Decomposing Automation: Apparent Simplicity, Real Complexity

David D. Woods
Cognitive Systems Engineering Laboratory
The Ohio State University

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Introduction

We usually focus on the perceived benefits of new automated or computerized devices. Our fascination with the possibilities afforded by technology in general often obscures the fact that new computerized and automated devices also create new burdens and complexities for the individuals and teams of practitioners responsible for operating, troubleshooting, and managing high-consequence systems. First, the demands may involve new or changed tasks such as device setup and initialization, configuration control, or operating sequences. Second, cognitive demands change as well, creating new interface management tasks, new attentional demands, the need to track automated device state and performance, new communication or coordination tasks, and new knowledge requirements. Third, the role of people in the system changes as new technology is introduced. Practitioners may function more as supervisory controllers, monitoring and instructing lower order automated systems. New forms of cooperation and coordination emerge when automated systems are capable of independent action. Fourth, new technology links together different parts that were formerly less connected. As more data flows into some parts of a systems, the result is often data overload. Coupling a more extensive system more tightly together can produce new patterns of system failure. As technology change occurs we must not forget that the price of new benefits is often a significant increase in operational complexity. Fifth, the reverberations of technology change, especially the new burdens and complexities, are often underappreciated by the advocates of technology change. But their consequences determine when, where and how technology change will succeed.

My colleagues and I have been studying the impact of technology change on practitioners -- those people who do cognitive work to monitor, diagnosis and manage complex systems -- pilots, anesthesiologists, process plant operators, space flight controllers (e.g., Woods, Johanessen, Cook and Sarter, in press). In these investigations we have seen that technology change produces a complex set of effects. In other words, automation is a wrapped package -- a package that consists of changes on many different dimensions bundled together as a hardware/software system. When new automated systems are introduced into a field of practice, change is precipitated along multiple dimensions. In this paper I will examine the reverberations technology change produces along several different dimensions.

- Automation seen as more autonomous machine agents. Introducing automated and intelligent agents into a larger system in effect is a change in the team composition. It changes how human supervisors coordinate their activities with those of the machine agents. Miscommunications and poor feedback about the activities of automated subsystems have been part of accident scenarios in highly automated domains.

- Automation seen as an increase in flexibility. As system developers, we can provide users with high degrees of flexibility through multiple options and modes. We also have the ability to place multiple virtual devices on one physical platform so that a single device will be used in many contexts which can differ substantially. But do these flexibilities create new burdens on practitioners, burdens that can lead to predictable forms of error?

- Automation seen as more computerization. Technology change often means that people shift to multi-function computer-based interfaces as the means for acquiring information and utilizing new resources. Poor design of the computer interface can force users to devote cognitive resources to the interface itself (where is the data I want? what does the interface allow me to do? how do I navigate to that display? what set of instructions will get the computer to understand my intention?). Successful computer interfaces (e.g., visualization, direct manipulation) help users focus on their task without cognitive resources (attention, knowledge, workload) being devoted to the interface per se.

- Automation seen as an increase in coupling across diverse parts and agents of a system. Tighter coupling between parts propagates effects throughout the system more rapidly. This can produce efficiency benefits by reducing transfer costs, but it also means that problems have greater and more complex effects, effects that can propagate quickly. But when automated partners are strong, silent, clumsy and difficult to direct, then handling these demands becomes more difficult. The result is coordination failures and new forms of system failure.

Much technology change is justified, at least in part, based on claims about the impact of technology on human performance -- the new system will “reduce workload, help practitioners focus on the important part of the job, decrease errors, etc." But these claims often go unexamined. Studies of the impact of automation on the cognition and behavior of human practitioners have shown repeatedly that systems introduced to aid practitioners in fact created new complexities and new types of error traps.

The success of new technology depends on how it affects the people in the field of practice. The above dimensions represent some of the ways that technology change can have surprising impacts on human and system performance. By closely examining the reverberations of technology change we can better steer the possibilities of new technology into fruitful directions.

