Developing Human Factors Guidance for COTS Equipment Assessment

The work described in this document has been undertaken by the Human Factors Integration Defence Technology Centre, part funded by the Human Capability Domain of the U.K. Ministry of Defence Scientific Research Programme.

Reference HFIDTC/WP3.7.6/1

Version...2

Date...25th August 2005

Authors

Anne Bruseburg	**SEA**

Additional Contributors

Pam Newman	**SEA**
Mel Mock	**SEA**
Kerry Tatlock	**SEA**
Clare Borras	**SEA**

Contents

1 Introduction

1.1 Overview

This report describes the results of the work carried out on the HFI DTC work package 3.7.6: 'HFI for COTS' (commercial off-the-shelf). Whilst the use of COTS products generally prohibits influence on their design, the design of the socio-technical system into which the product needs to be integrated requires considerable attention. This is especially so when dealing with Human Factors (HF) aspects, which are often less tangible than engineering issues, and therefore more difficult to capture in requirements specifications and assessment metrics.

The work package resulted from an earlier recommendation (WP 3.1.4), having identified the need to "provide guidance for the assessment of COTS equipment in relation to HF and capability" [33]. It suggested the "extension of HFI guidance to cover the provision of systems procured as COTS items", including the "development of a methodology to assess HF 'fitness for purpose' of COTS equipment and systems". The increasing reliance on COTS products in the defence domain suggests the need for providing HF support, thus enabling HFI for all types of procurement.

This report identifies requirements for providing HF guidance for COTS equipment from a practical perspective, by identifying characteristics and processes of COTS equipment selection activities on the one hand, and HF impact, on the other. It presents the development of a tool in the shape of a checklist for a broad HFI COTS equipment assessment, aiming to support high-level decision-making processes for HFI. The assessment tool aims to capture the breadth of potential HF impacts for the specific requirements of COTS products. The COTS equipment assessment tool can be used as a stand-alone aid, or may be incorporated into the desktop tool.

Section 2 discusses the need for providing HFI guidance for COTS products. Section 3 identifies HFI COTS guidance requirements, by reviewing existing HF approaches. Section 4 reviews the breadth of COTS products and identifies COTS-specific HF impact areas. Section 5 further reviews the characteristics of COTS products and assessment approaches that exist in non-HF domains. Section 6 clarifies the process of COTS product assessments, to understand the questions, activities, and decisions that the tool should support. Section 7 describes a prototype of a Human Factors COTS assessment checklist in the shape of a questionnaire.

1.2 Summery and work progress

A comprehensive literature review was conducted to identify existing HF/HFI guidance, HF impact areas, and COTS equipment characteristics – both in terms of assessment process and assessment criteria. Initially, the output of this work was envisaged as a decision making aid in the shape of a series of flowcharts, combining process with relevant assessment criteria. For this, a suitable taxonomy of COTS equipment variables was sought, in order to identify suitable decision-making criteria depending on circumstances.

Various types of taxonomies were identified from the literature – and broadly distinguished as identifying (1) constraints, (2) product types, or (3) quality criteria. A list of variables was identified (see Table A1 in Appendix A). A COTS-specific taxonomy of HF impact areas was developed, aiming to cover the breadth of potential impacts of COTS products on HF issues. The initial, longer version of the taxonomy can be found in Appendix A, Figure A1. It was subsequently simplified and converted into the HFI assessment checklist in the shape of a questionnaire.

The literature review identified that the breadth of COTS equipment variables regarding COTS equipment types, integration types, assessment process, HF impact, HF assessment criteria, as well as assessment and decision-making options cannot be captured through a prescriptive process, but needs to provide flexible guidance at a high level – to be widely applicable.

It was identified that HF recommendations for COTS equipment must deliver advice for the specific characteristics of COTS equipment that differ from other types of equipment. Since input into the design process is not needed (unless products are assessed during the last prototyping stages and some limited design input is still possible), HF focuses on product assessment only (to support purchase decisions and implementation plans) – by making predictions about all aspects of anticipated use/disposal issues, and by drawing on comparisons with existing experiences of use.

A widely applicable, and simple, process model was sought as the basis for guidance material. The process model captures the underlying stages, activities and questions of the COTS assessment process. Based on this, and an understanding of COTS-specific HF impact areas, a practical assessment tool was developed. It is based on an HF impact assessment checklist in the shape of a questionnaire. The questionnaire aims to capture the breadth of potential HF issues, for an initial identification of issues requiring deeper attention. It provides an initial HF assessment tool to identify HF impact (e.g. risks, benefits), and action requirements (e.g. address problems; further HF studies to clarify).

The prototype questionnaire was tested informally, seeking practitioners’ feedback, and developed through a number of iterations. Details for a range of practical applications were sought to identify requirements for the HF tool, and to test example applications. The resultant product may be improved further through wider testing in practice, and covering further application areas and perspectives.

2 Background

The design of safe and efficient systems not only includes the development of new technology, but also the design of entire work systems, where the integration of new technical solutions within new or existing systems is central. In recent years, the use of COTS products has been increasingly promoted in many domains due to the potential cost savings, quick availability of solutions, and provision of cutting-edge technology. This considerably changes the design processes for the overall system, since component development is replaced by purchase [1]. Whilst designing the COTS product is not required, the scope for customisation and specification is limited – therefore replacing a number of variables with constants.

Requirements engineering and selection of COTS equipment is traditionally mainly driven by functional requirements (using the quality definitions of ISO 9126 for software products). However, it is increasingly recognised that non-functional issues are equally important [2,3,4], since they can severely impact overall functionality and efficiency. Likewise, the benefits of using COTS equipment are often ‘short-sighted’ [1,5], since the long-term costs including implementation (e.g. training, integration), maintenance, and support costs need to be taken into consideration as well.

Many of these non-functional requirements are HF issues. Currently, hardly any HF guidance specific to the selection of COTS equipment is available. HF concerns are often not considered since the potential implications are unclear, especially to non-HF professionals, and no practical assessment methods exist. HF issues can be understood here as including both ‘risks’ (in the sense of concerns and negative effects for health, safety, performance, and work quality) – as well as HF ‘benefits’ of COTS products (e.g. improved functionality). Both risks and benefits are usually assessed in terms of their cost implications for development and use.

The importance of considering HF issues is increasingly recognised due to its potential impact on overall project costs. For example, the new Def Stan 00-56 that is soon to supersede the existing Def Stan 00-55 (Requirements for Safety Related Software in Defence Equipment), outlining requirements and processes for making a safety case, provides much more detailed HF requirements than Def Stan 00-55 [30,31]. Whilst also providing much guidance for COTS equipment, it includes no reference on HF of COTS. The main HF reference used is Def Stan 00-25: Human Factors for Designers of Equipment. Practical aids for assessments are not included.

Generally, HF issues are often seen as problematic to incorporate into requirements specifications and assessments since they are ‘soft’ factors that are difficult to specify and measure concisely and consistently. Moreover, specific HF expertise is often lacking in procurement organisations, thus preventing sufficient consideration. A high-level guidance document for HFI [6] is available. However, additional support and accessible materials and tools are needed to promote the uptake of the information.

Military equipment acquisition covers an extremely wide range of applications, technologies, and levels of complexity. The solutions acquired may be entirely off-the-shelf, at one end of the scale, or may be entirely custom-made (the more traditional approach), by commissioning the design and manufacture to a contractor. Supply may incorporate the equipment only, or additionally, support, training, and/or operators. The amount of impact may range from single components to whole system changes, and may have an effect on the human element including training, procedures, personnel, and organisational structure.

HF guidance for COTS assessment mainly aims at supporting the MoD Defence Procurement Agency, however, the boundaries are often fluid. Thus, a standard tool usable by all partners (e.g. customer, supplier) would aid communication. HFI support is required for all of these lifecycle stages and needs to have inputs into all the main acquisition documents and decision-making points to be incorporated effectively.

3 HFI guidance needs for COTS equipment

COTS technology, goods, or services, are generally defined through the fact that they have not been designed or produced under government funding, and that they are offered for sale to the general market under commercial business practices [7]. In other words, they are not custom-made. The general characteristics of COTS equipment also extend to MOTS (military off-the shelf) products. MOTS are either commercially available for military applications, or can be customised to an extent for military requirements.

