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# Fundamentals of systems ergonomics/human factors

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ABSTRACT

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 technology looked both advanced and feasible. But, no mention was made of issues such as motivation, privacy, acceptability to local government, unintended consequences of third parties using the information for commercial purposes etc. OK, so they had forgotten, or just not recognised, the human factors issues, and we are used to that from (some) systems developers. But they also made no mention of equipment robustness, maintainability, battery life, replacement policy, spares availability, integration with other local and national community systems, and so on. In other words, there appeared to be little or no systems thinking within the proposal.

## 3. Notions in systems E/HF

The main aim of this paper is to establish a framework of what is included, even necessary in systems E/HF. The case made in this paper is that there are six overlapping defining features – systems focus, context, interactions (including complexity), holism, emergence and embedding – each of which will be explored in general in this section and then examples given from rail E/HF in the next section.

### 3.1. Systems focus

The first component of systems E/HF may seem blindingly obvious, indeed even trivial, but needs stating all the same. That is, systems E/HF treats the focus of interest as a system – as an interacting combination of DNA, materials (organic and inorganic), bytes, functions/processes and ideas. These combinations may not be stable, indeed where systems are complex they will not, nor should, be stable as recognized by the resilience engineering movement, and our focus is on the inter-connections as much or more than the components. Our systems of interest used to be limited to human- (or man-) made at one time, but now we also have an interest in the investigation and "design" of people's interaction with or within natural systems if not design of the natural systems themselves. Certainly the natural system increasingly becomes a parent system or a sibling system to our socio-technical system domain – think of Hurricane Katrina and the Fukushima Nuclear Power plant in the tsunami (The National DIET of Japan, 2012) – where knowledge of how such natural events occur and escalate will aid our contribution to risk assessment and resilience engineering-based solutions or consequence management systems. As an example close to my own work, natural events concerned with climate, soil, microbiology, botany needed to be risk assessed in combination with human and organizational failures in our work on grain inspection regimes in Australia (Wilson et al., 2009b).

An interesting notion of relevance to the idea of parent–child or sibling–sibling systems is "systems of systems" (e.g. Stasinopoulos et al., 2009). Where technology is concerned it is easier to draw clearer boundaries between systems, and thus the notion of systems of systems is perhaps easier to grasp and explain in the context of purely technical systems than for the socio-technical or human–machine systems of interest to E/HF. The people element of each system/sub-system crosses the boundaries and by doing so blurs distinctions. For instance, a bed in a hospital is a system, the patient monitoring equipment is a sibling system, the two together plus the patient's room comprise another system, perhaps a parent system; whereas the radiology or scanning equipment, the drugs dispensary, the beds, the ambulances are all systems, but together can be seen as a system of systems when looking at maintenance and replacement regimes. However, for each of these when we look at the socio-technical system – including the patient being brought to hospital in the ambulance, monitored in the bed, being scanned, having drugs administered, and the nurses monitoring the patient, administering the drugs, moving the patient in and out of the bed etc, the human elements cross all the boundaries and so the idea of a system of systems does not perhaps capture the integrated nature of the parent socio-technical system and all the child systems within it.

### 3.2. Context

Moray (1994) amongst others proposed that all behaviour and performance takes place in a setting or a context, and E/HF must understand and account for this context, which increasingly is that of complex socio-technical or even social systems. What is useful for analysis of complex systems, parent–child or sibling systems is some form of systematic representation which shows where and how system boundaries operate and how each can provide context for others. Rasmussen's (1990 and 1997) well known risk management framework for instance has been used by several authors to explain the layers of complex systems (e.g. Waterson, 2009b).

