to subsume automated functions when they fail. The redundant belief is that humans can recover such failures. From a different perspective, it should be noted that we still underestimate the complexity and capability of human operators, particularly in solving non-algorithmic problems. However, what we have failed to do effectively is to place these unique resources in their most beneficial circumstance in a systems sense. The overemphasis on speed of response has appeared to make humans redundant before their time. What has not been examined in sufficient detail are the intrinsic rewards of work in a complex environment, and how to integrate such rewards into system function.

In aircraft control, the problem of chronic underload and uncontrolled oscillations in load is one that is assuming increasing importance. Perhaps the ultimate example of underload comes from the now classic work of Norman Mackworth on vigilance. Having observed subjects who had scored a series of target "misses," Mackworth entered the experimental environment only to find the subjects asleep. Mackworth is rightly credited with the discovery of many of the central factors in vigilance and sustained attention, but it is this apparently mundane finding that he failed to emphasize as the key characteristic of vigilance. No other task combines the elements of boredom and demand in such a manner as to tax the exposed performer (Hancock & Warm, 1989). With little extrinsic or intrinsic motivation, there is little surprise that one appropriate strategy in such conditions is sleep. (Parenthetically, Mackworth's subjects held Naval ratings and risked punitive action for their failure to comply, which is indicative of how seductive sleep is in such conditions. We might speculate on the number of aircraft lost when all flight deck personnel were asleep on a long haul, early in the morning, following extra duties all-round.)

The central point is that the inability to integrate an understanding of such human characteristics is clearly punished at some point in time. Perhaps the basic faculty of any individual is self-determined intention. In the name of efficiency, we have removed this capacity from the operator, and for the sake of efficiency have given them displays that remove them from direct experience of the objects they are required to control. This is a recipe for disaster.

Systems and Goals

From a theoretical perspective, the only essential goal of a system is self-perpetuation. However, for the purposes of the present argument I shall deal with a subset of this generality and frame my discussion around current and near future goals.

Goals may be defined as desired future states of the system. The way in which system goals can be achieved is critically dependent upon the structure of that system. An example can be seen in strategies to control complex systems such as aircraft themselves. Two general strategies are rule-based and knowledge-based response. In rule-based response, look-up tables describe the scenario and appropriate responses are recommended. This approach works well when routine demands occur. However, under novel, and particularly emergency situations, such preset responses are not contained in the series of rules, and potential disaster can occur. In essence, not all states of a complex interactive system can be specified before operation. Knowledge-based action requires operators to "know" the system they are controlling. The expectation is of superior performance in situations for which rules are unavailable, such as unforeseen emergencies.

The increasing size and rapidity of complex systems presents constant challenges for each strategy. The supposed answer lies in the process of automation. Many of the specifics of automation of air-traffic control have been identified by Hopkin (1991), who examines the broad sweep of potential forms of interaction.

Increasing flexibility of systems make them more adaptive to uncertainties but may make them somewhat less efficient under steady state operation. Of course, the aim of design is to produce both flexible and efficient systems.

Rigid structures, such as a strict hierarchy, contain clear advantages and limitations. Among the advantages is speed of response to repetitive deterministic input which requires stereotypical output. The principal limitation is the reliance on the single source of command for setting goals and ordering the activity of subsidiary components. In *The Art of War*, Sun Tzu, pointed out the importance of neutralizing an opposing general, as without orders from the single commander, a rigid hierarchy is essentially powerless to respond. This failure is compounded because in a strict hierarchy there is a unidirectional flow of information from the top down throughout the hierarchy.

This particular weakness is counteracted in a heterarchical organization by designing information flow which is purposely bi-directional, in that both top-down and bottom-up flow becomes possible. As the flow of information becomes less constrained, response becomes less stereotypical and the number of potential paths that can be generated toward a goal state proliferate. The trade-off between flexibility of response and the rapidity of reaction is one that recurs throughout the present argument concerning the application of automation to air traffic control.

A third mode of organization, the holarchy, has the character that any node of the system may assume command, depending upon the nature of the momentary task demands. For those familiar with theories on brain organization, it is clear that these various forms have been sequentially proposed as the manner in which perception-action systems are controlled. Amendments to structure may divide such a framework into a collection of such holarchies where specific demands are met by flexible action.