In the military domain, there can be an extremely wide scope of products (e.g. software, hardware, personal equipment, services, and combinations of these). Therefore guidance on COTS equipment cannot possibly cover all applications and specific circumstances in depth. Likewise, the perspective of HF assessment may differ. It may be carried out either (1) as part of the system development by a contractor to be presented to the IPT, or (2) within the functions of the procurement agency, in a purchasing, or auditing role. The tool aims to support primarily team members with no or little HF expertise. On extension, it can be supported with more detailed guidance for HF experts. We also aim to set out central COTS equipment characteristics, to aid HF experts in what they may need to communicate to process managers (e.g. understanding COTS constraints; referring to specific COTS challenges). Table A3 in Appendix A provides more details regarding specific characteristics of COTS products.

The HFI process for COTS equipment integration includes (1) specifying HF requirements for product search, assessment, and pre-selection (as an iterative process); (2) product identification and selection of suitable products (if a COTS solution is acceptable at all) – through market surveys, evidence gathering, evaluation, and comparison techniques, determining options and approaches for system design; (3) system design and adaptations to accommodate COTS components (e.g. adapted procedures; maintenance schedules; 'glue code' – software that makes COTS software fit into a larger system); (4) implementation of the system design. We focus here mainly on providing guidance for the first two activities, including planning activities for stages 3 and 4.

Very little specific guidance on HF for COTS equipment is available in the public domain, thus often preventing sufficient consideration of HF. The HFI for IPTs guidance document [6] only provides a very high-level task list with a strong focus on identifying requirements due to new contexts of use, in comparison to evidence of human performance with the envisaged equipment in current use. Lockett and Powers [8] identify that the main difference between COTS equipment and other products lies in the mechanisms available to intervene (i.e. not through product design). Therefore, a critical requirement for HFI is to foresee potential problems before making purchasing commitments.

Compliance with HF standards is usually seen as the easiest way of making sure HF are considered, but only for the areas in which standards are available (often civil) and can be applied to the requirements of the military domain. 'Open systems' (i.e. complying with standards accepted by a certain community) are often considered to provide safeguards, however with limited success since depending on suitable agreements [9]. Howard &

Strong [10] provide a review of applicable HF standards, but stress that standards often lag behind technological advances. Similarly, Sinclair [11] gives a number of recommendations for ensuring functional safety of COTS software, having identified a lack of standards addressing specific COTS characteristics – mainly because they were written before the term became widely used.

The Federal Aviation Administration (FAA) [12] provides a detailed HF guide for COTS equipment, based on an extensive HF concern taxonomy for the areas that were identified to be impacted through COTS equipment acquisition (i.e. maintenance automation; designing equipment for maintenance; human-equipment interfaces; workplace design; user documentation; system security; personnel safety; environment; anthropometry and biomechanics). However, it does not address specifically issues of *integrating* COTS equipment into a larger system. Long lists of potential HF risks for all possible areas tend to be impracticable, especially for specialised tasks and applications, or for novel technologies. As a document with over 1000 pages it provides a checklist too large to handle (especially for non-HF-experts), and without sufficient consideration of underlying assessment processes, and provision of required values. However, at the level of HFI, quick identification of concerns is essential.

Williams et al [28] identify two types of COTS equipment procurement – either by matching technologies to a statement of use need, or by identifying potential uses for emerging technologies. They propose a method (MEDIUS-C) consisting of several task stages, closely relating to processes that support creativity. HF considerations are suggested to be located mainly within the assessment phase. As part of the same project, Martin et al [29] developed specific HF assessment checklists for interface evaluation of COTS computer equipment, based on a list of particular observed problems for Command Information System, with links to interface design standards. These methods, however, are not in the public domain. Moreover, we aim to produce slightly higher-level guidance covering a wider range of applications.

Therefore, a careful balance needs to be struck between providing guidance at a high level, but with a sufficient amount of detail, having to cover an extremely wide range of possible technologies and applications. To provide support at the management level, we envisage an easy-to use tool for initial HF assessment that identifies potential areas of HF concerns, or benefits, to be addressed further if needed. Beyond this, specific HF expertise may be required for more detailed predictions, assessments, and tests.

4 HF impact of COTS equipment

Different types of COTS equipment may have different effects on HF issues. For example, night vision equipment for urban combat operations can be purchased as COTS equipment to be used in combination with handguns. HF issues that may arise include standard usability issues (e.g. weight, ease of carrying, usability of buttons and screens), but also issues such as the extent to which they should or should not be mounted on guns, how to avoid a bright screen being seen by the enemy, or how to deal with the change of optics between different magnifications on gun and night vision equipment.

In contrast to this, a piece of COTS computer hardware, such as a screen (e.g. as part of a surveillance sonar system on a ship), may need to fit physically into an existing control platform, and comply with ergonomics workstation design requirements (e.g. working position, glare, screen size). There may be requirements for consistency with parallel equipment. In environments such as submarines, there may be extreme operational constraints on COTS equipment dimensions and installation due to space restrictions (e.g. screens need to fold out to enable operators to get in; COTS components may create excessive heat). A network card, however, as another example for COTS hardware, is likely to have no HF impact other than HF effects of maintenance tasks. Besides, the use of standard laptops and Windows platforms may create positive implications for reducing training requirements, since operators tend to be familiar with these systems.

COTS software, representing another category, has an extremely wide scope of functionalities (e.g. data recording, interface display, speech recognition, control of hardware), with HF implications ranging from the compatibility with existing interface design philosophies, to training needs, or the provision of adequate user documentation.

Beyond this, COTS equipment may comprise entire modules consisting of both hardware and software components that are supplied with an interface (e.g. collision warning systems for aircraft). Here, a range of HF issues of the product itself, as well as its integration requirements may arise.

The manner of COTS equipment incorporation into an existing system may vary substantially. They could be part of a custom-made solution provided by a customer (e.g. incorporation of COTS hardware), may be acquired directly as part of a solution, or (more rarely) as the ‘complete’ solution. The aim may be to identify a single COTS product, or a number of interacting system components supplied through COTS equipment. In many cases, special technical adaptations are necessary, all of which may have their own HF implications.

Whilst there can be significant differences, there are also similarities across COTS equipment. In the software community, a number of concerns have been raised for the cost benefits of COTS equipment, especially by considering more long-term and integration aspects – mainly of a functional nature. HF requirements need to be considered in relation to a range of technological and business integration issues. HF considerations are part of the wider implications that are often not sufficiently considered through ‘short-sighted’ cost savings (e.g. not considering implications of servicing, technical support needs, training/manning, implementation, problems of use). Many

COTS software products however may not directly interface with users other than through reliability and functionality issues. Interfaces are considered as one of the major HF issues [13], whether supplied or impacted; the other major issue is technical integration, which influences HF mainly on a functional level, and associated knock-on effects where reliability problems remain. Generally, not much guidance is available for non-functional requirements. Information about user needs is often neither accessible nor demanded by the right people in the process, when HF requirements are unclear.

HF requirements apply depending on the extent to which COTS equipment creates an impact on users, either directly (e.g. provision of own interface; stand-alone device), or indirectly (e.g. operators required to manage additional hazards due to technical problems of COTS equipment integration; additional information about the COTS software component needs to be on the displays).

In order to provide guidance, it is essential to identify the types of impact that COTS products can have on HF issues. We aim to focus here on issues that are fairly unique to COTS equipment, thus avoiding reproducing extensive listings of HF impact and risk areas that are available elsewhere. HF assessment requires predictions about how the product can be integrated with work systems and technical systems. For COTS equipment, these predictions can often be informed by evidence from existing product use and integration. Beyond this, it is necessary to compare anticipated and previous contexts of use, to assess potential *transfer* problems. Clearly, military environments are often much more demanding than the environments which the products were initially designed for. We have identified the following types of HF impact:

(1) HF effects of product as such (direct impact) – on functionality and effectiveness of operation, including

- presence or absence of a functional benefit in choosing a specific COTS solution (e.g. screen technology usable in bright daylight);

- effects of product functionality, including reliability problems impacting safety, and requiring additional procedures, workarounds, training etc. (e.g. fault tolerance, suitability, maturity, accuracy, efficiency);

- usability of product: HF issues of COTS product as such (e.g. quality of graphical or physical interface; physical handling and usability; suitable allocation of functions between user and automation);

(2) HF effects due to integration into a technical and work system (indirect impact), including

- task and operational context requirements (e.g. organisational structures, task conditions, procedures, safety-criticality);

- transfer issues (e.g. implications due to the difference to the original use, implementation issues), as well as compatibility and consistency issues.