If everything that people do and everything that E/HF studies, improves and implements, takes place in a context, and is part of a system of goals, activities, means and artefacts, then we must define what elements within the system of interest are of proper interest to E/HF and to any particular analysis or development. By extension we need to decide what lies outside this remit, even though impacting on the work we do and the systems we critique or design. If we are working at a systems level then in defining our system we need some version of the old task analysis stopping rule, but working outwards rather than inwards. In other words, where is the boundary of our system of interest, at what point does our system end and another – sibling or child or parent system – begin? Deciding on and being clear about this is the first step in an analysis for a systems E/HF initiative. There are no real rules for deciding where to define the boundaries for the system of interest, other than being clear and sensible enough to acknowledge that the setting of the boundary must be useful for the purposes of the analysis, recognising that the boundary for one form or analysis of the system may be different than for another.

An extension of the argument of the primacy of context is to suggest that few if any laboratory studies are properly ergonomics because they cannot account properly for the complexity and multiple factors found in real settings (see de Keyser, 1992; de Montmollin and Bainbridge, 1985). A key problem with laboratory work is that even the most statistically significant of results in the best controlled experiments may only account for a fraction of the real variance in real practice (largely due to the issue of complexity as alluded to below). For example, an experiment might show clear statistically significant differences in recognition and comprehension performance for participants using two alternate colour codes for an alarms management system. However, in practice in an electrical control room, the better performance with one coding may only be responsible for a fraction of variance in human–machine systems performance, whereas the layout of the room, the lighting, relationships with colleagues, shifts worked, the quality of supervision, and the degree of control in the operators' role may actually explain almost all the variation in quality of alarms management. My own view is that systems ergonomics should be carried out "in the wild" except for where ethical or substantial pragmatic issues intervene. That is, laboratory research has its place but not a primary one.[1]

[1] I do recognize that for some this may be a little extreme, and must point out to the reader that this may not be a universal view in E/HF.

### 3.3. Interactions

The basic nature of a system is that it consists of interacting parts. Or at least that is how a systems approach typifies the object of interest. This very fundamental view lies at the heart of many of E/HF approaches and concepts – human–machine systems, socio-technical systems, joint cognitive systems etc. Our purpose is to optimise (or at least satisfice) the interactions involved with the integration of human, technical, information, social, political, economic and organisational components. Such integration takes place mainly within the development and implementation phases, but continues throughout the system lifecycle into operational use, maintenance, testing and decommissioning (including sustainability).

The argument that the most useful E/HF has a focus on the interactions themselves and not on the things interacting (Wilson, 2000) is basic to many approaches within E/HF such as joint cognitive systems for person–artefact interactions, or distributed cognition for people – people–work tasks–organization interactions. Since E/HF is about understanding and design for the interactions not the components in the system we analyse and design a "people–building" interaction not a building, a "person–device–person" interactive network rather than an interface or device alone, and a person–team–organization interaction not a team per se. In our world of E/HF the interactions we are interested in are purposeful. It is particularly interesting to view interactions from an ergonomics perspective in the light of studies, analyses and understanding of co-operation – e.g. McMaster and Baber (2012), and identification of factors of collaboration – e.g. Patel et al. (2012).

To take a systems E/HF approach means that we do not treat an equipment or workplace development say as if it were an island, separate from the end users, other stakeholders and the organisation. Parallels may be found in other fields: manufacturers must account for supply chain interactions and influences, on both local and international scales; train operating companies and infrastructure owners must account for the inter-operability of their operations with other modes of transport or railway in other countries; software engineering enterprises must integrate planning for development across the product life-cycle and allow for integration with other software; procurement departments must account for the interface of new pieces of equipment (physically or in software) with existing systems; and manufacturers will examine the design and implementation of a production system with respect to its interaction with maintenance systems in a design for maintainability approach.

