Nosocomial automation: technology-induced complexity and human performance

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2 authors:

David D Woods
The Ohio State University

Richard Cook
Adaptive Capacity Labs

Nosocomial Automation: Technology-Induced Complexity and Human Performance

David D. Woods and Richard I. Cook
Cognitive Systems Engineering Laboratory
Department of Industrial and Systems Engineering
The Ohio State University
Columbus OH 43210

Abstract-**As technological possibilities expand and threaten to radically change or replace the human role in complex high consequence task domains, various concerned groups from researchers to government regulators to designers to users have begun to debate how we should use the technological possibilities. Many have proposed that human-centered automation should be the target. In other words, technology should be used to support and expand human performance, to keep the human in-the-loop, i.e., responsible, informed and aware. But what is human-centered automation? This paper examines automation from a cost-benefit point of view revealing some of the hidden costs of "clumsy" application of technology.** [1]

> The gadget-minded people often have the illusion that a highly automatized world will make smaller claims on human ingenuity than does the present one ... This is palpably false. Norbert Wiener, 1964, p. 63

INTRODUCTION

The impact of electronic technology and related automation on human performance is controversial. Safety, precision, efficiency, and economy are all putative benefits of increasing the quantity and sophistication of technology in complex high consequence domains such as commercial aviation flightdecks, nuclear power plant control rooms, space control centers, or surgical operating rooms. Some authors have suggested that reliance on ever more complex technologies may have unanticipated effects on human performance and introduce new kinds of system faults (Perrow, 1984; Woods, 1990; Reason, 1990).

We have been studying the impact of technology on practitioner performance in the above four domains (Sarter and Woods, 1991; Roth, Bennett and Woods, 1987; Cook, Woods and Howie, 1990 and in press; Woods et al., 1991. The results, taken as a whole, have helped us to identify features of devices and interfaces which prevent humans from understanding device function and to identify features of "automation" which increase human workload at critical times, a condition called clumsy automation by Earl Wiener. Overall, technology centered automation appears to produce increments in workload and subtle decrements in practitioners' understanding of their environment. Significantly, these deficits can create opportunities for human error that would not exist in less automated systems, producing a new class of failures.

NOSOCOMIAL AUTOMATION

We have coined the term *nosocomial automation* to refer to the complexity that results from the accumulation of small increments of technology and how this accumulated complexity affects human performance. Nosocomial is used here in the same sense as in nosocomial infection in medicine. Nosocomial infections arise over time in the hospital setting because the concentration of infected patients and antibiotics change the environment to promote certain types of infection. Remarkably, antibiotics are both the cause and the cure for the condition; nosocomial infections prompt the search for more powerful antibiotics to treat the condition which in turn gives rise to new species of infection, etc.

Similarly, nosocomial automation refers to the characteristics of accumulated technology and its effect of transforming the nature of the environment. A single automated device has performance impacts which are readily borne by the practitioners without noticeable effect on outcome. Adding other individual devices, interface features, and capabilities appears to increase complexity very little but the environment is transformed gradually to one in which the overall complexity presents a barrier to successful practice under certain situations. Each individual addition seems justified when considered in isolation. However, the combined cost and impact of this increased complexity on human performance is not appreciated by the designers.

This is especially true because practitioners (commercial pilots, anesthesiologists, nuclear power operators, etc.) are responsible, not just for device operation but also for the larger system and performance goals of the overall system. Our results show that practitioner skill and adaptability is critical in moderating the effects of nosocomial automation. Practitioners tailor their activities to insulate the larger system

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from device deficiencies and peculiarties of the technology. This occurs, in part, because practitioners inevitably are held accountable for failure to correctly operate equipment, diagnose faults or respond to anomalies even if the device setup, operation, and performance are ill-suited to the demands of the environment. However, there are limits to practitioner's range of adaptability and there are costs associated with practitioners' coping strategies, especially in non-routine situations when a variety of complicating factors occur (Woods, 1990). These limits/costs represent a kind of latent failure in complex, high consequence systems (Reason, 1990) whose effects are visible only when other events and circumstances combine with the latent failure to produce critical incidents. Thus, the technology-induced complexity represented by the term nosocomial automation creates new pathways to disaster. Ironically, these types of incidents typically are labeled "human error," while the human skills required to cope with the effects of nosocomial automation are unappreciated except by the beleaguered practitioner. Paradoxically, practitioners' adaptive responses to cope with technology-induced complexity often help to hide the corrosive effects of clumsy technology from designers.

In developing new information technology and automation we often act as if the domain practitioner were a passive recipient of the resulting "operator aids," the user of what the technologist provides *for* them. However, this view overlooks the fact that the practitioner is an *adaptive* element in the person-machine ensemble, usually the critical adaptive portion (e.g., Hutchins, 1990). "The design of new technology is always an intervention into an ongoing world of activity. It alters what is already going on – the everyday practices and concerns of a community of people – and leads to a resettling into new practices ..." (Flores et al., 1988, p. 154). Practitioners adapt information technology provided for them to the immediate tasks at hand in a *locally* pragmatic way, usually in ways not anticipated by the designers of the information technology (Roth et al., 1987; Flores et al., 1988; Woods, 1988).

