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Fundamentals of systems ergonomics/human factors

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A R T I C L E I N F O

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A B S T R A C T

Ergonomics/human factors is, above anything else, a systems discipline and profession, applying a systems philosophy and systems approaches. Many things are labelled as system in today's world, and this paper specifies just what attributes and notions define ergonomics/human factors in systems terms. These are obviously a systems focus, but also concern for context, acknowledgement of interactions and complexity, a holistic approach, recognition of emergence and embedding of the professional effort involved within organization system. These six notions are illustrated with examples from a large body of work on rail human factors.

1. Introduction

There should be few researchers or practitioners in ergonomics/human factors (E/HF) who do not think of it being a systems discipline, and of themselves as taking a systems-oriented perspective. However, long acceptance that to be meaningful (E/HF) is systems-oriented does not mean that there are widely accepted explanations of exactly what this means in principle and in practice (although see Siemieniuch and Sinclair, 2006; Waterson, 2009a for instance). This paper is written to redress, to an extent, this vacuum in E/HF thinking. At the outset it should be said that, to avoid sterile debate and any implications that ergonomics has to do with one kind of system and human factors another, and to avoid the complications of any confusion between ergonomics/human factors systems thinking and human systems integration or human factors integration (ref), the term ergonomics/human factors and the abbreviation E/HF will be used throughout, denoting the single nature of the discipline.

Many of the early leaders in E/HF (Chapanis, Corlett, Singleton) saw it clearly as a systems discipline (e.g. Singleton, 1974 in a short but prescient book). Several leading authorities such as Sheridan (2013) and Sheridan and Ferrell (1981), Rouse (2007, 2013) and Rasmussen (1997) actually came into E/HF from a control and systems engineering background, and worked with many people from control engineering who brought systems-level models with them. Many examples of the work of others from this background can be seen in the proceedings of the periodic [hu]man–machine systems IFAC/IFIP/IFORS/IEA conferences of the 1980s and related NATO workshops on human control of systems and decision making (e.g. Hollnagel et al., 1985). Their interest in human capability and fallibility, when it became clear that apparently advanced process control systems would fail if these induced errors in operators and managers (and actually needed human expertise to work properly), spawned a movement in cognitive systems engineering and subsequently joint cognitive systems (Hollnagel and Woods, 2005; Woods and Hollnagel, 2006). It is not surprising that there is a systems design orientation to the work of those mentioned above, and many others in E/HF, since they were usually dealing with large and complex systems, with many interacting components, and where the cognitive interactions are intimately related to the physical ones through positioning and layout of information displays for instance and the social (communications, coordination and collaboration with others). However, even within the classical ergonomics applied to industrial workplaces, physical work, and manual handling, and to devices and equipment used within them, leading ergonomists worldwide have clearly seen that we can only usefully address the relevant human factors concerns at a systems level, whether we call it systems ergonomics, or participatory ergonomics/design (Haines et al., 2002) or, as has become prevalent in North America at least, macroergonomics (Hendrick and Kleiner, 2001; Kleiner, 2006).

Even with all this support for the primacy, indeed necessity, of a systems view, in some areas of ergonomics application it sometimes seems that a single problem-single solution ethos still prevails (see Dul et al., 2012). My own work, as joint editor-in-chief of Applied Ergonomics and as an editor or board member for several other journals exposes me to reports of some E/HF which, far from actually analysing or investigating at a system-level, does not even acknowledge the importance of context, which influences the

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interactions between the researchers' focus and other parts of the system in practice. This may be for a number of reasons. Most acceptably, this may be because of the impracticality in some circumstance, given project or investigation remits and resources, to do more than concentrate upon a micro view of the human factors involved. A recent quote from a project team I audited was – "yes we know there are larger systems issues which are relevant but we only have time, permission and access to address this small part of the problem". Less acceptable are those cases where a narrow non-systems approach is taken because the investigators concerned are only competent or interested in a narrow channel of E/HF; the manual handling charlatans of a few years ago come to mind.

It is tempting to be hard-nosed and suggest that any study, investigation, analysis or development which does not take a systems view is, in fact, not E/HF at all. Rather such an initiative should be seen as a sub-set of E/HF, a biomechanical, cognitive psychology or physiology study, and possibly of limited practical value. So, a musculoskeletal disorders (MSD) investigation or improvement which does not account for psychological/emotional/social influences, on MSD causation or success of solutions, is not properly E/HF. Likewise, any experimental study which assumes that cognitive task performance occurs in a vacuum away from emotional, motivational, supervisory and environmental influences and impacts means that findings have less value. Taking such a hard-nosed position might be too extreme for some, but such a stance does start to more clearly delineate what is our discipline and what it is not.