- wider issues of use, causing HF costs (indirect effects), including, for example, maintenance, health hazards, continued training, disposal hazards.

- needs for physical and operational integration of (a) interfaces and controls; (b) other parallel and integrated equipment (e.g. fit into space/physical dimensions, consistency problems, reliability due to software integration); this includes compatibility and consistency issues;

- HF issues due to the need for additional (purchased or custom-made) software or hardware to accommodate devices – e.g. problems due to custom-made interfaces (e.g. additional data to be displayed), supporting equipment, or additional software (e.g. 'glue code');

COTS components are usually sourced to provide financial benefits. This means that the use of COTS equipment almost always requires compromises in order to save costs. The extent to which a sub-optimal solution is acceptable is often a central question. Therefore, HF issues tend to be considered as minor considerations unless causing major constraints and performance problems (e.g. effects of health hazard).

HF impact may be specified not only in terms of risks (i.e. what aspects speak against choosing the product), but also in terms of potential benefits (e.g. reduced training cost due to familiarity with standard equipment), as well as system design requirements to accommodate the COTS component. Assessments can be made according to qualitatively very different criteria.

Part of risk identification is the specification of potential HF costs. These can vary widely regarding the way they may be quantified – including (1) in-service spending (e.g. manning, training, servicing, safety culture); (2) one-off costs (e.g. development, implementation); (3) incidental cost due to undesired events (e.g. failures, accidents, absence); (4) effectiveness (e.g. performance, mission success, task achievements). Cost implications vary depending on how many products need to be purchased. In some cases, only one product may need to be integrated into a system (e.g. voice recognition software), on others, a large number of the products may need to be purchased and distributed for use (e.g. folding beds) – where HF risks or benefits may have different weights.

Risks need to be identified based on the likelihood of problems in relation to a set of values to be achieved. Risks may be formulated based on (a) the presence and impact of adverse conditions on performance and safety (e.g. environmental factors); (b) anticipated problems of use (e.g. effectiveness, efficiency, failure due to error, workload etc.); or (c) non-adherence to known design guidelines and principles (including standards). When aiming at identifying a single assessment taxonomy covering all relevant aspects, these qualitatively different issues need to be combined carefully.

5 Specific challenges for COTS equipment

There is a large body of literature on the integration and assessment of COTS software, with a variety of methods and taxonomies, primarily for assessment criteria. Challenges result from the circumstance that there is little, or typically no direct influence on product design and original requirements specification. Hence, the product is often purchased as a 'black box' [1,14], which may have unwanted or undesired functionality, or may have a build that does not fit other parts of the system well, usually requiring modifications to the existing technical systems (e.g. 'glue code') and modifications to work systems (e.g. training on dealing with potential faults). The ISO 9126 standard on software quality is widely regarded as the basis for evaluation, with various types of extensions and detailing of categories [15,16,17]. None of these focus particularly on HF issues, but they are partly included within 'non-functional' criteria (e.g. efficiency, usability, maintainability, portability).

Thus, COTS products can provide a number of generic advantages (e.g. cost savings; universally applicable; advanced technology; available within short time frame; evidence of existing use obtainable). They also display a number of universal disadvantages (e.g. unpredictable effects; unwanted functionality possible; need for frequent upgrades; customisation options limited; robustness not up to military requirements (non-HF)).

Other types of COTS equipment such as hardware and stand-alone equipment get considerably less attention in the literature. However, a number of messages from the software community also apply to other COTS products. The development process involving COTS equipment is significantly different from the usual life cycle stages – requiring a more iterative approach, where all issues (e.g. requirements, solutions) are being evolved in parallel [1,13]. Requirements specification is central, and iterative, ideally moving from high-level statements of use needs, enabling searches, to comparisons of solution options provided by suppliers approached. Whilst requirements need to have a flexible nature as they are developed in relation to the options available on the market, at some point a concise definition of requirements is essential for comparing alternatives [13,18].

The difficulties of assessing COTS equipment as part of COTS requirements specification, selection and integration activities are reflected in the large number of COTS software assessment techniques. They include: PORE: Procurement-Oriented Requirements Engineering [19]; OTSO: Off-The-Shelf Option [20]; STACE: Social-Technical Approach to COTS Evaluation [21]; CAP: COTS Acquisition Process [15]; CBCPS: Contract-based COTS Product Selection [14]; CARE: COTS-Aware Requirements Engineering [4], CRE: COTS based on Requirements Engineering [3]. All of these focus on comparing purchasing options using multiple criteria ratings, and rely on providing a set of suitable assessment criteria reflecting COTS equipment characteristics. Some of them focus more on functional requirements, others recognise the increased need for the inclusion of non-functional requirements. However, none of them are tailored to HF issues at a sufficient level of depth.

Most of these methods supporting COTS assessments use some form of taxonomy. These may be broadly classified into (1) product taxonomies, e.g., by integration types

[22], product characteristics [23], system types [1]; (2) procurement variables taxonomies, e.g. V-rate taxonomy [24]; (3) quality taxonomies, e.g. evaluation taxonomy [15]; ISO 9126 [25].

A generally used assessment tool applied in military procurement is the assignment of Technology Readiness Levels (TRLs). TRLs express the level of product maturity regarding the extent to which the product has been designed, tested, and proven adequate for the application required through practical use. They tend to correspond to different design stages. When not assessing single products, the UK MoD recommends SRLs – System Readiness Levels [26]. These are more suitable to COTS equipment assessments since they also account for integration issues at the system level. COTS products often display higher levels, from level 5 (sub-systems verification in laboratory environment), up to 9 (system proven through successful representative mission profile) – but not always. Moreover, it needs to be taken into account that the issues of system integration often create new configurations for which readiness cannot be demonstrated. Recent SRL definitions also give recommendations for HFI compliance (e.g. operability trials conducted – at Level 8). The chosen criteria for specifying HF Readiness, however, do not take account of unique COTS requirements (e.g. transfer to new task; new context of use).

Likewise, Smith [27] identifies a number of difficulties for using TRLs for COTS software assessments, since it blurs a number of issues that should be treated separately. For example, mixing together different values such as “correctness,” “usability,” and “relevance” achieves a questionable meaning. Smith [27] suggests an alternative measuring system (ImpACT) that distinguishes between ratings for importance (i.e. criticality for system functioning); availability (i.e. widespread use); capability (i.e. functional fit); and timeframe (i.e. matching lifecycle considerations).

6 Identifying central questions and processes

To effectively aid COTS equipment integration, the underlying questions and processes need to be understood. Figure 1 provides an overview of the main decisions to be taken when assessing HF implications of COTS equipment, in relation to the underlying questions and activities required throughout the major process stages.