How To Make Automated Systems Team Players

Heuristic and algorithmic technologies expand the range of subtasks and cognitive activities that can be automated. Automated resources can in principle offload practitioner tasks. Computerized systems can be developed that assess or diagnose the situation at hand, alerting practitioners to various concerns and advising practitioners on possible responses.

Our image of these new machine capabilities is that of a machine alone rapt in thought and action. But the reality is that automated subtasks exist in a larger context of interconnected tasks and multiple actors. Introducing automated and intelligent agents into a larger system changes the composition of the distributed system of monitors and managers and shifts the human's role within that cooperative ensemble (Hutchins, in press). In effect, these 'intelligent' machines create joint cognitive systems that distribute cognitive work across multiple agents (Roth, Bennett and Woods, 1987; Hutchins, 1990). It seems paradoxical but studies of the impact of automation reveal that design of automated systems is really the design of a new human-machine cooperative system. The design of automated systems is really the design of a team and requires provisions for the coordination between machine agents and human practitioners (e.g., Layton et al., 1994).

However, research on human interaction with automation in many domains including aviation and anesthesiology has shown that automated systems often fail to function as team players (Billings, 1991; Malin et al., 1991; Sarter and Woods, 1994b). To summarize the data, automated systems that are strong, silent, clumsy, and difficult to direct are not team players. Automated systems are:

(a) *strong* when they can act autonomously;
(b) *silent* when they provide poor feedback about their activities and intentions,
(c) *clumsy* when they interrupt their human partners during high workload, high criticality periods or add new mental burdens during these high tempo periods , and

(d) *difficult to direct* when it is costly for the human supervisor to instruct the automation about how to change as circumstances change.

Systems with these characteristics create new problems for their human partners and new forms of system failure.

"Strong" automation refers to two properties of machine agents. In simpler devices, each system activity was dependent upon immediate operator input. As the power of automated systems increases, machine agents, once they are instructed and activated, are capable of carrying out long sequences of tasks without further user interventions. In other words, automated systems can differ in degree of autonomy (Woods, 1993). Automated systems also can differ in degree of authority. This means that the automated system is capable of taking over control of the monitored process from another agent, if it decides that intervention is warranted based on its perception of the situation and its internal criteria (Sarter and Woods, 1994a).

Increasing autonomy and authority create new monitoring and coordination demands for humans in the system (Wiener, 1989; Norman, 1990; Sarter and Woods, 1995). Human supervisors have to keep track of the status and activities of their automated partners. For example, consider the diagnostic situation in a multi-agent environment, when one notices an anomaly in the process they monitor (Woods, 1994). Is the anomaly an indication of an underlying fault, or does the anomaly indicate some activity by another agent in the system, unexpected by this monitor? In fact, in a number of different settings, we observe human practitioners respond to anomalies by first checking for what other agents have been or are doing to the process jointly managed (Johannesen et al., 1994).

When machine agents have high autonomy, they will act in the absence of immediate user input. Human practitioners have to anticipate how the automated system will behave as circumstances change. Depending on the complexity of the system and the feedback about system activities, this may be difficult. As one commentator has put it, the most common questions people ask about their automated partners are: "what is it doing? why is it doing that? what will it do next? how in the world did we get into that mode?" (Wiener, 1989). These questions are indications of coordination break downs -- what has been termed "automation surprises." Automation surprises are situations where automated systems act in some way outside of the expectations of their human supervisors. Data from studies of these surprises in aviation and medicine (Norman, 1990; Sarter and Woods, 1994b; Moll van Charante et al., 1993) indicate that poor feedback about the activities of automated systems to their human partners is an important contributor to these problems.

Autonomy and authority are properties that convey an agent-like status on the system from the point of view of human observers. This raises an important point. Automated systems have two kinds of interpretations. Based on knowledge of underlying mechanisms, an automated system is deterministic and predictable. However, those who monitor or interact with the system in context may perceive the system very differently. For example, with the benefit of knowledge of outcome and no time pressure, one can retrospectively show how a system's behavior was deterministic. But as system complexity increases, and depending on the feedback mechanisms available, predicting the system's behavior in context may be much more difficult.