The notion of interaction is strongly related to that of systems complexity. It is the very complexity of the world and of the social and socio-technical systems within it that is part of the rationale for a formal discipline and profession of E/HF. Wisner (1995) talked of the inapplicability of the linear model as the paradigm for ergonomics, in the context of recognizing the effects of complexity. The phenomena of interest in systems in respect of the nature of complexity, and by extension of great interest in human factors, are, according to Rouse (2007, p. 267): human and social behaviours (including human performance, mental models and social networks); interdependencies across time and space and across domains; rapid change and uncertainties; and the location of system boundaries (broadly or narrowly drawn, or even non-existent) (see also Beguin, 2011). It is however the very complexity in many of today's social and socio-technical systems, and the related uncertainties, which at one and the same time necessitates a clear E/HF systems approach to understanding but also creates difficulties for E/HF analysis and understanding. Flach (2012) and Hollnagel (2012) provide interesting discussions of complexity.

### 3.4. Holism

Many early systems thinkers pointed out that systems should be seen as a whole, as holistic (e.g. Angyal, 1969). The discipline and profession of E/HF are holistic; that is we see the person "in the round", seeking to understand the physical, cognitive and social (and increasingly today emotional) characteristics of people in order to enhance the interactions they have with artefacts, information, environments and other people. Such a holistic perspective is the very raison d'être for E/HF. However, for simplicity of explanation to the outside world and to rationalise the broad church of ergonomics, we may sometimes describe various technical branches of E/HF such as physical, cognitive, and organisational/social ergonomics. At a level below this we may have branches such as forensic, macro, participatory ergonomics etc. But whilst this is understandable for convenience it is potentially dangerous if it leads us to think that the discipline can be so easily partitioned. In a holistic systems view the cognitive, physical and social must be combined to an extent which is appropriate to the project and system, the issues to be studied or improved, and the type of investigation, analysis and solutions involved.

The above mainly concerns the holism of E/HF inputs, but outputs should be addressed holistically also. These are the impacts of people on the performance of the human–machine, socio-technical and social systems, and the impacts of systems design on the well-being of all stakeholders (i.e. all effected by, or coming into contact with, the system) – physically, mentally, emotionally. Being holistic means that a design change expected to produce safety benefits should be specified so as to enhance, say, system efficiency and reliability as well, and that solutions to enhance physical health could be addressed to increases in mental health also.

### 3.5. Emergence

The fifth significant feature of a systems E/HF approach is the recognition of the emergent properties of systems (see Johnson, 2006), including the emergent properties of the human components. Emergence is central to E/HF in three closely related ways. First, all systems in real use, with real users and under the constraints such as of time, space, management pressures, motivation that are found in practice, will display characteristics and operate in ways not expected or planned for by their designers. Every ergonomist working with real users in real companies will be familiar with the cry from the engineers – "but we didn't expect them to do that!" The history of failure of grandiose ICT projects is littered with examples of end users who did not (and never had if the developers had troubled to find out) behave as the job specification, operating procedures or developers/managers' (or worse, ICT consultants') idealisations had suggested (e.g. National Audit Office, 2011). Dysfunctional emergent properties of the human–machine system can be reduced through better human factors integration throughout the development lifecycle.

The second type of emergent properties is intimately related to the first, whereby the impact of poor designs in fact may be mitigated through the well recognised ability of users to find a way to make the system work despite its shortcomings. As recognized by Bainbridge's (1983) ironies of automation many years ago, people find ways to accommodate, avoid, overcome or work around system deficiencies in designs which were predicated on poor intelligence about the context, the tasks, the constraints, the users and their needs and contributions. Thus people may behave in non-specified and non-predicted (though probably predictable by E/HF expertise) ways which are in fact beneficial to system performance; many ways of working with a system emerge due to the intuition, creativity and ingenuity of people.

Third, and again positively, there is the idea of emergence where people unexpectedly take advantage of capabilities in a product or role not dreamed of by designers, or find new system uses. We are all familiar with the child who finds pleasure in using the box for imaginative games rather than the toy inside it, and the well known example of the possibility of widespread texting being little thought of by early mobile phone developers. This kind of emergence can be found in the increased inroads into large company or defence community use of COTS (commercial off the shelf technologies) and, conversely where what starts out as a piece of capital equipment finds its way onto the consumer market some time later.