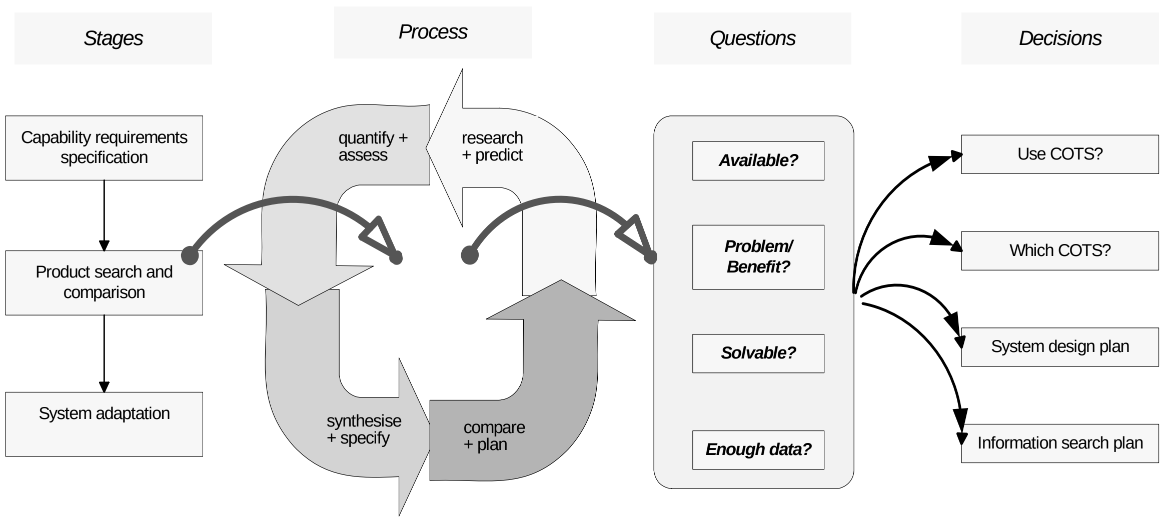

Figure 1 - Activities underlying COTS equipment assessments.

The main decisions concern purchasing, selection, system design and planning options – in relation to specifying capability and functional requirements. COTS equipment assessments usually aim to provide answers to one or more of the following questions:

- Is a COTS equipment solution an option, or should the product be designed and developed instead? What are the underlying risks and cost factors that may not favour COTS equipment use?
- Which COTS product option should be purchased? What are the advantages and disadvantages for each option?
- What are the technical and socio-technical system design and modification requirements to accommodate a COTS solution? (This is needed both for option comparisons and planning activities.)
- Which information search, testing, or further assessment activities are required?

Central to making such decisions is providing answers to the following *questions*:

- *Can the technological options available on the market be matched to the requirements?* Usually, this is a question of matching a product to requirements, however, on occasions, it may be necessary to identify useful applications for emerging technologies, thus taking the opposite approach [28]. Identifying capability requirements may be part of the task. This requires search, specification, and comparison activities.

- *Has the product itself, or its integration into a technical/work system, any capability-limiting, or capability-supporting, implications?* This requires the predictions of risks and/or benefits in relation to specified values.

- *What are the feasible HF mitigation options available?* This requires activities of planning.

- *Is enough information available*, or are there any specific research or assessment needs, due to high levels of uncertainty (e.g. to make purchasing decisions, identify selection and design requirements and criteria, assess readiness levels)?

To be able to answer these questions, HF risks and opportunities need to be specified and assessed. This requires a gradual iteration between several types of qualitatively different activities, which need different types of process support. The activities can be distinguished into:

- Understanding, by researching and predicting impact, as well as identifying options, variables and constraints.

- Quantifying, by assessing impact through cost predictions and importance ratings.

- Specifying requirements and assessment criteria, by synthesising the information collected.

- Planning, by identifying acceptance and comparing options in relation to benefits, to make decisions and specify actions.

The process guidance incorporates insights from COTS-specific selection requirements. A widely applicable, and simple, process model was sought as the basis for guidance material. Figure 2 visualises the activities underlying risk management. They inform each other in an iterative manner, and relate very closely. However, they require different resources for support. Table 1 further specifies these activities regarding their outputs, underlying processes, and requirements for HF support. Figure 5 in ANNEX A shows that a categorisation of the underlying activities identified as necessary for COTS equipment assessments has led to the process model.

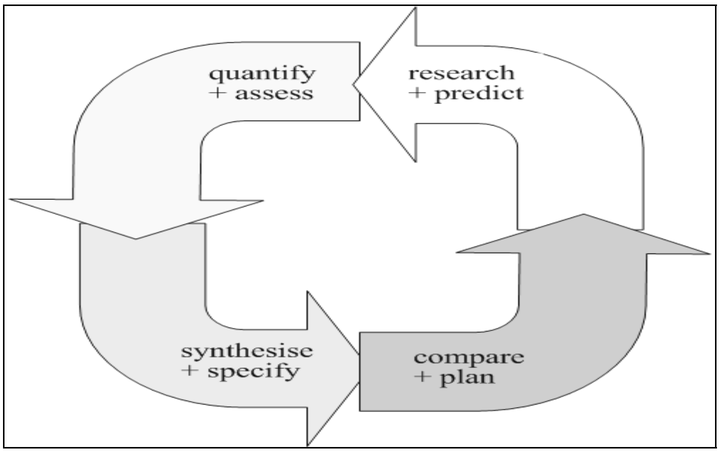

Figure 2 - Activities underlying risk management.

Table 1 - Activities to be supported by HF guidance

Component tasks	Outputs	Description	Support needed
Understand, Predict + Identify	Concerns, Risks; Benefits; Variables and Options	• Research, record, and iterate HF-relevant characteristics to support iteration • Identify products and product details (e.g. existing information of use constraints) • Predict impact of COTS equipment use and integration into technical and work system; • Identify areas of HF concern, and HF benefit • Relate to variables (design options)	• How to identify relevant product factors influencing HF risks • What are the COTS-specific HF risk, benefit and design areas • How to link COTS characteristics (specific and generic list) to HF issues • Guide through impact assessment process (risks, benefits, design requirements) • Provide choice of options
Quantify, Assess	Cost implications; Impact ratings	• Predict potential cost implications of risks and options • Identify Trade-off issues • Establish priorities and relative importance of issues/options identified	• What are potential cost implication areas • How to judge severity of impact • What are suitable assessment criteria for risk impact ratings
Synthesise + Specify	Requirements; Assessment Criteria	• Identify HF requirements (non-functional) • Identify descriptions of criteria for assessment (that can be related to non-HF criteria; can be quantified in relation to each other)	• How to specify HF requirements with increasing level of detail (from statements of use needs towards technical detail) • How to identify (project-specific) assessment criteria for product comparison
Compare, Choose + Plan	Choices, Decisions; Plans	• Compare options based on risk ratings for all identified areas • Specify list of relevant HF activities (plan, research, HFI tasks) for all identified areas	• How to compare products based on risk ratings for requirements • Planning activity and HF task identification

7 Developing a COTS equipment assessment tool for HFI

Based on these insights regarding the COTS equipment acquisition processes, assessment values, potential HF implications, and information requirements, we developed a prototype of a HF COTS equipment assessment checklist in the shape of a questionnaire (see Figures 3 and 4). It fits onto two A4 pages. It is primarily intended to be used as a checklist by non-HF professionals, to consider the breadth of potential HF issues, and identify issues that require further consideration. It is intended to be applied at early decision-making stages, when uncertainty is high, and any needs for more in-depth HF involvement are being established.

The questionnaire includes means for applying basic metrics to judge relative importance of issues. It is, however, not intended to be used as a tool for quantification, but as a tool for identifying HF concerns and benefits. Various methods exist for measuring human performance (e.g. as a combination of effectiveness, efficiency, work/product use satisfaction) – from different HF perspectives (e.g. usability, health and safety, training). They need to be applied by HF specialists, and often cover fairly narrow areas (e.g. software ergonomics). In contrast, this questionnaire is intended for capturing the entire breadth of HF issues, with a specific focus on COTS product characteristics. It is intended to feed into initial cost scoping and cost-benefit analyses as part of product option assessments.

The questionnaire has been matured and tested informally through feedback from both engineering practitioners with expertise in COTS equipment integration (n=7), as well as HF professionals (n=3). The engineering practitioners included experts for COTS software, hardware, and stand-alone equipment. Feedback was sought regarding the modes and ease of application, as well as the assessment categories and values.

Appendix C gives further details on the examples and feedback given by engineers. The interviews were conducted at different stages of the questionnaire development – hence different types of information was retrieved. Insights were gained regarding general applicability, the potential scope and process of use, the types of HF issues arising from example projects, the usefulness and understandability of the HF impact categories, as well as the suitability of the assessment options for the questions that arise to practitioners. Many of the observations made from the literature for COTS software were confirmed for COTS hardware. Later on, the interviews focused more on format and ease-of-use issues.