Why write this paper at this time, and indeed why is this special issue appearing now? Well, if the world of E/HF is to have a future then we have to accept that it is a systems discipline and that, to paraphrase Hal Hendrick, good ergonomics is systems ergonomics. However, it is all very well to espouse the systems viewpoint and approach but we need to be clearer what we mean. This paper, based on an earlier and shorter version published in the proceedings of the IEA Triennial Congress 2012 (Wilson, 2012), brings together ideas from earlier efforts (e.g. Moray, 2000; Wilson, 2000), other sources from outside our discipline, and practical experience in different industries to move beyond the easy statement of E/HF as a systems discipline and to try to exemplify what we mean by this. In the next section the relationship between systems E/HF and systems engineering is explored. Following this, the heart of the paper is two sections the first of which defines the fundamentals and components of systems E/HF and the second provides examples for each through research and practice in rail systems E/HF over a number of years.

2. Systems engineering and systems E/HF

So, what is systems ergonomics (or systems human factors)? A deceptively easy definition, if somewhat circular, is that systems ergonomics examines, accounts for and enhances the design of a system, and people's interactions with it, rather than concentrating on an individual part of it. That system can be an artefact, facility, environment, building, work site, group, community, organization or society. This definition immediately begs the question of: what is a system? If we agree that the notion of systems E/HF is key to the ergonomics/human factors profession, then we need to understand what is agreed, or not, about "system" (and by extension "systems engineering").

Singleton (1974) proposed that systems had related objects, changed over time and, for human-made systems, have a purpose (people nowadays from other sciences might argue with his contention that natural systems do not have a purpose or goal). From a central position within E/HF, Chapanis (1996) noted that the term "systems" is used in many ways but he concentrated on what he calls "equipment systems", defined as "an interacting combination, at any level of complexity, of people, materials, tools, machines, software, facilities, and procedures designed to work together for some common purpose." (p. 20). Extending the idea of a system as an organized whole, the interdependent components can only be defined in relation to one another depending on their place inside this whole (Luzeaux and Ruault, 2008, p. 12, quoting de Saussure), and the technical and human components, and their attributes and relationships, are addressed towards a goal (Stasinopoulos et al., 2009). So a motor car is a system whereas a selection of car parts on a shelf is not; a book is not a system but a reader with a book is a system.

So, based on these earlier definitions, at the outset of this paper it is proposed that:

> A system is a set of inter-related or coupled activities or entities (hardware, software, buildings, spaces, communities and people), with a joint purpose, links between the entities which may be of state, form, function and causation, and which changes and modifies its state and the interactions within it given circumstances and events, and which is conceptualised as existing within a boundary; it has inputs and outputs which may connect in many-to-many mappings; and with a bow to the Gestalt, the whole is usually greater (more useful, powerful, functional etc) than the sum of the parts.

Any understanding of systems ergonomics must be related to the idea of systems engineering. And it is here that we have another problem because of the variety of viewpoints and opinions available – not an unusual situation! From the general world of systems analysis and design rather than E/HF, Blanchard and Fabrycky (2011) accept that there is no commonly accepted definition of systems engineering. They identify five different definitions which, they say, show the variations in viewpoint (p. 31) but do suggest systems engineering features as: top–down approach; life-cycle orientation; early concentration on defining systems requirements; and an inter-disciplinary or team-based approach in the development process. The increasingly strong contribution of human factors within systems engineering is shown in modern textbooks on systems analysis and design which these days have whole chapters on this (e.g. Blanchard and Fabrycky, 2011; Luzeaux and Ruault, 2008) – although unfortunately these sources do report a fairly old-fashioned view on ergonomics/human factors.

Rouse (2010) sees human system integration (HIS) as an element of systems engineering concerned with understanding, designing and supporting human roles and performance in complex systems. Chapanis (1996) provides a selection of definitions of systems engineering which tends towards ones which, with small changes, might also define a design-oriented human factors. He also suggested that, at that time, debate over the nature of systems engineering was not settled, but preferred a definition that involves understanding of (evolving) user needs, and incremental development of requirements and specifications. He also suggests that systems engineering includes integration of all disciplines throughout the system life cycle so as to assure that all user requirements are satisfied (which starts to sound like the modern approach in large infrastructure projects of Human Factors Integration).

The antithesis of a systems approach to development was seen clearly in a recent proposal for a major international project reviewed and evaluated by the author. In this, some very clever use of future mobile and ubiquitous technology and wireless networks was proposed, in order to create a citizen participant movement for sensing environmental traces and communicating these to centralised databases and knowledge management systems. The