The E/HF practitioner, whilst not blessed with 20/20 predictive capability, should at least be alert to potential or actual changes – whether dysfunctional or functional – in use of products and systems and the ways of working of people. E/HF analyses and evaluations should allow for the possibility of emergence from the inter-connected economic, political, legal and other interactions as well as the physical, cognitive and social ones that we may have designed for.

### 3.6. Embedding

The sixth feature of a systems approach is the way in which we as ergonomists carry out our work, and who we do this with. This means the way ergonomics fits within the organisational system and is embedded within practice (Wilson, 1994). Of course good ergonomics is participatory and so, as far as possible, we work with all key stakeholders and subject matter experts (Haines et al., 2002). However, all large companies with an E/HF function have to make a choice of where to place them within the organisation. This might be within operations, design, engineering, safety, training and so on. Some companies might try to distribute human factors across all these groups, or across product-based or regional sites, but unless the numbers of E/HF specialists are large this, in my experience, runs the risk of the small (sometimes single person) groups being isolated, being picked off or marginalised, or of them "going native" and ceasing to offer an ergonomics view, and seeing things from the perspective of their host department or function.

## 4. Rail systems ergonomics/human factors

In this section practical examples of systems ergonomics are taken from work on a large number of projects in rail ergonomics/human factors. This research has included fundamental development of new ideas, theory, tools and knowledge, and applied research to improve rail work systems (e.g. Wilson et al., 2005, 2007, 2012).

### 4.1. Systems focus in rail E/HF

Without wishing to overstate the case there has been a shift in the approach of human factors in domains such as rail over the past few years, with human factors taking a holistic, socio-technical and root cause view on systems. This is partly in response to dealing with systems complexity and partly due to the human roles, functions and activities being often distributed – temporarily, spatially and functionally. Activity in a system may take place continuously or discretely over a period of time and we can "follow" the artefacts or people of interest through that system over time (an equivalent here is following the "patient journey" through a health system – e.g. Buckle et al., 2010). Action may also take place over a wide geographical area, for instance the work of a forest fire fighting crew as they carry out their work in a command centre, on the ground in the forest and from the air. Activity may also be functionally distributed, for instance an Olympic Games design and development team containing planners, concept designers, engineers, architects, stylists, production engineers, systems engineers, marketing specialists and customer representatives.

Fig. 1 provides a simple model of our contribution wider rail systems engineering work, capturing the holistic nature of E/HF and the contribution to people and human–machine systems performance, the equipment and interfaces they use and the wider systems and organisations involved. We carry out or support analysis, design and integration activities, in order to understand people's knowledge and competence (who they are), their tasks and functions as employees or customers (what they do), the artefacts or equipment to support their work or tasks (how they do it) and the setting, culture and context they perform in (where they do it). The diagram was first constructed to describe the apparently very different areas of activity undertaken by the Network Rail Ergonomics Team – from occupational psychology to design engineering and embracing culture, competence, cognition, equipment, environment, functions and tasks – as part of a coherent (systems-oriented) whole.

We can see the trend to take a systems viewpoint when studying rail in a large number of instances. For instance very early work to examine how to support rail passengers through improved architectural design or information display carried out classical studies of design of signs and their placement in key positions within stations. More recently such studies have developed and defined personas, and tracked passenger journeys (e.g. Pattison et al., 2007) from leaving home or at least arrival at the station through all aspects of access, information finding and train boarding, and then subsequently alighting at the other end, and including interaction with other vehicles in a multi-modal transport system. Current concerns are with identifying and understanding the siting, information density and updating needs for passenger decision points and confirmation points on their journey (Moncrieff, 2012, personal communication).