A user's perception of the device depends on an interaction between its capabilities and the feedback mechanisms that influence what is observable about system behavior in relation to events in the environment. What feedback is available depends upon the "image" the device presents to users (Norman, 1988). When a device is complex, has high autonomy and authority, and provides weak feedback about its activities (what has been termed low observability), it can create the image of an animate agent capable of independent perception and willful action. We will refer to this as the perceived animacy of the automated system. In effect, the system, though determinate from one perspective, seems to behave as if it were an animate agent capable of activities independent of the operator (Sarter and Woods, 1994a).

Flightdeck automation on commercial transport jets illustrates how autonomy combined with low observability can create the perception of animacy (Sarter and Woods, 1994b, 1995). Pilots sometimes experience difficulties with tracking system behavior in situations that involve indirect mode transitions. In these situations, the system changes its behavior independent of any immediate pilot instructions. The system acts in response to reaching a preset target (e.g., leveling off at a target altitude) or because an envelope protection threshold is crossed. In other words, based on the programmed mechanisms, the system "realizes" the need for a mode change and carries it out without requesting pilot consent and provides only weak feedback about the change or the implications of the change for future aircraft behavior. It is in this type of situation that pilots are known to ask questions such as: "What is it doing?" "Why did it do this?" or "What will it do next?" (Wiener, 1989). These are questions one asks about another agent with an agenda of its own and one that does not communicate very well to the pilot.

Much work in this area has noted that poor feedback on system status and behavior is at the heart of automation surprises. But what does it mean to say poor feedback? When we take a close look at the data provided to the operators of many advanced systems, it becomes quite clear that the amount of data available to the human is increasing. All of the necessary data to build a picture of their automated partner's activities is present in general. But the effectiveness of this data depends on the cognitive work needed to turn it into a coherent interpretation in context.

Effective feedback depends on more than display formats; it is a relation between the system's function, the image the system presents to outsiders, and the observer embedded in an evolving context (Woods, in press). As a result, it is better to refer to interface and feedback issues in terms of observability. This term captures the fundamental relationship between thing observed, observer and context of observation that is fundamental to effective feedback. Observability depends on the cognitive work needed to extract meaning from the data available. We, as researchers, need to make progress on better ways to measure this property of cognitive systems.

Since automated system are deterministic, if one has complete knowledge of how the system works, complete recall of the past instructions given to the system, total awareness of environmental conditions, then one can project accurately the behavior of their automated partner. However, as the system becomes more complex projecting its behavior also becomes more cognitively challenging. One has to have an accurate model of how the system works; one has to call to mind the portions of this knowledge that are relevant for the current situation; one has to recall past instructions which may have occurred some time ago and may have been provided by someone else; one has to be aware of the current and projected state of various parameters that are inputs to the automation; one has to monitor the activities of the automated system; and one has to integrate all of this information and knowledge together in order to project how the automation will behave in the future. As a result, an automated system can look very different from the perspective of a user in context as compared to an analyst taking a birds eye view with knowledge of outcome. The latter will see how the system's behavior was a direct and natural result of previous instructions and current state; the former will see a system that appears to do surprising things on its own. This is the paradox of the perceived animacy of automated systems that have high autonomy and authority but low observability (Figure 1). This situation has strong implications for error analysis and incident reconstruction (Woods et al., in press).

The trend in automation seems to be for greater increases in system autonomy and authority while feedback mechanisms are stagnant at best. The result appears to be that "strong and silent" automation is on the increase (Norman, 1990). Yet the research to date has revealed that there are latent dangers of powerful yet silent automation (e.g., Cook et al., 1992).

Designing automated systems is more than getting that machine to function autonomously. It is also making provisions for that automated agent to coordinate its activity with other agents. Or, perhaps more realistically, it is making provisions so that other human agents can see the assessments and activity of the automated agent so that these human practitioners can perform the coordination function by managing a set of partially autonomous subordinate agents (see Billings, 1991; Woods et al., in press).

Flexibility: Burdensome or Instrumental?