The scope of impact areas was generally perceived as useful. Non-HF practitioners appreciated the example section. Improvements were made regarding the simplification of structure and wording, organisation of assessment options in relation to impact areas, provision of instructions, and graphical layout. The intended use by non-HF professionals calls for particularly rigorous presentation requirements to encourage use. Space for notes was added to facilitate referring back to the document at a later stage.

The observed example applications confirmed that the purpose and perspective of how COTS products may be acquired and integrated can vary substantially, often from project to project. They can vary from situations where broad market searches and tests of COTS products are carried out for purchasing recommendations addressing capability gaps – to situations where systems are built, integrating several COTS components. Thus, few assumptions can be made regarding the perspective of assessment. Moreover, the scope of HF impact can vary from fundamental issues to hardly any impact at all. HF issues often arise as part of the design process without being labelled that way. To some, the specific HF label was confusing. The provision of a simple reference aid that triggers potential issues and arguments early was generally welcomed, but only if very straightforward to use. It may need to be presented with an introductory sheet providing further explanations, and several concrete filled-in examples.

***** HUMAN FACTORS ASSESSMENT AID FOR COMMERCIAL-OFF-THE-SHELF (COTS) PRODUCTS ***** ***page 1***

Instructions:
**Relate the potential HF impact areas listed on the left (1-29) to the assessment options listed across the top and tick the appropriate column.*
**Positive and negative effects are mutually exclusive.*
**Negative effects may require system design requirements.*
**There is no need to tick if nothing applies.*

		Impact assessment								EXPLANATIONS AND EXAMPLES			NOTES
		Does product cause or increase Human Factors related problems or costs (i.e. risk)? negative effect?			Does product eliminate or reduce Human Factors related problems or costs? positive effect?			Does issue require system adaptations? design need?	If not sure and/or more study is needed, tick here.				
		high --		low	low		high +	yes?	low certainty	all	software	hardware	
a)	Does the COTS product need to operate in a system that is constrained by particular task needs, and/or operational contexts? ☐ *tick, if YES, and consider options 1-4. If NO, go to (b).*												
	CONTEXT. How does the work context impact product use? Is product design and operation *constrained* due to -												
1	impact of task requirements (functional/ organisational/physical/psychological)									e.g. time-critical; procedural structures; logistics requirements; communication structures; use under stress/tiredness/boredom			
2	effects of fit into space (physical dimensions)										not applicable (n/a)	e.g. human body size, viewing range, technical constraints	
3	safety-criticality of environment									e.g. presence of hazards, high impact of failure			
4	impact of environmental conditions									e.g. light, climate, noise, vibration, space			
b)	Does the COTS product need to be integrated with other parts of the system that users interact with? ☐ *tick, if YES, and consider options 5-8. If NO, go to (c).*												
	INTEGRATION. Does the COTS product affect *compatibility and consistency* issues, regarding -												
5	compatibility with other equipment/interfaces									within or across tasks: e.g. interference, ease of carrying everything, same menu structure			
6	consistency with other equipment/interfaces									within or across tasks, locations, organisational boundaries: e.g. same structure/ standards/ conventions/ look and feel			
7	consistency with other elements on same interface										e.g. same symbology, orientation	n/a	
8	compatibility with previous versions of system									e.g. ease of skill transfer, working habits			
c)	Does the COTS product require additional components that users may interact with? ☐ *tick, if YES, and consider options 9-11. If NO, go to (d).*												
	RELATED PARTS. If there is a need to buy or custom-make *additional* components to accommodate COTS product, is there a -												
9	need for creation of own interface										e.g. need to control COTS through interface	n/a	
10	need for additional information on existing interface											n/a	
11	impact of additional software or hardware										e.g. HF impact of glue code	e.g. clarity of added screen	
d)	Does the COTS product potentially impact the design of the work system (e.g. training, manuals, organisation)? ☐ *tick, if YES, and consider options 12-14. If NO, go to (e).*												
	ONE-OFF COST. Does the product cause a need for system *changes* (resulting in one-off implementation costs), such as -												
12	need for change of skills (procedures, recruitment, training needs)												
13	need for new documentation (manuals, guidelines)												
14	need for change of task/social/ organisational/cultural structures												

Figure 3 - Human factors assessment questionnaire for COTS products (page 1)

page 2

***** HUMAN FACTORS ASSESSMENT AID FOR COMMERCIAL-OFF-THE-SHELF (COTS) PRODUCTS *****

		Impact assessment								EXPLANATIONS AND EXAMPLES			NOTES
		Does product cause or **increase** Human Factors related problems or costs (i.e. **risk**)? negative effect?			Does product eliminate or **reduce** Human Factors related problems or costs? positive effect?			Does issue require system adaptations? design need?	If not sure and/or more study is needed, tick here.				
		-- high		low	low		+ high	yes?	low certainty	all	software	hardware	
e)	Does the COTS product potentially impact system operating costs (e.g. training, manuals, maintenance, reliability issues)? ☐ *tick, if YES, and consider options 15-20. If NO, go to (f).*												
	RECURRING COST. Is there an *(indirect) impact* of the product on the socio-technical system's operation that causes cost due to -												
15	continued training needs									e.g. recurring costs for new staff, refreshing courses			
16	impact on working conditions (health, safety, performance, efficiency)									e.g. heat or noise generation, health impact, physical obstacle, stress.			
17	maintenance efforts requiring human interventions									e.g. servicing, repair, upgrades (may be in multiple locations) - analysability; changeability; stability; testability; installability, replacability, accessibility			
18	impact of reliability problems due to integration of components									e.g. impacting safety, requiring workarounds - due to low fault tolerance, maturity, recoverability			
19	customer support needs									e.g. technical support, user support by supplier			
20	disposal requirements requiring human interventions										n/a	e.g. need for contact with hazardous materials	
f)	Does the COTS product affect the quality of use, or provide in itself a function that fulfils a user need? ☐ *tick, if YES, and consider options 21-25. If NO, go to (g).*												
	FUNCTIONALITY. Has the product itself any features that require *functional quality* criteria impacting use, such as -												
21	adequate provision of required function									accuracy, suitability, HF support, provision of HF function in itself (e.g. screen for bright daylight, provision of shelter)			
22	maturity									i.e. proven performance under required use conditions			
23	time and resource efficiency									e.g. fast/small/light/cheap enough - to set up, use, remove etc.			
24	adaptability									e.g. customisation possible for specific user and site needs			
25	durability for required use										n/a	e.g. weight, strength, frequency effects in operation	
g)	Does the COTS product interface with users in some way (through screens, buttons, physical handling, adjustments)? ☐ *tick, if YES, and consider options 26-29. If NO, revisit form later as needed.*												
	USABILITY. Has the *product itself* any features that affect its ease of use impacting -												
26	effective support of human senses (e.g. vision, hearing)										e.g. font size, colours, contrasts)	e.g. screen size, resolution, refresh rate, glare)	
27	effective understanding and information exchange (through displays, input devices)									learnability/ understandability, error tolerance - e.g. effective layout, clear functionality of buttons, task-based menu structure			
28	effective control and handling (through physical/sensory interfaces)										n/a	e.g. size and position of buttons, fitting human shape and strength	
29	effective manipulation									ease of installing/uninstalling (e.g. assembly, putting on, setting up); portability (ability to transport, carry, mount and dismount)			

Figure 4 - Human factors assessment questionnaire for COTS products (page 2)

The checklist incorporates five functional components, encapsulating both HF impact areas and process requirements, and guiding the user. They include:

1. The HF assessment taxonomy specifies potential impact areas. It comprises the numbered items (1-29) that are grouped into categories (a-g). The assessment of individual items is triggered through a question formulated specifically per category, thus aiding clarity. The HF assessment taxonomy helps to predict potential HF risks, benefits and requirements. It provides categories that help to compare options, by providing a set of values and potential areas of concern. It combines insights into the nature of COTS equipment issues identified above (e.g. integration, consistency, direct/indirect impact), with different types of implications (e.g. implementation, use, maintenance, disposal), and some elements of the software quality standard ISO 9126 (e.g. reliability, operability, portability, changeability).

2. Examples and explanations are provided for the impact categories, where needed. They are added on the right, and, where applicable, have been distinguished between hardware and software. This also provides an aid as to which items only apply for either hardware or software.

