SHAPING THE SUCCESSFUL IMPLEMENTATION OF HUMAN FACTORS INTEGRATION

S.R. Harmer, J.L. Evans[1] and P.R Wilkinson[2]

BAE SYSTEMS

Abstract

This paper describes the response of BAE SYSTEMS to Human Factors Integration (HFI), an initiative introduced by the UK MoD, and now mandated on all defence acquisition projects. Following a brief introduction to the origins, drivers and aims of HFI, the response of BAE SYSTEMS is summarised, with particular reference to the formation of an HFI Special Interest Group (HFI-SIG).

Within BAE SYSTEMS, HFI is viewed as an integral part of Systems Engineering (SE). However, it is the authors' view that acceptance of HFI by the SE community requires a number of challenges to be addressed; most notably, clarification of the confusion that exists between the similar, and sometimes apparently overlapping, roles and responsibilities of HFI and Integrated Logistics Support (ILS).

It is suggested that the HFI community must take care not to set itself up as a separate specialised entity. HFI is not a specialised discipline in its own right - it is simply good Systems Engineering practice.

1 Introduction

Human Factors Integration (HFI) is a term that was introduced by the UK Ministry of Defence (MoD) in 1993. It refers to the integration of all human-related design, development and support factors in the engineering of complex systems. In 1997, HFI was mandated on all UK defence acquisition projects. Although it is an MoD initiative, HFI is equally applicable to the engineering of non-military systems.

The origins of HFI date back to the 1980s, when MANPRINT was introduced in the US Army. MANPRINT, standing for Manpower and Personnel Integration, aims to provide a focus for the needs and capabilities of the soldier in US defence procurement. The MANPRINT initiative (US) and HFI (UK) are still very similar in terms of objectives, although in practical terms there are some important differences in how the two are implemented. Most notably, MANPRINT is still predominantly a US Army initiative, whereas in the UK, HFI is tri-service.

HFI encompasses the following six domains:

- **Manpower** - the number of men and women, military and civilian, required and available to operate and maintain the system.

[1] Steve Harmer and Laird Evans are employees of BAE SYSTEMS Advanced Technology Centres - Sowerby, Filton, Bristol, England, BS34 7QW

[2] Peter Wilkinson is an employee of BAE SYSTEMS, Warton Aerodrome, Preston, Lancashire, England, PR4 1AX

- **Personnel** - this refers to the aptitudes, skills, physical and mental abilities, and experience necessary to achieve optimum system performance.

- **Training** - the specification and evaluation of the training systems required to develop the knowledge, skills and abilities needed by the available personnel, in order to operate, maintain and support systems to the specified level of effectiveness under the full range of operating conditions.

- **Human Factors Engineering** - this is concerned with optimising performance and eliminating sources of human error through user-centred system design for both operation and maintenance of the system.

- **System Safety** - safety risks need to be identified and assessed to maximise readiness and operational performance through the prevention of accidents.

- **Health Hazard Assessment** - the process to identify and address conditions inherent in the operation or use of a system which can cause death, injury, illness, disability and reduce the performance of personnel (e.g. vibration, toxic fumes, radiation, noise, shock, recoil, etc.).

HFI is about the total integration of all human-related aspects in defence systems acquisition, throughout the entire life-cycle of a system. Its prime objective is to field totally integrated systems by successfully marrying Users and Technology in the Operational Environment, as illustrated in Figure 1.