Flexibility and customizability are central to the perceived advantages of the growth in technological powers (Woods, 1993). New automated systems are often flexible in the sense that they provide a large number of functions and options for carrying out a given task under different circumstances. For example, the computers on commercial jet flightdecks provide at least five different mechanisms at different levels of automation for changing altitude. This customizability is construed normally as a benefit that allows practitioners to select the mode or option best suited to a particular situation. However, it also creates a variety of new demands.

To utilize highly flexible systems, the practitioner must learn about all of the available options, learn and remember how to deploy them across the variety of real operational contexts that can occur, and learn and remember the interface manipulations required to invoke different modes or features. Monitoring and attentional demands are also created as practitioners must keep track of which mode is active. All of this represents new burdens on the practitioner to set up and manage these capabilities and features.

If the new tasks and workload created by such flexible systems tend to congregate at high workload, high criticality periods, the result is a syndrome called clumsy automation by Earl Wiener (see Wiener, 1989). Clumsy automation is a form of poor coordination between the human and machine in the control of dynamic processes where the benefits of the new technology accrue during workload troughs and the costs or burdens imposed by the technology (i.e., additional tasks, new knowledge, forcing the user to adopt new cognitive strategies, new communication burdens, new attentional demands) occur during periods of peak workload, high criticality or high tempo operations (Cook and Woods, 1994; Sarter and Woods, 1994b). Significantly, deficits like this can create opportunities for new kinds of human error and new paths to system breakdown that did not exist in simpler systems (Woods, Johannesen, Cook and Sarter, in press).

The result is that we need to understand the difference between two types of flexibility in cognitive artifacts: (a) flexibilities that serve to increase practitioners' range of adaptive response to the variability resident in the field of activity and (b) flexibilities that simply create new burdens on practitioners, especially at high tempo or high criticality periods (Woods, 1993).

Properties of the Computer Shape Practitioner Cognition and Behavior

Today technological change is transforming the workplace through the introduction and spread of new computer-based systems. Thus, automation can be seen in part as computerization. But there are a variety of properties of the computer as a medium that shape practitioner cognition and behavior in predictable but problematic ways.

Computer based information technology allows designers to combine multiple features, options, and functions onto a single physical platform. The same physical device can be designed to operate in many different contexts, niches, and markets simply by taking the union of all the features, options, and functions that are needed in any of these settings. In a sense, the computer medium allows one to create multiple virtual devices concatenated onto a single physical device. After all, the computer medium is multi-function—software can make the same keys do different things in different combinations or modes, or provide soft keys, or add new options to a menu structure; the CRT or other visual display unit (VDU) allows one to add new displays which can be selected if needed to appear on the same physical viewport.

But to do this pushes the designer to proliferate modes and thereby create the potential for mode errors, to proliferate displays hidden behind the narrow viewport and create navigation problems, to assign multiple functions to controls so that users must remember complex and arbitrary sequences of operation. In other words, the modularity of the computer medium helps designers follow Don Norman's (1988) tongue-in-cheek advice on how to do things <u>wrong</u> in designing computer-based devices. Such systems appear on the surface to be simple because they lack large numbers of physical display devices and controls; however underneath the placid surface of the CRT workstation a variety of clumsy features may exist which produce operational complexities.

Computerization also has tremendously advanced our ability to collect, transmit and transform data. In all areas of human endeavor, we are bombarded with computer-processed data. But our ability to digest and interpret data has failed to keep pace with our abilities to generate and manipulate greater and greater amounts of data. Thus, we are plagued by data overload. User interface technology has allowed us to concentrate this expanding field of data into one physical platform, typically a single visual display unit (VDU). Users are provided with increased degrees of flexibility for data handling and presentation in the computer interface through window management and different ways to display data. The technology provides the capability to generate tremendous networks of computer displays as a kind of virtual perceptual field viewable through the narrow aperture of the VDU. These changes effect the cognitive demands and processes associated with extracting meaning from large fields of data (Woods, in press).