An interesting example of the increased contribution of E/HF to understanding natural systems, and certainly in terms of their potential impact on people, can be found on the railways and in a drive to improve environmental sustainability. In classical E/HF terms, there has been a drive to develop information and other systems to aid fuel efficient train driving. But moving more into the natural systems territory, an agenda setting exercise to establish human factors relating to environmental sustainability at an organizational level has also led to identification of potential impacts on and of people under a variety of scenarios for serious and long-term climate change (Ryan and Wilson, 2012).

Rail provides interesting confirmation of the argument advanced above, that it is more difficult to be clear about system boundaries and systems of systems for socio-technical systems

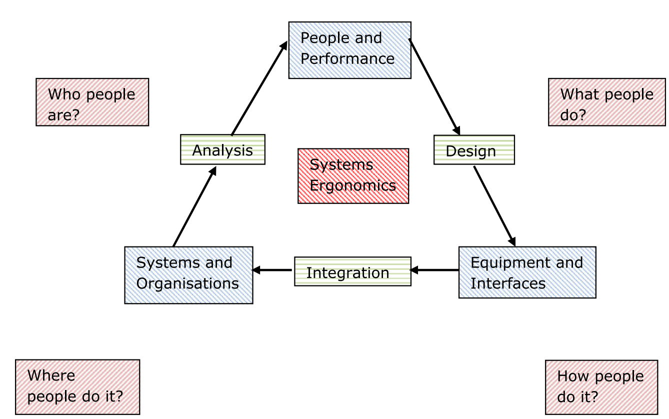


**Fig. 1.** Representation of rail systems ergonomics/human factors.

than for purely technical ones. A train traction unit (engine) or maybe a whole train including carriages etc can be defined as a system but the whole transportation network – the train, the track, the electrical power system, the stations, car parks, the roads used to get to the station etc – as a system of systems. Wider still, the rail industry is a very large and complex system of systems, with at the top level individual interacting systems of the rail infrastructure owner, the rail operating company, the maintainers and contractors, passengers, regulatory authorities etc. The road network can be typified in a similar fashion, and wider still road and rail together comprise an enormous complex system of systems with intermodal carriage of people and freight the goal. When we examine the socio-technical system(s), a passenger sitting on a train, together with the seat, light, table, window etc, can be represented as a human–machine–environment system. But, a whole carriage containing multiples of such HMES is not a system because there is little inter-connection (other than when someone talks loudly into a phone!) and no shared goals. However, when the context changes so does the notion of the system; in an emergency evacuation the whole carriage and the passengers in it become a system, with shared goals and interacting with each other and with the lighting, space (corridors), seats (as obstructions), any instructions in the carriage or over a PA system etc.

### 4.2. Context of the rail network and rail companies

As far as context is concerned, this is critical for the railway. At the top level government policy and strategies, especially in terms of the organisation of the industry (how it is divided up between infrastructure owners and rail operating companies for instance) and the consequent commercial and operating contracts, has a profound effect on meeting human factors requirements. Strongly related to this, the position of the railways in the public's affection (in many societies) effects their perception of when things go right or wrong, including their perception of how much safety they can expect (as with other complex systems such as healthcare, they perhaps expect greater levels of safety than can possibly be delivered). At another level we have the regulators, those concerned with health and safety as are found in any safety critical industry, and those concerned with commercial contracts and public value for money. Then, and the astute reader will realise that we are following Rasmussen's (1997) stages of risk management in large systems, there are the layers of the organisation, its management, its supervisors, all direct and indirect staff, and the hardware and software systems they work with. Whilst it would be idle to pretend that in every piece of work we do on the railway we account explicitly for all these levels, we do so wherever possible.