2 Drivers for HFI

There are a number of important drivers for HFI that are as relevant and critical today as they were in the 1980s, when MANPRINT was first conceived.

a) **Recruitment** - recruitment has always been an issue for professional armed forces. Over the last twenty years or so the labour market has become increasingly competitive. The decline in the number of school leavers due to the demographic trough has exacerbated the problem. Currently, the British Army is undermanned by about 6000.

b) **Cost of Human Resources** - not only are people a scarce resource, they are also an increasingly expensive one. Approximately the same percentage of the UK defence budget is spent on people as is spent on systems and equipment. The message is clear - we must make more effective use of the limited numbers of people available to us.

c) **Sub-optimal Human-Machine Interface Design** - there are many examples of inadequate Human-Machine Interface (HMI) design leading to poor performance, human error and accidents. However, as systems become increasingly complex, and as the cognitive demands on operators and maintainers increase, the impact of poor HMI design on operational effectiveness is become increasingly visible and unacceptable.

d) **Human Error** - there is a growing awareness that incidents that traditionally would be attributed to human error are in fact due to factors such as poor HMI design, inadequate training, or personnel issues (e.g. people being asked to perform outside their capabilities), etc.

e) **Health & Safety Legislation** - the MoD used to enjoy crown immunity from health and safety legislation. However, following the removal of immunity in the mid-1980s, the MoD is now faced with a growing range of both UK and European legislation affecting almost every aspect of its business.

3 Aims of HFI

The primary aim of HFI is to achieve the most cost-effective lifetime fielding of a system in its fully operational role. This is equally important to the design and support of a complex civil system, such as an aircraft or ship, for example. To achieve this, the HFI processes must:

a) tune system design for optimum total system performance by considering human performance and reliability issues related to the six HFI domains.

b) identify the most cost-effective trade-offs between the six HFI domains. This requires the exchange of information between related areas such as Integrated Logistics Support (ILS), Reliability & Maintainability (R&M), Safety, and Human Factors Engineering.

b) ensure that the requirements associated with each operational, maintenance and support task are compatible with the capabilities of the operators, maintainers and support personnel.

c) minimise the Manpower, Personnel and Training requirements to operate and maintain the system.

4 Recent MoD HFI Developments

In 1995 a major review of defence research provided an opportunity to establish a specific research activity in HFI. This enabled the MoD to develop specific HFI tools, techniques and guidance material. As stated previously, HFI was mandated on defence procurement projects in 1997.

More recently, the Smart Procurement Initiative (SPI) has been introduced and this offers new opportunities and challenges for HFI. The MoD is currently reviewing HFI to assess how it should operate within the context of SPI. It is anticipated that the MoD will view HFI as a priority for the success of SPI's aspiration to acquire systems "Quicker, Cheaper, Better". This is because due attention to the cost-effectiveness of the human elements in the defence system acquisition process has been revealed to be a critical component in achieving fielded system success.

Previously, there was an implicit assumption that an HFI specialist from MoD would be assigned to all procurement projects. Practically, this is just not possible, due to the insufficient number of MoD HFI specialists available. With SPI came a move towards the formation of Integrated Project Teams (IPTs), of which there are approximately 150 currently. It is likely that MoD will mandate the appointment of a person to act as an HFI Focus on each IPT. This could well be someone who is not an HFI specialist but whose responsibility will be to manage HFI by means of an HFI working group. It is also likely that, in keeping with IPT philosophy, the HFI working group will consist of representatives from the MoD, the military end-user, the industrial prime contractor, and the prime contractor's principal sub-contractors. The approach of forming an HFI working group, including representatives of the customer, the end-users and the principal contractors and suppliers, is equally pertinent to civil applications of HFI, and is highly recommended.

5 BAE SYSTEMS' Response to HFI

In 1999 British Aerospace and Marconi Electronic Systems merged to form BAE SYSTEMS, one of the largest aerospace and defence companies in the world. The product range of the new organisation is extensive and impressive, covering military and civil aircraft, naval systems, land systems, and a multitude of associated sub-systems, equipment and components. The challenge for BAE SYSTEMS is to ensure that best practice HFI is applied throughout its product range.

Fortunately, BAE SYSTEMS is well placed to meet this challenge. Although it did not then exist as a single entity, the Company has been preparing for the challenges of HFI since the introduction of MANPRINT in the late 1980s. Guidance documents have been developed by several of the Company's Business Units to support the application of HFI on projects. The Military Aircraft division of what was British Aerospace, and Matra BAe Dynamics (UK) Limited, have been particularly active in this respect.