We have demonstrated in several studies how characteristics of computer-based devices influence cognition and behavior in ways that increase the potential for erroneous actions and assessments. In one case (Cook and Woods, 1994), a new operating room patient monitoring system was studied in the context of cardiac anesthesia. This and other similar systems integrate what was previously a set of individual devices, each of which displayed and controlled a single sensor system, into a single CRT display with multiple windows and a large space of menu-based options for maneuvering in the space of possible displays, options, and special features. The study consisted of observing how the physicians learned to use the new technology as it entered the workplace.

By integrating a diverse set of data and patient monitoring functions into one computer-based information system, designers could offer users a great deal of customizability and options for the display of data. Several different windows could be called depending on how the users preferred to see the data. However, these flexibilities all created the need for the physician to interact with the information system—the physicians had to direct attention to the display and menu system and recall knowledge about that system. Furthermore, the computer keyhole created new interface management tasks by forcing serial access to highly inter-related data and by creating the need to periodically declutter displays to avoid obscuring data channels that should be monitored for possible new events.

The problem occurs because of a fundamental relationship: the greater the trouble in the underlying system or the higher the tempo of operations, the greater the information processing activities required to cope with the trouble or pace of activities (Woods et al., in press). For example, demands for monitoring, attentional control, information, and communication among team members (including human-machine communication) all tend to go up with the tempo and criticality of operations. This means that the burden of interacting with the display system tends to be concentrated at the very times when the practitioner can least afford new tasks, new memory demands, or diversions of his or her attention away from patient state to the interface per se.

The physicians tailored both the system and their own cognitive strategies to cope with this bottleneck. In particular, they were observed to constrain the display of data into a fixed spatially dedicated default organization rather than exploit device flexibility. They forced scheduling of device interaction to low criticality self-paced periods to try to minimize any need for interaction at high workload periods. They developed stereotypical routines to avoid getting lost in the network of display possibilities and complex menu structures.

These are all standard tactics people use to cope with complexities created by the clumsy use of computer technology (Woods et al., in press). We have observed that pilots, space flight controllers as well as physicians cope with new burdens associated with clumsy technology by learning only a subset of stereotypical methods, underutilizing system functionality. We have observed these practitioners convert interface flexibility into fixed, spatially dedicated displays to avoid interacting with the interface system during busy periods. We have observed these practitioners escape from flexible but complex modes of automation and switch to less automated, more direct means of accomplishing their tasks when the pace of operations increases. This adaptation or tailoring process occurs because practitioners are responsible not just for the device operation, but also for the larger performance goals of the overall system. As a result, practitioners tailor their activities to insulate the larger system from device deficiencies (Cook and Woods, 1994; Woods et al., in press).

Highly Coupled Systems Breakdown in New Ways

The scale of and degree of coupling within complex systems creates a different pattern for disaster where incidents develop or evolve through a conjunction of several small failures, both machine and human (Perrow, 1984; Reason, 1990). There are multiple contributors; all are necessary, but they are individually insufficient to produce a disaster. Some of the multiple contributors are latent, that is, conditions in a system that produce a negative effect but whose consequences are not revealed or activated until some other enabling condition is met. This pattern of breakdown is unique to highly coupled systems and has been labeled the latent failure model of complex system breakdown (Reason, 1990).

Computerization and automation couple more closely together different parts of the system. Increasing the coupling within a system has many effects on the kinds of cognitive demands to be met by the operational system. And increasing the coupling within a system changes the kinds of system failures one expects to see (Perrow, 1984; Reason, 1990). The latent failure model for disaster is derived from data on failures in highly coupled systems.

Automation and computerization increase the degree of coupling among parts of a system. Some of this coupling is direct; some is based on potential failures of the automation; and some is based on the effects of automation on the cognitive activities of the practitioners responsible for managing the system. For example, higher coupling produces more side effects to failures. A failure is more likely to produce a cascade of disturbances that spreads throughout the monitored process. Symptoms of faults may appear in what seem to be unrelated parts of the process (effects at a distance). These and other effects can make fault management and diagnosis much more complicated.

