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The Future of Function Allocation

It's time to rethink how tasks are allocated to people in human-machine systems.

BY
P. A. HANCOCK &
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IN THE INAUGURAL ISSUE OF *Ergonomics in Design*, Robert Fuld provided a severe criticism of function allocation as a practical design process (Fuld, 1993). His thesis, backed by his own experience, was that formal function allocation was a problematic and frustrating way to pursue practical design. Yet such function allocation was still being championed in many of the major textbooks in human factors/ergonomics.

We were not surprised by his criticisms, but we were concerned by the absence of response. If silence connotes acceptance, it appears that the human factors community is in agreement with Fuld over the failure of function allocation.

This is a disturbing prospect. Surely, the allocation of tasks to humans and machines lies at the very heart of human factors and is critical for system design. Indeed, who does what surely must remain a crucial factor in the design of any future human-machine system. If we accept Fuld's criticism, we must also accept that the conception of function allocation is flawed or, perhaps worse, totally inoperable in practice. Where does such a conclusion leave our field? Is human factors/ergonomics then merely a collection of ad hoc heuristics? Are we destined to have no function allocation principles other than the apocryphal "common sense?" What is the state of our discipline and profession if such conclusions are accepted?

As one group that has been working on function allocation, we were disturbed by the implications of Fuld's criticism, and perhaps more disturbed that significant discussions of the issue did not immediately follow. Those of us in human factors/ergonomics must always be prepared to refute the "egg-sucking" argument (Flach, 1989; Simon, 1987), which, in its crudest terms, states, "As I am human, and (perhaps) also an engineer, therefore I am a human factors engineer."

In what follows, we do not seek to engage in this particular polemic, nor do we seek to refute the specific arguments made by Fuld, because we are in agreement with many of the points that he makes. Rather, we seek to illustrate why what we call *static task allocation* has failed as a design process and, further, what contemporary developments have been made in *dynamic task allocation* that can answer such concerns.

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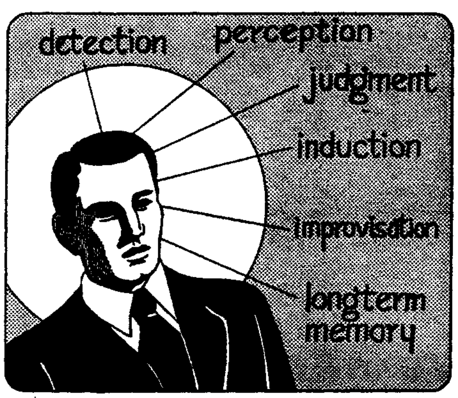
The Foundation of Function Allocation

Any discussion of the concept and process of function allocation has to start with the now-classic report edited by Fitts (1951). Unfortunately, like many other classics, this one is more often cited than read. This is a great pity, because a detailed reading of the Fitts report reveals many interesting and telling observations. For example, although Fitts' name is directly associated with the work, it was authored by 10 researchers, inluding Fitts:

A. Chapanis
F. C. Frick
W. R. Garner
J. W. Gebhard
W. Grether
R. H. Henneman
W. E. Kappauf
E. B. Newman
A. C. Williams, Jr.

Humans Surpass Machines in the:



- Ability to detect small amounts of visual or acoustic energy
- Ability to perceive patterns of light or sound
- Ability to improvise and use flexible procedures
- Ability to store very large amounts of information for long periods and to recall relevant facts at the appropriate time
- Ability to reason inductively
- Ability to exercise judgment

Figure 1. Used with permission from the original Fitts (1951) report.

These contributors are recognized today, with Fitts, as some of the "founding fathers" of human factors science.

If there has been a lack of recognition of the contributors, there has also been a lack of acknowledgment of the content. The goal of the report was to improve air navigation systems and to guide future interdisciplinary research in the area. Issues such as technical feasibility, economy, and manpower and personnel were considered only briefly, whereas dynamic human issues such as selection, morale, motivation, fatigue, and monotony were indicated as important future issues but were not considered at all in the final report. This latter point has an enormous impact when one considers what was extracted and highlighted from this report.