In recent years the MoD's HFI initiative has gained momentum and, as stated previously, is currently undergoing review and revision as a result of SPI. BAE SYSTEMS has been responsive to this change, with the formation in 1999 of an HFI Special Interest Group (HFI-SIG). The HFI-SIG reports directly to the Company's Systems Engineering Management Board (SEMB), which aims to direct a generic approach to Systems Engineering across all Business Units of the organisation. Hence within BAE SYSTEMS, HFI is being viewed as an integral part of Systems Engineering.

The aims of the HFI-SIG are:

- To develop and promote benchmark HFI practice throughout BAE SYSTEMS.
- To ensure that the customers of BAE SYSTEMS find a consistent and exemplary treatment of HFI throughout the organisation.

To achieve these aims, the HFI-SIG plans to undertake the following activities:

5.1 Identification of Best Practice

One of the principal aims of the HFI-SIG is to identify best practice HFI, both within and outside BAE SYSTEMS. As stated previously, the Company is now very large and covers a wide product range. One consequence of this is that what constitutes best practice in one context may not work well in another. For example, an approach to HFI that works well in small teams of systems engineers may be unsuccessful when applied in large teams. Equally, best practice on a naval project may not transfer well to a military aircraft project, as the issues of concern may well differ. For example, in the naval domain crew complementing is an issue on a completely different scale from military aircraft, where the Manpower and Personnel requirements may often be defined by the customer (at least for the operators of the systems). For these reasons, the SIG aims to address the extent to which generic best practice can be identified, and the tailoring necessary for its application throughout the projects and Business Units of the Company. Where deficiencies in current best practice are identified, the SIG will propose development activities to enhance the practice in line with the MoD's stated HFI requirements.

5.2 Promotion of Best Practice

Having identified best practice, an important next step is to encapsulate it in a suitable form for dissemination throughout the Company. This could be achieved in a number of ways although the traditional approach of producing paper-based reports is being superseded by the development of an HFI web site on the Company's Intranet. This approach has already been adopted by what was the Military Aircraft division of the former British Aerospace, which has launched an HFI site on its own Intranet. Within this site are electronic versions of six volumes of HFI guidance material, as follows:

- Volume 1: Human Factors Integration Framework
- Volume 2: HFI (MANPRINT) Management Plan Model
- Volume 3: Early Requirements Capture
- Volume 4: Systems Requirements Analysis (HF)

- Volume 5: Integrated Human Factors Design
- Volume 6: HFI Qualification, Test & Evaluation

It is the HFI-SIG's intention to extend this approach, with much more guidance material, to the whole of BAE SYSTEMS. It has been proposed that the following additional guidance material could be developed under the auspices of the SIG:

Process Issues
- HFI Management Plan Preparation
- Integration with Systems Engineering/Integrated Logistic Support
- Integration with Project Management
- HFI Trade-offs
- Task Analysis/Sharing of Task data etc.
- HFI Concerns Registers/HFI Log
- Allocation of HFI Activities across disciplines
- Management of Subcontractors HFI Activities
- Guide to use of HFI Standards
- HFI Assessment and Acceptance

People Issues
- Project HFI Organisation
- HFI Training/Education
- Multidisciplinary Integration

Technology Issues
- HFI Tools/Techniques Directory
- HFI Application of Systems Engineering tools (e.g., DOORS, RDD-100, etc.)
- Task Databases

In addition to the creation of an HFI Intranet site, other preferred options for promoting best practice include organising a travelling 'road-show' to disseminate information to the various sites of the Company, and holding learning events and workshops.

Clearly, for any of these promotional activities to succeed, the HFI-SIG must reach its intended target audience. For reasons that will be outlined later, that audience is the Systems Engineering community within BAE SYSTEMS, particularly at the level that can influence the application of HFI on projects, i.e. at the level of Chief Engineer.