To take a number of examples, for study of the behaviour of control room operators (e.g. Balfe et al., 2012; Farrington-Darby and Wilson, 2009; Dadashi et al., 2012) with a view to the design of better information interfaces – then our focus of interest would be the roles and functions of the operators, the strategies they employ and the decisions they make, the collaborative work undertaken in the control centre and with remote agents, and the information interfaces used to support their work. Therefore we may be interested in the position of electrical power points and desk dimensions (for layouts to support high quality work behaviour) but certainly not in how the national electricity grid works. If our focus is the design of operating procedures and their influence on violations then we could benefit from knowing something about the workings and priorities of the national regulator but at a practical E/HF level we are far more interested in organisation culture, influences on errors, short-cuts and work-arounds, and the incidence and consequences of such behaviour in terms of incident reports. If we have as a central issue the choice between large shared screens and personalised displays we may be interested in team interactions but, at the level of performance we are concerned with, not concerned about the font size and contrast on the displays; such issues and design choices would come into play at a later stage.

What these three examples have in common is the need to decide early on what level of system we are gathering data at and what level we might be implementing changes for. Other system layers may be interpreted as contextual, and although we need to understand a certain amount about them we would not be working at a deep data collection level. For instance our work on the understanding of planning for engineering work (Wilson et al., 2009a) was strongly related to the impact of the regulator and unions in terms of acceptance of somewhat radical changes for provision of protection on track. Understanding of intra- and inter-organisation levels was vital because of the lead times and multi-agency cooperation required. Our function analysis leading to risk analysis was clear about the interactions between technical supervisory, safety supervisory, planning and track workers levels.

### 4.3. The railway is a distributed interactive system

In relation to interactions, in essence the railway is a large, complex distributed system of many technical, organisational, economic and human components. This distributed system is spread across regional, national and cultural boundaries, giving additional problems of inter-operability. Clearly this is a system of inter-connected parts, with multiple links, and very complex in functional, topographic, temporal and communication terms. The links are multiple and constantly changing.

E/HF can only be successfully accounted for, and an E/HF function can only add value, if an integrated systems view is taken of activities and processes throughout the development and operational life of rail systems. This involves an integration plan with consideration of all operational modes (normal, abnormal, degraded and emergency), across technical (for example, lineside signals and in-cab information displays) and organisational (train and freight operating companies, projects and regions) systems. An extension of the inter-connectedness and complexity of the systems that we deal with is that all such systems will have multiple, and frequently competing, goals, meaning that the railway and the ergonomics support for it must continually make trade-offs. Work on planning and delivery risks in track engineering and maintenance identified these as being across E/HF goals (or criteria) of safety, reliability, efficiency, use of capacity, security, environmental sustainability and cost (Wilson et al., 2009a).

Our research into track maintenance and engineering activities, including access and protections, investigated the roles and contribution of a number of inter-acting functions such as the person in charge of possessions, engineering supervisors, controllers of site safety, lookouts, signallers, drivers (of engineering trains and other network users), and machine controllers (Wilson et al., 2009a). From an E/HF perspective all aspects of rail engineering and the rail system are interconnected and a number of efforts have been made to typify the system involved, to establish how different parts interact, from planning through to delivery, and including how both safety as well as efficient performance is propagated through the system. Amongst the means used to do this we have included social network and communications analyses (Moncrieff, 2009), command/control graphics, models and metrics of resilience (Ferreira et al., 2011), visual scenario analysis (Schock et al., 2010), and span of control measures (White et al., 2013).

### 4.4. Holistic approaches to railway ergonomics

The rail network is an excellent example of a complex socio-technical system – the health service, emergency services, off-shore gas and oil are others – where every kind of work and human factor is present. The stakeholders include signallers and controllers (electrical, infrastructure fault and traffic); drivers; station and on-train staff; planners, engineers and managers; track (maintenance) engineers and workers, lookouts and site safety controllers; passengers and the general public (the last both legitimate – e.g. at level crossings, and illegitimate – e.g. trespassers). The rail system includes work in vehicle control, systems process control, monitoring, planning and physical work, occurring in settings such as vehicle cabs, control rooms, outdoors in all weathers, and large buildings and spaces. The artefacts used include VDUs, signals, paper, CCTV, hard wired controls, hand tools and large engineering plant and vehicles. Therefore the human factors contribution must be multiple, combining cognitive, physical and social theories, methods and knowledge.