We have identified several types of practitioner adaptation to the impact of new information technology, that we have termed system tailoring and task tailoring (Cook et al., 1990). In system tailoring, practitioners adapt/change the surrounding context of activity (the set up of device and device configuration, how the device is situated in the larger context) in order to maintain or support or preserve a fixed or unchanging style or strategy for carrying out tasks. In task tailoring, practitioners adapt/change the way they carry out domain tasks, especially associated cognitive processing strategies, in order to accomodate the characteristics or constraints imposed by the new devices. Note these forms of tailoring are as much a group as an individual dynamic. Understanding how practitioners adaptively respond to the introduction of new technology and, especially the limits of that adaptation, is critical to understanding how new automation creates the potential for new forms of error and system breakdown.

Just as nosocomial infections are particularly difficult to eradicate, the effects of nosocomial automation are particularly difficult to remedy. The effect results from technology aggregation rather than the impact of individual components considered in isolation. Interestingly, a proposed solution for correcting this condition is the addition of another layer of technology (e.g. central 'harmonized' alarms in the operating room, artificial intelligence based "automation") which are supposed to address each manifestation of trouble in the system (e.g., treating the symptom – human error, rather than the cause – technology-induced complexity). Such uncoordinated and technology-driven changes to the system are likely to produce further increases in complexity from the point of view of practitioners. The resulting situation is not dissimilar to the production new generations of antibiotics to overcome the problems produced by their predecessors.

Even when complexity is recognized as a contributor to performance troubles, we often see design efforts focus on developing new subsystems or devices with the appearance of simplicity (integrating diverse devices into a single multifunction CRT display and interface). But systems which appear simple because they lack large numbers of physical display devices and controls will create new complexities for users when designers assign multiple functions to single controls, hide states from user view, allow automation to change system status without clearly informing users, devise complex arbitrary control sequences, impair users' ability to form accurate mental models of device function, mislead users into thinking that their models are accurate when they are in fact buggy, add new interface management tasks that shift practitioner attention away from domain tasks especially at high criticality, high tempo periods (Cook et al., in press; Sarter and Woods, 1991; Norman, 1990). When these device characteristics are combined with demands for tracking complex changes, severe time pressure, and a technologically crowded environment, the potential for practitioner coping strategies to break down is multipled and the possibility for disaster is enhanced. Avoiding these types of 'hidden' complexities is the essential remedy for combating nosocomial automation.

Hidden Costs of Clumsy Automation

From this point of view, human-centered automation is concerned with managing the operational complexity of systems. It is not about the level of technological sophistication per se (Norman, 1990). Rather it is concerned with discriminating clumsy and adept utilization of technology and with identifying the factors that lead to clumsy and adept "automation." This point of view can be described as human-centered because it is concerned with system complexity from an operational point of view – one can only see nosocomial automation by taking on the point of view of the practitioner in situ.

Note that nosocomial automation is a disease that occurs only in the presence of highly technological systems. It is a cost associated with highly technological systems that must be weighed with other costs and benefits when designing technological change. Attempts to automate portions of the practitioner's role may fail because putative improvements (e.g., in precision and accuracy) either are largely illusory or more than offset by the complexity they add to the overall system and by the cognitive demands they make on the practitioner. Designers and technologists find it difficult to adopt a cost-benefit view of automation impact. In part, this is because the benefits of technology change are local and relatively specific (e.g., fuel saving from more precise fligth path control), while the costs in terms of operational complexity are global and uncalibrated (wierd failure modes) and these costs (disasters) are seen in special circumstances, surprises, disturbed conditions given the adaptive response of the people in the system.

Nosocomial automation suggests another cost center in complex human-machine systems. For event-driven domains, one can distinguish stiff versus flexible human-machine ensembles - operational systems that can reconfigure and customize on the fly in response to new events and demands (the human-machine system at Bhoupal is an example of the former; the human-machine system in place at NASA during Apollo, especially Apollo 13, and the system that supports carrier flight operations are examples of the latter). One cost of nosocomial automation is to stiffen or limit the adaptability of an operational system due to the increased complexity. For example, people develop coping strategies that allow them to operate an overally complex device/interface for typical tasks and contexts despite a poor mental model of how the device actually functions. One common workaround strategy that we have observed in the operating room context is to adapt the on/off button as a reset switch to cope with inscrutible, distracting and too frequent audible alarms. Our studies have shown how these strategies create latent failures that can contribute to incidents when other complicating factors are present.

If people are a critical adaptive element in operational systems for high consequence domains, then, as part of a human-centered approach, we need to develop design and training for resourcefulness as well as design and training for routinization or automatization. To shift a remark by van Creveld (1989, p. 316) to the technological context under discussion here, 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."

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