3. A narrowing facility is included to speed up the process by pre-selecting relevant areas – by providing an initial, short, list of question identifying whether there is a need for further HF assessment – heading sections (a) to (g). If the question can be answered with ‘no’, then the items in the associated category need no further consideration; if ‘yes’, then they may be relevant.

4. The assessment options against which the potential impact areas need to be assessed reflect the information needs identified to make decisions and plan activities. The items across the top can be rated in terms of relevance for each impact area, thus providing a basic way of quantification. Both positive and negative effects can be rated through a tick on a scale. It can be identified whether HF issues require system design activities. It also provides a facility to judge the certainty of the assessment, thus prompting either research activities or specialist HF involvement where needed. The questionnaire can be used as the basis of an issues log, in combination with methods such as EHFA (Early HF Analysis). For specific assessment domains, other assessment options may be added (e.g. which are related trade-off issues?; can compliance with HF standards be demonstrated?; is testing needed?; is HF expertise and knowledge obtainable? is this item a constraint or a variable?).

5. A final column is included that provides space to attach notes that explain the assessments made for later reference, where needed. It also aids communication with other professionals.

For example, an engineer may use the questionnaire to identify potentially relevant HF implications for a fold-out screen to be fitted as part of an emailing workstation into a small space on a submarine. The items that can be identified as potentially problematic include, due to the physical nature of the product: (2) ‘fit into space’ (i.e. the screen needs to be able to be folded away far enough so that the operator can get in, and then use a keyboard at the same time as seeing the screen); (4) ‘environmental conditions’ (i.e. the lighting in the cabin may affect screen readability); (26) ‘support of senses (i.e. display quality issues such as clarity and flicker). Additionally, the questionnaire can identify a number of positive HF effects, including (17, 20) ‘maintenance’ and ‘disposal’ (e.g. due to the modular nature of the product, service efforts are reduced due to easy access), and (22, 25) ‘durability’ (e.g. the product is mature and has been proven to last long in a range of contexts, thus, user health and performance should not be effected due to frequent visibility quality problems). The screen itself does not require any dedicated interface components, or other equipment that users may interact with, thus section (c) of the questionnaire does not apply and can be neglected. Likewise, the information content is not relevant for the screen selection. After filling in the form, an immediate overall visual impression shows that there are no major, but some minor HF risks, with many items not being relevant, and some with positive HF effects. A few notes give details of the items identified, for future reference. Another form may be filled in for the keyboard/keyboard fittings to be used. The questionnaire may be used either generically to scope requirements (i.e. problems of any screen of this type), or for a particular product on the market. Lastly, the questionnaire may be revisited. For example, as a new operating requirement, several workstations may be operated in parallel, thus adding consistency requirements (6). Likewise, some items may not be as important as initially thought (e.g. the lighting conditions can be adapted easily).

It may be argued that different types of COTS equipment, and different assessment perspectives require different questionnaires, since the technical detail, and the exact questions asked, may differ. Assessment requirements can vary with the scope of design responsibility (e.g. component integration only; work system design), the assessment perspective (e.g. audit, design), the type of COTS equipment (e.g. software, hardware), and the assessment purpose (e.g. looking for application for novel technology, aiming to address capability gaps, finding a product that fulfils a specific function).

We decided to provide a universal tool, based on the similarities of HF issues for COTS equipment assessments across applications. Based on a generic process, and a high-level description of HF impact areas without extensive technical detail, it becomes a widely applicable template. By choosing an all-in-one checklist, we aim to provide a communication tool that can bridge gaps between professionals. It is intended to support process management activities rather than in-depth technical evaluation. It provides an understanding that covers input from different disciplines. For example, it provides HF professionals with an understanding of COTS-specific issues. It prompts system engineers to consider the breadth of potential HF issues and provides an issues log. It provides MoD auditors with a template that triggers consideration of COTS-specific HFI issues across domains. If used as a reference that all professionals use, it has the potential of providing a shared understanding to aid communication.

8 Conclusions and further development plans

The increased political and economical pressure to use COTS equipment calls for suitable HF assessment guidance. The integration of COTS products into existing technical, organisational and work systems is a complex task. Many interdependencies exist that may have a HF impact.

Within the context of providing guidance at the HFI level, we have identified a range of COTS-specific challenges and derived high-level descriptions of HF impact and assessment values. We identified the need for accessible, process-based support to ensure the inclusion of HF at the management level – in a team environment with competing objectives. We identified the need for widely applicable high-level guidance material to assess COTS-specific HF aspects, including both the direct and indirect implications of COTS products in often demanding operating conditions.

The main aspects to be considered specifically for COTS equipment are (1) the transfer into a new context of use, and (2) integration into a larger system. Other HF issues can be assessed in the standard way (no additional guidance is needed since covered elsewhere – e.g. standards, desktop tool). However, a stronger focus is needed on product assessment and comparison of purchasing options. The process for acquisition of COTS equipment differs significantly from the standard CADMID stages, thus requiring a slightly different approach to requirements specification and assessment.

Based on a review of fundamental requirements for the development of an HF assessment tool, we provide an initial solution, based on initial feedback after a first stage of development. The tool presented is intended to be complementary with other methods, both COTS-specific, and HF-specific, by bridging the disciplines through an up-front assessment tool that can be used by a range of different professionals, both in auditing and design roles. It supports the initial identification of HF issues, and helps to relate these to risk-related issues such as requirements, assessment criteria, and activity plans.

The questionnaire design underwent a first stage of informal analysis, to produce a first version of a tool that can be distributed to practitioners for initial use. The first version also enables further, more formal testing and development. We envisage distribution to a wider group of potential users and domains – for both qualitative and quantitative feedback.

The design of the questionnaire should undergo a few further iterations. This should include the attachments of ‘surrounding’ material, such as a cover sheet with background, aims, and instructions, including some support on the envisaged application process. Moreover, a number of filled-in examples from diverse applications may be added to provide practical suggestions for use. Some references to related assessment materials may be included.

9 References

[1] Carney D. Assembling Large Systems from COTS Components: Opportunities, Cautions, and Complexities. SEI Monographs on the Use of Commercial Software in Government Systems. http://www.sei.cmu.edu/cbs/monographs/assembling-systems/assembling.systems.htm. 1997.

[2] Beus-Dukic L. Non-functional requirements for COTS software components. In: *COTS Workshop in ICSE2000*, Limerick, Ireland, ACM. http://users.wmin.ac.uk/~beusdul/papers/cotsw00.pdf. 2000

[3] Alves C, Castro J. CRE: A Systematic Method for COTS Components Selection. In: *XV Brazilian Symposium on Software Engineering (SBES)*, Rio de Janeiro, Brazil, October 2001.

[4] Chung L, Cooper K, Courtney S. COTS-Aware Requirements Engineering: The CARE Process. In: *Proc. of Int. Workshop on Requirements Engineering on COTS (RECOTS '04)*, September 2004, Tokyo, Japan. http://www.lsi.upc.es/events/recots/04/papers/Chung.pdf. 2004.

[5] Basili V R, Boehm B. COTS-Based Systems Top 10 List, *Computer* 2001; (34)5: 91 – 93.

[6] MoD UK HF Integration. A Practical Guide for IPTs. http://www.ams.mod.uk/ams/content/docs/hfiweb/data/current/HFI Guidance2.pdf. 2001.

[7] COTS Journal http://www.cotsjournalonline.com/home/publication.php. 2005.

[8] Lockett J., Powers J. Human Factors Engineering Methods and Tools. In: Booher H. R. *Handbook of Human Systems Integration*, Hoboken, NJ: Wiley-Interscience. 2003. p 185-188.

[9] Oberndorf T. COTS and Open Systems - An Overview. http://www.sei.cmu.edu/str/descriptions/cots.html#ndi. 1997.

[10] Howard B, Strong R A. Review of Human Engineering Standards and Implications of their Application to COTS Issues. Unpublished DERA Report for MoD (DERA/CHF/MID/CR010179). 2001.

[11] Sinclair I J. The Use of commercial off-the-shelf (COTS) software for safety-related applications. HSE contract research report No. 80/1995, Real Time Engineering Ltd, Capital House, 20 Park Circus, Glasgow G3 6BE. http://www.hse.gov.uk/research/crr_pdf/1995/CRR95080.pdf. 1995.