Highly coupled processes create or exacerbate a variety of demands on cognitive functions (Woods, 1988). For example, increased coupling creates:

- new knowledge demands, e.g., knowing how different parts of the system interact physically or functionally;
- new attentional demands, e.g., deciding whether or not to interrupt ongoing activities and lines of reasoning as new signals occur;
- more opportunities for situations to arise with conflicts between different goals. New strategic tradeoffs can arise as well. Creating or exacerbating conflicts and dilemmas produces new forms of system breakdown (see Woods et al., in press).

Automation may occur in the service of stretching capacity limits within a system. But these efficiency pressures may very well create or exacerbate double binds that practitioners must face and resolve. These pressures may also reduce margins, especially by reducing the error tolerance of the system and practitioners' ability to recover from error and failures. Characteristics such as error tolerance and the degree of observability through the computer interface can change the ability of practitioners to buffer the system in the face of contingencies and complications (Woods et al., in press).

Technology change often facilitates greater participation by formerly remote individuals. People, who represent different but interacting goals and constraints, now can interact more directly in the decision making process. Coordination across these diverse people and representatives and cooperation among their interacting interests must be supported.

Overall, changes in automation, through increased coupling, make systems more vulnerable to the latent failure type of system breakdown where multiple contributors come together in surprising ways (see also Hollnagel, 1993; Woods et al., in press). Thus, increases in level of automation can change the kinds of incidents, their frequency and their consequences in ways that can be very difficult to foresee. Interestingly, the signature of failure in tightly coupled systems is often misperceived and labeled as simply another case of 'human error.'

Technology Change Transforms Operational And Cognitive Systems

These effects of technology change run counter to conventional wisdom about automation. There are two broad themes that run throughout the above discussion.

First, changes in level of automation <u>transform</u> systems. Technology change is an intervention into an ongoing field of activity (Winograd and Flores, 1987; Flores et al., 1988). When developing and introducing new technology one should realize that technology change represents new ways of doing things; it does not preserve the old ways with the simple substitution of one medium for another (e.g., paper for computer-based; hardwired for digital; automatic for manual).

Marketing forces tout the universal benefits of all types of new technology without reservations. However, the difference between skillful and clumsy use of technological powers lies in understanding how automation can transform systems. For example, where and when does it create new burdens? How does the keyhole property of the computer shape practitioner cognition in ways that reduce error and failure recovery? What are the new patterns of system breakdown? What is the new cooperative or joint human-machine system created by more automation? How does this cooperative system function when complicating factors arise at and beyond the margins of normal routines?

Understanding the potential transformations allows one to identify and treat the many post-conditions necessary for skillful use of technological possibilities. To do this one must unwrap the automation package. In doing so we must come to recognize that new technology is more than object in itself. When we design new automated and computerized systems we are concerned with more than just a hardware and software object. We are also designing:

- a dynamic visualization of what is happening and what may happen next that provides practitioners with feedback about success and failure, about activities and their effects;
- a tool that helps practitioners respond adaptively to the many different circumstances and problems that can arise in their field of activity
- a team of people and machine agents that can coordinate their assessments and activities as a situation escalates in tempo, difficulty and criticality.

Apparent Simplicity, Real Complexity

Conventional wisdom about automation makes technology change seem simple. Automation is just changing out one agent (a human) for another. Automation provides more options and methods. Automation frees up people for other more important jobs. Automation provides new computer graphics and interfaces. However, the reality of technology change as revealed through close examination of device use in context, is that technological possibilities often are used clumsily resulting in strong, silent, difficult to direct systems that are not team players.

The discussion of how technology change transforms systems points out the irony present in conventional claims about the effects of automation and technology change. The very characteristics of computer-based devices that have been shown empirically to complicate practitioners' cognitive activities and contribute to errors and failures are generally justified and marketed on the grounds that they reduce human workload and improve human performance. Technologists assume that automation, automatically, will reduce skill requirements, reduce training needs, produce greater attention to the job, and reduce errors.