5.3 Support and Influence MoD HFI Developments

It is an aim of the HFI-SIG to not only maintain an awareness of MoD HFI developments, but also to support these developments and, where appropriate, to influence them. The SIG is well placed to do so, as BAE SYSTEMS currently contributes four members to the UK MoD/Industry HFI Working Group, one of whom is the current Chairman.

Of particular interest to the HFI-SIG is an initiative within the MoD to consider development of an HFI Defence Standard. This initiative is currently under review by the MoD/Industry HFI Working Group. As BAE SYSTEMS would be a key user of such standards, the HFI-SIG aspires to support and influence their development as much as possible.

6 Challenges Facing HFI & Systems Engineering

As stated previously, within BAE SYSTEMS, HFI is viewed as an integral component of Systems Engineering (SE). However, acceptance of HFI by the SE community requires a number of challenges to be addressed.

In the first instance, it must be acknowledged that HFI is not a discipline, but an integration activity. Its aim is the successful integration of people with equipment in an operational environment, and to achieve this requires:

- the integration of project effort across the six HFI domains

- the integration of HFI with related disciplines within SE, especially Integrated Logistics Support (ILS).

The discipline of ILS has a key role to play in the successful implementation of HFI. HFI and ILS require different but complementary activities. Both are concerned with integration, although the focus for HFI is the human in the system, while the 'traditional' focus of ILS might be viewed as providing support to the equipment elements of the system. Since there are human issues involved with support, there is clearly an area of common interest.

HFI is complicated by the fact that there is not a direct one-to-one mapping of all six domains on to established Systems Engineering disciplines. The domains of Training, Human Factors Engineering (HFE), System Safety and Health Hazard Assessment map sufficiently on to corresponding SE disciplines, but the domains of Manpower and Personnel do not (see Table 1). There is neither a Manpower discipline nor a Personnel discipline within SE. Traditionally, these two domains have been the responsibility of either the ILS discipline or the HFE discipline, depending upon the life-cycle phase in question. The HFE discipline has traditionally focussed on Human-Machine Interface (HMI) design, particularly during the requirements analysis and design phases of the life-cycle. Understanding who the eventual users are, and what their physical and mental capabilities and limitations are (i.e. Manpower and Personnel issues), clearly has an important bearing on HMI design during these early design phases. On the other hand, ILS has traditionally focussed on providing support to equipment during the in-service phase. A comprehensive understanding of Manpower and Personnel requirements is clearly fundamental to the successful provision of affordable support.

Unfortunately, this has led to some confusion over the roles and responsibilities of HFE and ILS. This confusion has been highlighted in recent years as a result of both ILS and HFE recognising the need to take a whole life-cycle perspective. As a result, HFE has extended its area of interest to maintenance and support activities normally associated with ILS. At the same time, ILS has extended its area of influence to include considerations traditionally viewed as the preserve of Human Factors Engineering. For example, by influencing the HMI design early in the life-cycle, the ILS discipline is able to reduce the cost of support activities during the in-service phase.

By adopting a whole life-cycle perspective, the disciplines of HFE and ILS are in some respects moving closer together, although with the added issue that their respective roles and responsibilities require further clarification. The same may be said of the HFI and ILS initiatives.[3]

The key areas where the HFI and ILS initiatives require common data sets are in the Manpower, Personnel and Training domains. These overlaps principally concern information about the likely user population - the numbers and types of operators, maintainers and support personnel, and their mental and physical attributes, skills and abilities.

The important point must surely not be which of HFI or ILS takes responsibility for acquiring the necessary data, but that one does, and that the interdependencies for data between the various SE disciplines are identified sufficiently early in the process to avoid unnecessary duplication of effort.

In this respect, in the absence of a mandate from MoD, strong leadership is required from within the project, ideally from the Chief Engineer. This is the person with sufficient authority to ensure that HFI and ILS interact in a cost-effective manner to the benefit

[3] Part of the confusion is that both HFI and ILS are integration initiatives within Systems Engineering. At the same time, ILS is also a Systems Engineering discipline, whilst HFE is both a Systems Engineering discipline and a domain of HFI.

of the project, and that their respective roles and responsibilities are clearly defined.