Linking the contextual and the holistic in our approach to systems ergonomics, in the research addressing rail engineering we have examined the use of mobile computing (Dadashi et al., 2012). Clearly use of such devices involves examination of physical, cognitive and organisational interactions, and the way these are multiplely connected. The devices need to be usable in all outdoor conditions, robust yet easy to handle; the screens need to be able to present location maps and access routes, maintenance histories, technical advice and to do so in a meaningful and accessible manner given space constraints; and we need to understand the change in organisational relationships and communications links once more information access and thereby control is given in the field to “remote agents”. To allow for context we developed a functional use assessment tool, EDARE, to understand what different functional needs, and thereby information access requirements, different job groups would have in the practice. This has been extended more recently into similar analyses of information needs, and development of a framework for relevant human factors, for different functional groups as contemporary intelligent infrastructure systems begin to be implemented (Dadashi et al., 2013).

### 4.5. Emergent properties of rail systems

Many of the aspects of emergence – both potentially dysfunctional and potentially beneficial – are found in rail engineering. Two examples only are given here, both with implicit considerations of holism also. First of all, the advent of intelligent infrastructure will have a profound effect on how things are done in railway inspection, planned maintenance and reactive maintenance, and control of operations, and on who carries out the work. The aim of intelligent infrastructure is to move from find and fix to predict and prevent (Dadashi et al., 2012). Key decisions will have to be made about the degree to which the continual monitoring and diagnosis of the state and performance of assets is handled by people or automated systems, and how these will be integrated. A choice will also have to be made about the extent to which first and second level alerting and decision making will take place on-site (with potential benefits of immediacy, having local knowledge and decisions and actions being appropriate to location and circumstances), or else off-site in remote control centres (with potential benefits for cost, consistency and co-location of key expertise). Major E/HF contribution to intelligent infrastructure will also come through developing the means to reduce what will be millions even billions of bits of data from sensors down to manageable knowledge and intelligence to be used by people with different roles and agendas. We will need the development of appropriate data screening/filtering routines, and conversion into intelligence via human-centred and ecologically valid displays, appropriate to, for instance, control centre operators, mobile staff on track, and business analysts. Given the needs to create effective working systems out of “clever technology” of intelligent infrastructure, new human factors will certainly emerge over the next decade, which may be expected or unexpected, and which will profoundly alter the ways in which the rail socio-technical system delivers its objectives. Our system-based early work has at least prepared us for the likely challenges ahead.

The second example of emergence is shown when we study how people’s jobs will change as their information sources and decision supports become more mobile and personal (Dadashi et al., 2012, 2013), and – with increased use of sensors – as information becomes ambient. Although intended at first as a convenient non-paper way of supervisors on track recording or down-loading required information, the advances in mobile computing will inevitably mean that people will work in different ways, communicating with different people, and making decisions differently given the increased knowledge and interrogation facilities available to them. Therefore we will see the emergence of new roles, communication channels, relationships, power structures, sources of decision making and liaison/collaborations. Taking a systems-oriented view enables us to see that the socio-technical system will change far beyond the early expectations of the engineers and operational specialists. A major question to be addressed by a rail organisation is of the degree to which they want to restrict the span of control and decision latitude of their remote agents on-track or whether they want them to be able to use all the new information and processes available to them in order to behave as a true high-skill and high-knowledge operative.