[12] Wagner D, Birt J, Snyder M, Duncanson J. HF Design Guide for Acquisition of Commercial-off-the-shelf Subsystems, Non-Developmental Systems, DOT/FAA/CT-96/1, Atlantic City, NJ; http://www.tc.faa.gov/hfbranch/hfdg. 1996.

[13] Lauesen S. COTS Tenders and Integration Requirements. In: *Proc 12th International Requirements Engineering Conference*, Kyoto, RE 2004, 2004. p. 166-175.

[14] Ye F, Kelly T P. COTS Product Selection for Safety Critical Systems. In: *Proc 3rd International Conference on COTS-Based Software Systems (ICCBSS)*, Redondo Beach, USA. http://www.ida.liu.se/~snt/teaching/SCRTS/Kelly-ICCBSS2004.pdf. 2004.

[15] Ochs M A, Pfahl D, Chrobok-Diening G A. Method for Efficient Measurement-based COTS Assessment ad Selection - Method Description and Evaluation Results. In: *Proc of IEEE 7th International Software Metrics Symposium*, London, England. p. 285-296. 2001.

[16] Torchiano M, Jaccheri L, Sørensen C, Wang A I. COTS Products Characterization. In: *Proc 14th international conference on Software engineering* and *knowledge engineering*, (Ischia, Italy), ACM Press: New York, 2002. p. 335 – 338.

[17] Botella P, Burgués X, Franch X, Huerta M, Salazar G. Modeling Non-Functional Requirements. In: Amador D, Miguel T. (eds) *Applying Requirements Engineering* (papers

from JIRA'01), Salamanca: Catedral publicaciones. http://www.lsi.us.es/~amador/JIRA/Ponencias/JIRA_Botella.pdf. 2002.

[18] Alves C, Finkelstein A. Challenges in COTS Decision-Making: A Goal-Driven Requirements Engineering Perspective. In: *Proc 14th international conference on software engineering and knowledge engineering (SEKE)*, New York: ACM Press, 2002. p. 789-794.

[19] Ncube C, Maiden N A. PORE: Procurement-Oriented Requirements Engineering Method for the Component-Based Systems Engineering Development Paradigm. In: *Proc International Workshop on Component-Based Software Engineering*, May 1999, http://www.sei.cmu.edu/cbs/icse99/papers/11/11.pdf. 1999.

[20] Kontio J A. COTS Selection Method and Experiences of Its Use. In: *Proc of the 20th Annual Software Engineering Workshop*, Maryland, November 1995.

[21] Kunda D, Brooks L. Applying Social-Technical Approach for COTS Selection. In: *Proc of 4th UKAIS*, University of York, York, UK, McGraw Hill, http://www.cs.york.ac.uk/mis/docs/ukais99_chap53_42.pdf. 1999.

[22] Yakimovich D, Travassos G, Basili V A. Classification of Software Components Incompatibilities for COTS Integration, http://sel.gsfc.nasa.gov/website/sew/1999/topics/yakimovich_SEW99paper.pdf. 2000.

[23] Jaccheri L, Torchiano M. Classifying COTS products. In: *Proc. 7th European Conference on Software Quality (ECSQ)*, Helsinki, Finland, 2002. p. 246-255.

[24] Ellison R, Linger R, Lipson H, Mead N, Moore A. Foundations for Survivable Systems Engineering, *CrossTalk*, July 2002. http://www.cert.org/archive/pdf/SSE_foundations.pdf. 2002.

[25] ISO/IEC 9126. Information technology - Software Product Evaluation - Quality characteristics and guidelines for their use. Geneva, International Organisation for Standardisation. 1991.

[26] MoD UK. System Readiness Levels (SRLs): A Taxonomy to Assess and Communicate System Maturity. http://www.ams.mod.uk/ams/content/docs/sirl/sirl.htm. 2005.

[27] Smith J D. ImpACT: An Alternative to Technology Readiness Levels for Commercial-Off-The-Shelf (COTS) Software. In: Kazman R, Port D: *Proc ICCBSS 2004* (3rd International Conference on COTS-Based Software Systems, Redondo Beach, CA, USA, February 1-4, Springer-Verlag, www.iccbss.org/2004/proceedings/ImpACT.pdf. 2004. p. 127-136.

[28] Williams R A, Martin J, Lawrence S. A methodology for exploiting COTS interaction technologies. Unpublished report to MOD by QinetiQ Ltd. (QintiQ/KI/CHS/TR032147/1.0). 2004.

[29] Martin J, Strong R, and Williams R A. Assessment of COTS interfaces: Final summary report. Unpublished report to MOD by QinetiQ Ltd., (QintiQ/KI/CHS/TR033070/1.0). 2004.

[30] Ministry of Defence (1997) “Requirements For Safety Related Software In Defence Equipment, Part 2: Guidance”, Defence Standard 00-55(PART 2), Issue 2, 1 August 1997, http://www.dstan.mod.uk/data/00/055/02000200.pdf

[31] Ministry of Defence (2004) “Safety Management Requirements for Defence Systems, Part 2”, Interim Defence Standard 00-56, Issue 3, 17 December 2004, http://www.dstan.mod.uk/data/00/056/02000300.pdf

[32] Ministry of Defence (1987) Def Stan 00-25: Human Factors for Designers of Equipment, http://www.dstan.mod.uk/

[33] Newman P, Tatlock K. Barriers & Enablers to HFI: Final Review and Recommendations (WP 3.1.4), Unpublished Report, SEA/04/TR/4710, 11th October 2004.

10 Abbreviations and Acronyms

COTS	Commercial off-the shelf
FAA	Federal Aviation Administration
HF	Human Factors
HFI	Human Factors Integration
IPT	Integrated project team
MoD	Ministry of Defence
MOTS	Military off-the shelf
SRL	System readiness level
TRL	Technology readiness level

ANNEX A COTS equipment taxonomies

- HF Impact of product as such
  - Compliance with accepted standards
  - Impact of functionality on all aspects of use
    - functional benefit in choosing **specific** COTS solution (e.g. screen technology usable in bright daylight)
    - balancing **generic** HF benefits of COTS solution against disadvantages
    - impact of functional failure and reliability problems (e.g. impacting safety, requiring workarounds)
      - reliability
        - fault tolerance
        - maturity
        - recoverability
      - functionality
        - accuracy
        - suitability
        - interoperability
      - efficiency
        - resource behaviour
        - time behaviour
  - Usability of product **(direct** impact on use): quality of graphical or physical interface; physical handling and usability
    - interaction issues (usability) of display, information input devices, physical/sensory interfaces
      - learnability
      - operability
        - error prevention and tolerance
        - efficient handling and interaction
        - health and safety
      - understandability
      - safety-criticality
    - portability
      - adaptability
      - conformance
      - installability
      - replaceability
  - Indirect impact of product
    - continued training needs (e.g. recurring costs for new staff, refreshing courses)
    - maintenance efforts
      - analysability
      - changeability
      - stability
      - testability
    - disposal requirements
    - customer support needs (by supplier/additionally)
- HF effects due to integration into work system
  - work system design needs: fit into work system and context
    - environmental conditions
      - adverse conditions
      - specific hazards
      - special requirements
    - task and organisational conditions
      - scenarios
      - goals and motivations
      - expertise and procedures
    - relationship with other task-related equipment and new/existing system components
    - relationship with overlapping applications and needs
      - logistics
      - survivability
    - compatibility (e.g. consistency) with similar systems used by people in work system (e.g. multiple locations, related part
      - same structure
      - same standards
      - same conventions
      - same look and feel
      - customer support when deployed in multiple locations
      - customisation possible for specific user and site needs
    - overall modularity
  - implementing integration into work system
    - change of training needs (tasks and skills changes required)
    - recruitment needs (based on existing/needed skills)
    - compliance with current procedures and best practice
    - compliance with organisational/social/cultural structures
    - ability to re-use documentation and guidelines
  - maintaining integration into work system
- HF effects due integration into technical system
  - HF impact of need to custom-make or buy additional components to accommodate COTS product
    - need for additional information on existing interface
    - need for creation of own interface
    - additional software (e.g. HF impact of glue code)
    - additional hardware or supporting equipment
      - problems due to custom-made interfaces (e.g. additional data to be displayed)
      - impact of functional failures
  - physical and operational integration needs of COTS **interfaces and controls**
    - fit into space/physical dimensions
    - consistency with other related interfaces
    - reliability due to software integration
    - compatibility with other elements on same interface
      - same style, colour coding
      - same design philosophy
      - same information structure
  - physical and operational integration needs of COTS **hardware, software, services**
    - space
    - consistency
    - functionality
  - implementing integration into technical system
    - space
    - consistency
    - compatibility with previous versions of system
      - need for adaptation and re-training
      - need for new documentation (e.g. reflecting change, task-oriented, simple)
      - need for new procedures

Figure 5 - HFI taxonomy for COTS equipment impact – long version.