Experience within BAE SYSTEMS has indicated that HFI can be applied to very good effect from within the ILS discipline. This has been shown to be true at least for certain types of projects, although this approach may not work well in all instances. The challenge for the HFI-SIG is to identify why this approach has worked well in these cases and to determine whether it can be applied or tailored to others.

It is the authors' view that the name, Human Factors Integration, has not helped the cause of HFI, since it is often confused with Human Factors Engineering (HFE). This is true even within the Human Factors community. Also, because of the name it is often assumed that HFE specialists will naturally take the lead in co-ordinating and managing HFI activities on a project. Whilst this may be entirely appropriate in many cases, in some instances it may be more appropriate for ILS specialists or specialists from another engineering discipline to perform the management of HFI. In short, its name has probably not done HFI any favours, and arguably the term MANPRINT was more appropriate. It is worth noting that in the US the ILS community has taken the lead in promoting MANPRINT, whereas in the UK it has been the HFE community that has taken the lead in promoting HFI.

7 The Way Forward for HFI

With the adoption and development of the HFI programme, the UK is taking positive steps to ensure that fielded system capability better harnesses and matches the attributes of the human and equipment components. Both the customer procurement agency and the user community alike will benefit from increased system cost-effectiveness as a result of improved procurement and development processes.

Systems Engineering as a discipline is concerned with enhancing the overall fielded capability of a system in a cost-effective manner by synergistic integration of the system components. In this context, the development of good HFI practice has a significant contribution to make to the overall aims of the SE discipline.

The future success of HFI is dependent upon its acceptance by the wider SE community. The traditional technology-centred approach to systems definition, design and test must give way to a more human-centred Systems Engineering approach, where the needs, capabilities and limitations of the human operators, maintainers and support personnel are seen as the key design drivers. This change to a human-centred Systems Engineering culture in military systems acquisition will not be easy, and will require commitment from both customer agencies and industry alike.

To achieve acceptance from within Systems Engineering, the HFI community must take care not to set itself up as a separate specialised entity. It is important to remember that HFI is not a specialist discipline in its own right. It is simply good Systems Engineering practice.

Within such a culture, BAE SYSTEMS has set up a steering group to oversee HFI developments within the Company that reflect and can influence customer effort. Under the auspices of the HFI-SIG, the identification, development and promotion of HFI best practice aims to ensure a consistently exemplary treatment of HFI issues throughout the Company. BAE SYSTEMS is committed to supporting HFI and Systems Engineering development throughout the UK by means of active partnership between MoD and Industry.

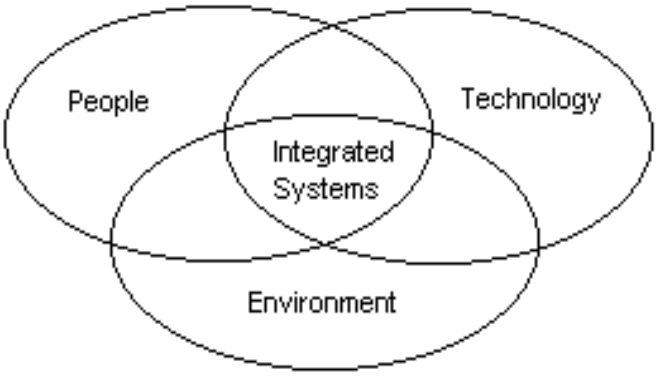

Figure 1: Human Factors Integration Concept

HFI Domains		SE Responsibility
Manpower	→	ILS engineers or Human Factors engineers
Personnel	→	ILS engineers or Human Factors engineers
Training	→	Training specialists (possibly within ILS)
HFE	→	Human Factors engineers
System Safety	→	System Safety engineers
Health Hazards	↗	

Table 1: Mapping of HFI Domains on to SE Disciplines