### 4.6. Embedding ergonomics/human factors in the rail industry

As regards embedding, in our own case of the Ergonomics Team within Network Rail, we were for over 10 years based within the engineering function, and more recently within a wider asset management function. Given what was said earlier about systems ergonomics and systems engineering, engineering is seen by this author as the best home for an E/HF team. Certainly the impact of the Ergonomics Team on new systems and projects, and on maintenance, renewal and enhancement activities has been facilitated greatly through close relationships with engineering, although the strategic relationships we have set up with operations as well have also proven very valuable, and the Team has at times worked closely with other functions such as safety and sustainability, corporate affairs and maintenance. The point is that wherever the E/HF function is situated it must collaborate with all other functions in order to do its job. It is often because a good systems-oriented E/HF practitioner actually does work with all other functions, indeed has to do this in order to do their job properly, and must understand all stakeholder needs (including those of people managing or building the system as well as of end users), that they are invaluable for successful systems engineering.

## 5. Conclusions

The widespread acceptance of need for and value of the systems orientation of ergonomics/humans factors is increasing. It is seen as one of the ways in which we can distinguish ourselves from other professions and define ourselves and our approach to potential clients (Dul et al., 2012). The debate over systems E/HF has in fact become more urgent as we seek to maintain and strengthen E/HF as a discipline and a profession. It is possible that we can recognise its absence better than we can define it, and so this paper has been an attempt to rectify that by explicitly defining six features of systems E/HF, and illustrating these with examples from work in rail human factors. This is particularly important since this author believes that all education and training for E/HF practitioners and researchers should build from a systems engineering and systems E/HF basis.

There are some dangers of course in taking a systems perspective. In fact there might seem to be some irony in investigating and enhancing at a systems level, since the very descriptor "system" can imply dealing with a number of constituent parts rather than being holistic. A study or implementation that starts out as manageable can become unwieldy and even impossible if layer upon layer of connected systems are brought into the remit; a clear danger is of micro-analysis where this is not needed. Even at a single sub-system level we have all seen analyses in which everything seems to connect with everything else, and the analysts appear to be unable to prioritise any groups of entities or links. Equally if an analysis is at too superficial and high a level then nothing of any value may emerge. The spectrum from not seeing the trees for the wood to not seeing the wood for the trees is a wide one and E/HF systems practitioners have to make clear choices about levels of analysis and extent of concerns early on.

Of course it is rare that any one ergonomics study, initiative or even programme can embrace every aspect of the system and hence all human factors. Resource availability and indeed logic dictate against this. In the author's own work there have been times when the enormity of trying to analyse and address all aspects of a system became too much and we concentrated on particular system parts instead (e.g. Wilson and Whittington, 2001). But even then, the rest of the wider system was acknowledged as context.

Nearly two decades ago Nigel Corlett said in an unpublished paper to the IEA Executive that "[a systems view] does not mean dumping the linear concept, many of our problems can be solved via a linear paradigm and for many situations it is a powerful approach. But it is not enough …and we must take on board some of the more recent [systems] thinking if we are to keep up with need." Even in projects which have been set up to have a narrow focus, perhaps because of sponsor and client constraints, there is a need to know what the wider system is, what the context and what the key interactions, and how all this can be accounted for in the interpretation and use of findings. A beneficial outcome of taking a systems-level perspective is that the right questions will be asked early on in the analysis programme, even if not everything can be addressed in development subsequently.

At the start of this paper a definition of systems was given, but not explicitly one of systems E/HF. Subsequently six defining features of systems E/HF have been discussed and illustrated in the body of the paper. Bringing together these different strands in the paper leaves us with a suggested definition of systems E/HF as:

> Understanding the interactions between people and all other elements within a system, and design in light of this understanding, a system being a set of inter-related or coupled activities or entities (hardware, software, buildings, spaces, communities and people) with a joint purpose; E/HF seeks to understand the links between the entities may be of state, form, function and causation; E/HF conceptualises any system of interest as existing within a boundary and thus a defined context, having inputs and outputs which may connect in many to many mappings; E/HF treats the system as holistic with the whole usually greater (more useful, powerful, functional etc) than the sum of its parts; and E/HF explicitly recognizes that the system changes and modifies its state and the inter-actions within it in the light of circumstances and events, thus showing emergent properties.

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