New technology can be used skillfully to increase skilled practice and to produce more reliable human-machine systems, but not through wishful thinking or superficial claims about the impact of new technology on human-machine systems. Understanding or predicting the effects of technology change requires close examination of the cognitive factors at work in the operational system. Studying and modeling joint human-machine cognitive systems in context is the basis for skillful as opposed to clumsy use of the powers of technology (Woods et al., 1994).

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Figure 1. A paradox associated with perceived animacy. Automated systems that have high autonomy and authority but low observability appear to behave as if they are animate agents capable of activities independent of the operator. However, such systems are deterministic, and their behavior is predictable if one has complete and available knowledge of how the system works, complete recall of the past instructions given to the system, and total awareness of the situation and environmental conditions.

Layton, C., Smith, P. and McCoy, E.

cooperation vs autonomy; animate machines; when do we see macines as animate

include Grudin's law?? under flexibility

AT&T's Thomas street outage provides a direct example. Consequences of power management in New York city affect AT&T's telecommunications network. Given a series of factors and latent failures, the switchover to DC power fails and remains undetected until battery backups run out. But the primary consequence is on communications in the air traffic control system for the New York area resulting in a shutdown for all three airports and redirecting hundreds of flights throughout the national air transport system.

I will lay out a series of dimensions that change when an organization changes the level of automation in their operational system. These are system dimensions -- dimensions that describe the overall operational system, including the ensemble of people and computers that manage the process in question.

I will examine trends in technology change related to several factors

automation as ...

flexibility -- burdensome versus instrumental

integration/coupling

cooperation vs autonomy

transformation -- the important latent factors change

computerization -- bring in virtuality, keyhole, modularity

penalities of virtuality; mode error and awareness

precision/efficiency vs robustness

textbook cases; complicating factors

apparent simplicity, but real complexity or is it better to say -- changes in level of automation are at the same time changes in

level of integration/degree of coupling

increase/change in flexibilities

change in cooperative architecture

myths about auto:
same tasks, just trading machine for people; more precision, efficiency; same only better

despite its apparent simplicity; technology change has a complex set of effects. The results are often surprising for the organizations involved in the change in level of automation.

automation as ...

flexibility -- burdensome versus

integration/coupling

cooperation vs autonomy

transformation -- the important latent factors change

computerization -- bring in virtuality, keyhole, modularity

precision/efficiency vs robustness

apparent simplicity, but real complexity

aspects of additional complexity -- buggy models, knowledge calibration, serial access, new infor/interface management burdens

describe calibration results, describe incient where don't know how auto played a role

where does observability go? apparent simplicity

integration/coupling coupling different parts of the system; temporally, through control

different signature of disaster with highly coupled systems. with auto there is a change in the kind of incidents and their frequency and consequences. auto change the factors that lead to disaster and near disaster -- links to transformation (changing failures/errors/paths to disaster) and to coupling

auto in the service of stretching capacity limits may create or exacerbate double binds in teh system, in part by reducing redundancy, safety margin, reducing error tolerance/recoverability changes the ability of people who buffer the system in the face of contingencies and complications

change which latent factors are important

the signature of failure in tighly coupled systems is different but is often misperceived as due to human error

2 sides of procedures: economy, mindlessness versus cognitive diversity ???

perceived dread is higher for a complex causal chain; managing small problem into a bigger onne is more dreadful and more open to counterfactual re-evaluation -- one small change proximal to the outcome -- what is counterfactual reasoning? looking for one small or smallest change that reverses the outcome (Kahneman and Miller)

understnading failure is harder (see above)

technology change facilitates the greater participation by remote individuals or influence by more and more representatives of various concerns or constraints (e.g., design activities include input or constraints from representatives of more and more different perspectives on design).