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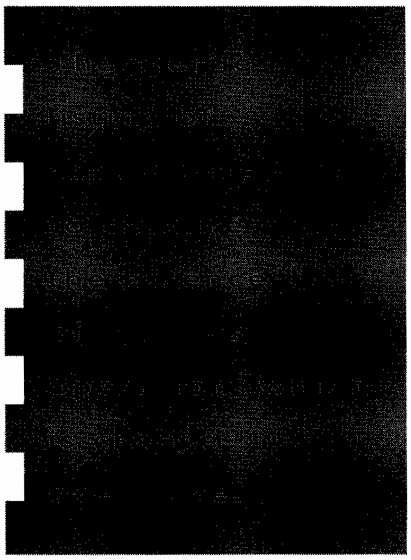
What caught the eyes and imagination of readers considering human design recommendations was the now-famous Fitts list. For completeness, we have reproduced the original lists with their original illustrations in Figures 1 and 2. Past and contemporary citations of Fitts (1951) are associated almost exclusively with these lists, as though they were the central product of the report. 5 were only a small portion of the report and then only provided in order to develop research objectives. These lists have been misinterpreted as a basis for design recommendations without an understanding of the context of their presentation.

Therefore, if static or traditional function allocation fails as a design process, one reason may be that such comparative descriptions were never meant to serve such a purpose in the first place. Consequently, some of the subsequent criticisms of the descriptive comparisons of human and machine abilities as a basis for design cannot be legitimately laid at the door of the authors of the landmark report – their purposes did not include such an aim. Regardless of the interpretation issue, the descriptive comparisons were in fact taken as a basis for function allocation, and it is the failure of such interpretations with which we must concern ourselves.

The Failure of Function Allocation

We shall not dwell too long on the failures of what we have called traditional or static task allocation; these have been dealt with in detail by other thoughtful commentators (see Chapanis, 1965; Fuld, 1993; Swain & Wohl, 1961). However, as a basis for understanding the future evolution of function allocation, such failures are instructive, given Petroski's (1992) observation that often "form follows failure."



An intrinsic failure of the static approach is found in its essential form, that of a descriptive listing. Lists are comparative and divisive by nature. Hence the dichotomy implied in the listing fosters a mindset for design in which tasks are similarly divided. This discrete division negates ideas of sharing, complementarity, or mutual involvement, which we consider vital for operational effectiveness (see Jordan, 1963).

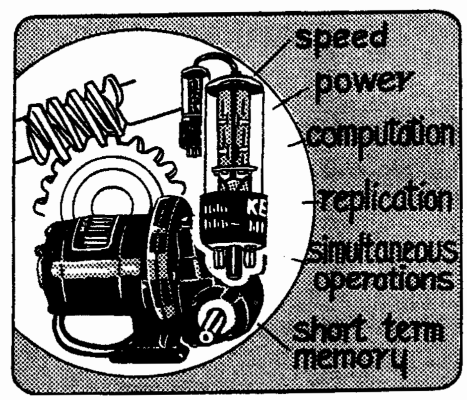
Listing also requires the semantic specification of abilities. The actual language used to describe such abilities is critical. Following the Fitts description, most lists use an information-theoretic-based description, a product of the information-processing era in which the list was developed. This inevitably leads to problems because abilities are expressed in machine-favorable terms, and it frequently appears that the machine alternative is the preferred one, especially for future development. The ramifications of this point have been elegantly expressed by Hopkin (1988):

> As technology advances, more functions can be considered for automation. Measures taken of manual and automated forms of the same task often introduce a bias: if functions are fulfilled better by the human, strenuous efforts are made to make the machine reach or surpass that performance. But, if the machine is superior to the human, comparable effort is not devoted to trying to raise the human's performance to the machine's level. The allocation of functions to person or machine depends more on measures of system and task efficiency than on satisfying the needs of people at work. (P. 552)

The point concerning description can be most effectively made if one considers a comparative listing that favors human qualities such as "the ability to experience remorse" or, more provocatively, "the ability to evaluate trust" (see also Lee & Moray, 1992; Riley, 1994). In circumstances with these requirements, one can quickly regain an appreciation for the superiority of the human operator in a number of realms.