Again the problem of temporal integration resurfaces, as it does, for example, in the operation of current generation parallel processing (connection) machines. Solutions to the problem of conscious, sentient action have been proposed, based upon this integration of response from essentially unconscious component elements (Minsky, 1985). A consequence is the hope of conscious action from multi-processor machines. As a parenthetical note, we should recognize that the degrees of explanatory freedom expand with each of these sequential conceptions, and so the potential to explain resultant outcomes increases. The elegance of each theoretical construct is thereby weakened. Only careful examination and imposition of constraints can divide the actual from the possible in such conceptualizations.

Potential and Probable Solutions

The potential solutions to the numerous questions raised in the above brief examinations of a number of issues are as wide as imagination can make them. However, the probable solutions are far more constrained. For example, probable solutions must be framed in terms of an evolution of the present system (a particularly pertinent constraint). Further, probable solutions must be cost effective, and again the practical motivation of cost will dominate concern when compared to human issues such as operator contribution and satisfaction, although it is clear that the latter elements are critical to the operation of a safe and efficient system.

Despite the range of solutions identified by Hopkin (1991), two radical forms of solution suggest themselves. First, fly less. The demand is driven by an ever increasing need for air transportation. Yet we are clearly aware of the global effect of ever increasing demand for technology in a ecosystem of limited resources (Moray, 1990). Perhaps, with superior methods of electronic communication, international and national travel for business can be curtailed. Second, alternative routing for freight traffic to less crowded locations could restrict the need for ever more technology in air traffic control.

Such questions are directed right to the heart of what is expected out of life. However, it is an alternative that must receive serious consideration. The method of interaction that I have advocated in previous works (Hancock & Chignell, 1987; Hancock & Chignell, 1988), is one that seeks mutually adaptive capabilities, mediated principally through intelligent interfaces (Chignell & Hancock, 1988; Hancock & Chignell, 1988). The principles governing such mutual adaptation and their instantiation are contained in the referenced material.

Summary and Reprise

Air traffic control, like many other process control sequences, is the subject at the physical level of convergent evolution. With prototypical workstations emerging and interfaces based on metaphor, such as the desktop, becoming so common, it becomes progressively more difficult to distinguish between the work stations of a nuclear power plant operator, a secretary, and an air traffic controller. Unfortunately, these forms of work environment have begun to become as sterile as the production lines of early manufacturing. The difference, however, is that prolonged repetitive actions were manifest and clearly designed to be "mindless" on behalf of the worker. Today, we couch such interfaces with high technology and use terms such as "decision-aiding" to cover the progressive divorce of the operator from the work. But more insidiously, we have taken not only physical action but self-determination from tasks in which operators have traditionally prided themselves on their work skills. Added to this is the complexity of remote representation and the intrinsic use of metaphor, so that the next generation of work stations will become not only harder to distinguish from each other, but harder to distinguish from popular video games.

As automation increases, operator workload profile begins to emphasize periods of prolonged underload into which are injected transients of untenable overload. Perhaps, if individual loading is seen as a major criterion, air traffic flow might be assigned as a pilot problem. Or, if we must have ground-based operations, we might look forward to air traffic controllers working as operators of remotely piloted vehicles. Each of these eventualities seems only a distant possibiliy. However, as with many contemporary process control operations being forced to face similar increases in demands, the response of gentle progress as usual is insufficient. As noted in *Time*, July 18, 1988:

> The central question is whether technology may be pushing the fallible humans who operate it beyond their ability to make wise judgments instantly on the basis of what, with even the most sophisticated systems, will often be ambiguous information.

Our purpose is to answer this question, and a global appeal to greater automation will not serve.

Addendum

In the course of the Institute many fundamental assumptions were purposely examined and assessed in the light of the changes that automation might make. One principle that received little attention was the question of object (aircraft) density. The assumption being that a progessive increase in density leads in some systematic fashion to an increased probablity of collision. This is essentially a thermodynamic statement in which object collisions increase with object velocity, where the later can be directly equated with density. However, in air traffic control we have more than Maxwell's demon, that is a sentient controller of objects. We also have intentionality and control within the objects thenselves. In automobile traffic there is no individualized dynamic controller (there is general control such as traffic bulletins) and yet even with rudimentary user rules and almost no exclusion from driving for most individuals (at least in the United States) remarkably few accidents occur (on a *relative* scale) for the density of traffic present. Thus, one critical research question is the role of human and machine intentionality in the process of "sky-packing" or progressive increase in aircraft numbers in limited air-space. Althought I have tried on a global basis to address this issue in the present work, I believe the fundamental assumption unnderlying "sky-packing" is a topic worthy of much greater investigation.

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