coordination across agents and physical interface: eg, voice loops in mission control; CDU hides activities, non-moving throttle, see the other agent and their attitude towards their task; see they are having difficulty; silent automation or ISs, control room TSC coordination in nuclear power,

diagnostically want to check your or other agents influences acting on process when you notice an anamoly eg look at physician and what they are doing to see if manipulation of heart is responsible for blood pressure change or amount of blood in the surgical field; check the infusion devices to see if they are on or turn them off; check what automatic systems are doing eg NPP data; check the suringe you just used to see if you gave the drug that you thought that you did or the amount that you thought or the concentration that you thought

under computerization/

separation of structure and function:

complex menu spaces;

new burdens:
navigation burdens, especially finding the right data at the right time;
the risk of getting lost in the network of options or displays;

cognitive system consequences:
a focus on navigating through the interface when the interface should support practitioners' focus attention on the underlying field of activity;

coping strategies: learn and stick to stereotypical routes and options; throw away flexibility to achieve simple operation

a few keys that do many things in combination creating complex and arbitrary, from a practitioner perspective control sequences; the result -- memory burdens, and fertile ground for a variety of phenotypical action errors -- omissions, repetitions (Hollnagel, 1991) and genotypical action errors -- various slips of action, lapses (Reason and Mycielska, 1982)
See Norman 1988
coping strategies: practitioners' create their own external memory aids;

or a generic keypad that, from a practitioner point of view, makes all interactions the equivalent of programming, ie the costs of interacting with the system's capabilities go up
which is creates bottlenecks in high tempo periods

extremely complex state transition spaces, one factor leading to poor mental models

alarms that are vague and ambiguous because they must be generic; instead of using the
power of data processing and flexible display to tailor the alarm to the circumstances,

And a proliferation of extra features to please every possible user in every conceivable way.

what is cognitive coordination? what is cooperation?

cooperation/competition implies a relationship based on goals or outcomes -- shared rewards; or mutually exclusive rewards

other aspects to coodinated activity:

coordination = how elements have a function within the whole; implies a higher order system categorization and a model of how the elements function within the whole.

One example of a characteristic of a field of activity that affects the kinds of problems that arise is the degree of coupling in the monitored process (Perrow, 1984). Highly coupled processes create or exacerbate a variety of demands on cognitive functions (Woods, 1988). For example, increased coupling creates:

- new knowledge demands, e.g., knowing how different parts of the system interact physically or functionally;
- new attentional demands, e.g., deciding whether or not to interrupt ongoing activities and lines of reasoning as new signals occur;
- new strategic tradeoffs, e.g., one must balance dynamically between the need to diagnose the source of the disturbances and the simultaneous need to cope with the consequences of the disturbances for safety goals.

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thoughts on automation, Dekker, keynote

- against any hint of a technological imperative;
- against Whig histories of technology that are paens to the current state as the cumulation of history;
- not technological progress but rather technology change;
- for, a view of technology change as a transformation along multiple dimensions -- surprising in its reverberations and linked to a wide ranging infrastructure.

- it seems inevitable in hindsight; it seems uncontrollable therefore “willful”, eg the centralized word processing; the TA maintenance computer story

- surprises the decentralizing force of computers; computer succeed in proportion to their help at moving creating paper.

- the stories that we tell about how great this technology will be in various ways before deployment in a larger system of people, org, infrastructure are fables and have been wrong over and over again

Paradox:
Tech change adapts around individual, social, org, and political constraints; individual, social, org, and political systems adapt around tech constraints

Paradox:
technology change is empowering and imprisoning at the same time (CDU example?) eg WWI, eg Thomas St -- new points of vulnerability

Paradox:
systems move to the edge of the performance envelope under other pressure (e.g., efficiency); the edge may be located somewhere different than before the technology change, but it is at an edge nonetheless. eg Napoleon to WWI

tech development and use is fundamental to the human species

use following quote to illustrate what it means to control technology rather than let it control us.

Instead of confining one’s actions to what available technology can do, the point is precisely to understand what it cannot do and then to proceed to do it nevertheless.

van Creveld

To paraphrase van Creveld, 1989, p. 316,

in managing high hazard high complexity technologies “no success is possible -- or even conceivable -- which is not grounded in an ability to tolerate uncertainty, cope with it, and make use of it.”

If we try to develop automation to eliminate uncertainty and control it, then there will be leakage, but we will call it human error. Instead, we tame uncertainty by tolerating it, learning how to cope with it (studying it), and ultimately finding how to make use of it in pursuit of our goals.”