The fundamental argument revolves around which human abilities can be replicated in a machine and which cannot. It is clear from the literature on artificial intelligence that some surprising cognitive activities can be mimicked through machine capabilities, such as exhaustive search. However, others relating to the emotive or energetic aspects of human behavior are far less amenable to machine instantiation. As a consequence, the omission of the energetic aspects of performance in the original Fitts work (for example, learning) turns out to be a critical omission when translated into a human-machine design recommendation.

Machines Surpass Humans in the:



- Ability to respond quickly to control signals, and to apply great force smoothly and precisely
- Ability to perform repetitive, routine tasks
- Ability to store information briefly and then to erase it completely
- Ability to reason deductively, including computational ability
- Ability to handle highly complex operations, i.e., to do many different things at once.

Figure 2. Used with permission from the original Fitts (1951) report.

Here we point out only one major problem with static allocation that is critical to our subsequent argument: the question of operational context. Behavioral scientists seek descriptions of human response that hold over the widest possible range of conditions. When no such relationships are found, they are occasionally elevated to the status of laws. Indeed, Paul Fitts is rightly famous for the Fitts law of movement control. Such laws are not acontextual expressions of behavior; rather, they are multicontextual expressions, and such is their ubiquity that one becomes concerned only in those circumstances in which they fail. At first sight, the Fitts list promises to possess this lawlike property by expressing what machines are good at and what humans are good at. However, the flaw is that the lists themselves are expressed in an acontextual framework. When individuals attempt to apply them in context, they fail, and frustration is the result. Why is this?

With regard to human factors, the answer is that the context is critical for the performance of the system (see Flach, Hancock, Caird, & Vicente, 1995; Hancock, Flach, Caird, & Vicente, 1995). More tritely, "static" allocation is not dynamic. Thus, the sterile listing of capabilities fails to capture the essence of systems operation, which is change over time. This change is especially true of the human component, whose expressions of nonstationarity include learning, boredom, fatigue, individual differences, and a plethora of other characteristics that defy a one-time, unchanging attribution (see also Chapanis, 1965). When we try to ignore change, it leads to the state of affairs so cogently described by Fuld (1993).

There is one more subtle but crucial effect of the static allocation approach. As observed by Hopkin, the outcome of such comparisons in machine terms fosters the development of systems with greater and greater degrees of function given to the machine. In contemporary design, this is seen in the expansion of automation in many processes and systems. The potentially catastrophic result is that the human operator is relegated to "the subsystem of last resort" (Kantowitz & Sorkin, 1987). In such systems, operators are required to engage almost exclusively in the prolonged monitoring of system performance, "a job for which they are magnificently disqualified" (Hancock, 1991; Hancock & Warm, 1989). Finally, operators are required to immediately take over in emergency conditions and recover the system when the machine has not found this possible or has failed in its function. When such a recovery is unsuccessful, one has operator "error," with which the news media are all too ready to regale us.

Despite its attendant frustrations, static function allocation at one level is a relatively simple procedure. At some point in the process of design, construction, shakedown, or operation, someone has to decide whether a task is to be performed by a human or a machine. It is certainly the case – and something that we do not dispute – that humans and machines have different capabilities. However, the fundamental problem is time. At all points in the design process, the allocation problem is chronically underspecified. That is, there is never sufficient knowledge of the situation so that all tasks can be described in Fitts-like terms and apportioned respectively. It is thus the indeterminacy of the real world that defeats the determinacy intrinsic to the static allocation strategy.

> [illegible] task allocation [illegible] from static [illegible] allocation.

An additional temporal problem is that no element remains constant. The machine breaks down or wears out. The human learns skills over the years but gets fatigued and bored on a daily basis. Even if these basic functions stay relatively constant, the environment against which system performance is set is itself often changing. Little wonder that the single specification of static allocation fails abysmally in the face of this constant fluctuation.

There are efforts afoot to change the fundamental approach to automation from a machine-centered to a human-centered one (Billings, 1989). It is clear that for this metamorphosis to succeed, one has to recast and reevaluate the entire view of task allocation. It is our argument that such reevaluation is in progress, and we present the new conceptual basis in the remainder of this article.

The Future of Function Allocation

If traditional static allocation is frustrating to the designer, ineffective for opera-

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tions, and incomplete as a descriptive structure, must it also follow that task allocation in general is a vacuous construct? We argue that the future of task allocation is much brighter if we shift focus from static allocation to a dynamic task allocation. But given our criticisms regarding the underspecification of static allocation, does dynamic allocation mean that all tasks are apportioned moment by moment depending on the whims and vagaries of immediate demand? Certainly not! To deny we know that humans and machines have respective strengths and weaknesses is to throw away valuable and hard-won knowledge. It is knowing both how and when to make such allocation changes that represents the promise of dynamic allocation.

Dynamic allocation seeks to circumvent the problem of underspecification by adapting to a world of change.

One particular facet of dynamic allocation that has been the focus of much recent research is adaptive allocation. In this form, a change in allocation is triggered by some change in, for example, the performance level of the human operator. Particular concern is given to the prevention of task overload (or, conversely, underload) imposed on the human. Hence, this process becomes a significant element of the human-centered automation philosophy (see Hancock & Chignell, 1987; Parasuraman, Bahri, Deaton, Morrison, & Barnes, 1990; Scerbo, 1996). Dynamic and adaptive allocation do not deny the differences in human and machine abilities. Rather, they seek to take extensive and efficient advantage of these differences through a strategy that allows the momentary, daily, monthly, or even yearly changes in task allocation to occur. The strategy can also be responsive to the knowledge of the context of current performance and the momentary and long-term abilities of both the human and the machine. In contrast, static allocation simply states who does what. It is unchanging in a world of change. Dynamic allocation seeks to circumvent the problem of underspecification by adapting to a world of change. It not only addresses "who?" (humans or machines) but many other questions as well. We have couched these questions in a list (ironically) of if-then relations.

IF: An operator performs within a predetermined criterion (WHO?)
THEN: The operator shall keep task control; otherwise the task is allocated to machine control.

IF: Only parts of tasks are being performed poorly (WHAT?)
THEN: Only these parts shall become available for dynamic allocation.

IF: Certain periods are associated with increased demand or error (WHEN?)
THEN: These periods will become available for dynamic allocation.

IF: Particular environments or combinations of environmental variables are associated with increased task demand or error (WHERE?)
THEN: Encountering these environments triggers dynamic allocation.

IF: Extended periods of allocation have detrimental effects (objective or subjective) (WHY?)
THEN: Allocation shall both remove and return control.

IF: Operator performance, environmental attributes, and psychophysiological indexes are paramount for successful human-machine interaction (HOW?)
THEN: Each of these are inputs for allocation shift.

We do not claim that the present advances in adaptive allocation solve all the problems of system design. Neither do we claim that many of the major research problems associated with dynamic change in human and machine function have been solved. However, we do claim that such a strategy provides an avenue of progress and does answer the intrinsic question as to whether human factors/ergonomics is a principled science as opposed to a collection of commonsense heuristics. Consequently, we still see function allocation as a central pillar of the human factors enterprise, even if the shape of that pillar has evolved somewhat in the face of changing technologies and changing design demands.

Design and Metadesign

Another benefit of dynamic allocation extends beyond the scope of human-machine systems themselves: the benefit to the designer. Elsewhere (Hancock, 1996) we have noted that design is directed evolution. The designer has the opportunity and privilege of creation and can be the inspirational source behind artifacts that may last years, centuries, or millennia. Much of what we understand of ourselves is bound up in the thought that is made material by designers and artisans of the past. However satisfying this achievement, design is never complete. One frustration of design is that there comes a point in the process when it must be considered "good enough" and pass beyond the designer's hand to those who manufacture and fabricate what was once only imagined.

We believe that the dynamic and adaptive approach to function allocation discussed here goes beyond this one realm. For the first time, design itself can be dynamic. That is, the nature of what is created can change as a function of circumstance. This is an exciting development for those in human factors who now have to turn their minds not merely to optimizing a human-machine system in a state of being but to how to optimize such a system in a state of becoming. Consequently, our concern is not interfaces per se but interface processes and the evolution of processes. Now the designer never has to part with his or her design but can watch it grow, self-correct, and evolve, perhaps in ways never initially conceived. With the cost and reliance we have invested and placed in many of our worldwide systems, can we afford to have less?

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