Table 2 - COTS equipment constraints, characteristics and variables.

Category	Examples

Type of COTS input	• COTS product acquired as complete (stand-alone) product to fit into operational context
	  o COTS as the solution as such to be integrated into operation/related systems – assess HF risk for purchase/adaptation/implementation decisions (i.e. stand-alone system or device)
	• COTS product acquired as complete product to be integrated with other technical components
	• Complete system acquired that incorporates COTS components
	  o COTS as part of a solution integrated into system designed by contractor – observe HF issues of integration into design process (including implications of ‘glue software’)

Type of COTS	Type and number of sub-components
	• Software only
	  o Entire software package
	  o Distinct (separate) software module
	  o Software producing particular function (less separate)
	• Hardware only
	  o Computer
	  o Device
	• Standalone device
	• User interfaces (i.e. software, interaction devices, combinations – e.g. GUI, large-scale projection/ information displays, haptic and galvanic feedback systems)
	• Combinations (e.g. software and hardware and interface)
	Software scope
	• simple components (e.g. sort procedures or user interface components)
	• complex operating systems and middleware (e.g. CORBA-based)
	• tool packages (e.g. MS Office)
	• complex application packages (e.g. ERP systems such as SAP or BAAN)

Size of product/ module	e.g. • Small device • Plug-in system • Entire networked system
Technology type	Technology type, e.g. • Computer system (e.g.) • Weapon • Physical equipment (e.g. tent, vehicles) • Personal device (e.g. hand controller, head-mounted display, wearable computer, eye tracker)
Level of integration requirements	Amount of relationships with other system parts Level of implications on other system aspects and components • dependence on interaction with other equipment • modular vs. unique • within organisational structure • existing training systems

Types of relationships	• with other software
	• with other interfaces
	• within other technology, e.g. portable devices, network
	• interaction with other devices,
	  o functional: e.g. information acquisition and planning system
	  o physical

Adaptability: Variables – Ability to modify	• Software – can be re-programmed (by supplier/ in-house) • Replaceable components • Modification as needed before/after supply • Opportunities for /implications of upgrades
Scope of supply envisaged	Technology + documentation + training + personnel
Time scope – design and application	length of use (project/product life span) • Short-term implementation (within months) - • longer-term project (few years) • long-term envisaged use (either within large projects – e.g. ship design; or for future technologies)

Potential unknowns	• Amount of impact on use criteria (e.g. organisational/ cultural change, new skills needed) • Related equipment (design/use/context/constraints) not known • Future conditions of use unknown (e.g. personnel available, operating purpose and conditions) • However, COTS are usually implemented more short-term since making use of available equipment.
Context of use/ Task types/ user types – HFI guide listings	physical/cognitive hazards etc.
Application domain/ purpose/ functionality	Purpose: e.g. Planning; Reconnaissance; Supply; Battle Predictions: e.g. • Skill/training/personnel requirements • Organisational impact (need for change, management of change) Potential decision implications (HF implementation issues) – types of lifecycle implications • Skill requirements problems • (Training costs, who will supply training, personnel selection implication, shortage) • Need for disposal • Need for managing organisational change • Change of operating procedures • Implication of managing/dealing with problems due to poor integration • Implications of bought-in maintenance, training, etc. (needs integration too)
Envisaged differences	Types of impact on current operations, e.g. • entirely new way of working • significant change of practices • small impact on few aspects • no change

HF mismatch implications (part of risk register?)	• Physical mismatch
	• Functional mismatch
	• Systems mismatch causing failures, reliability problems, and need for work-arounds (e.g. software module does not work with others, consistency issues)
	• Operational mismatch e.g.
	  • integration of interface into overall design concept and principles
	  • too many devices to coordinate/operate causing workload/errors – e.g. night vision equipment in helicopters
	• Need to modify other design/implementation aspects – knock-on effects
	• Implications of technical adaptations

Table 3 - Unique COTS-specific characteristics.

Assessment is placed *beyond the design stage*	• Product is already designed and manufactured • Potential availability of evidence of performance in (differing) use (task, context, conditions, experiences) • No influence on design process (need to provide up-front standards and HF requirements lists); no need to address design process • Focus only on later life cycle stages beyond manufacture – i.e. implementation, use/maintenance, disposal (e.g. anticipate use; provision of conditions for implementation and use; HF implications of update requirements and maintenance; disposal) • HF risk mitigation options reduced to (1) decision about purchase (options), (2) managing implementation, and (3) (where possible) minor modifications • Assessment needs to focus on human performance criteria and performance-driven design criteria • Cannot be changed later – few or no modifications possible
They are *not custom-made*	• Likely to not fit purpose exactly • Change of application/context – identify applicability (e.g. additional robustness requirements in military use); potential problems due to (1) different use; (2) use not envisaged • Need for, and cost of, adjustments for use in different context • HF part of input into customisation efforts • Trends: increasingly wider range of applications due to capability of IT, often from civil sources
There is a *need for integration with other parts of a technical and work system*	• COTS are usually part of a bigger picture – relationships may differ • Interaction/integration with other components is central – impact of change; lack of fit; unsuitable modularity • Characteristics of COTS equipment may function as constraints for embedding into other parts of technology (e.g. screen format, operating system).
Any assessments are an *input into purchasing decisions*	• Criteria variations: • Need to consider differing type of COTS input: • COTS as the solution as such to be integrated into operation/related systems – assess HF risk for purchase/adaptation/implementation decisions • COTS as part of a solution integrated into a system designed by a contractor – observe HF issues of integration into design process (including implications of ‘glue software’) • Envisaged length of use of equipment (e.g. until new supply/review of available technology; implications of modifications though different stages of surrounding technology development) • Outcomes: • Focus on comparison – support requirements specification, e.g. support and conduct market survey of similar products regarding compliance with HF requirements; conduct trade-off analysis between conflicting requirements (e.g. safety vs. purchase cost vs. training effort vs. reliability vs. physical integration vs. ease of use) • HF assessment should include facilities for assessment of advantages and disadvantages of solutions based on or involving COTS elements (i.e. the choice of COTS in itself may have HF advantages in the bigger picture) – e.g. COTS elements may be a standard system that reduces training cost due to existing familiarity
Other issues include:	• COTS are often part of custom-made solutions supplied by a customer: • Who evaluates (e.g. customer, MOD HFI manager); where lies responsibility for comparing COTS options? • COTS implementation through system design process (as part of implementations for development) • COTS hardware (or software) is often implemented through custom-made software, as part of a system containing many components, and may require additional system components for technical safety (e.g. multiple layers of power protection), that may or may not require additional display features – how far to stretch assessment needs of HF?

focussing										
identify assessment routes		risk assessment	search		prediction		specifying		assess + choose	
identify level of integration	(stand-alone or need for integration into technical or work system)		conduct market research to establish knowledge of technology and product options		specify high-level use needs (overall purpose)	(e.g. capability gap)	HF requirements specification for product search - as statements of specific use needs	including capability/ functionality as such, safety /efficiency/ usability requirements, integration needs - e.g. need to identify and reliably communicate location information to commanders	identify and assess amount of difference between original and predicted use	(e.g. difference to obtained evidence of use; compare compatibility criteria)
type of product	(e.g. hardware, software, interface, service)	*identify areas of HF concern*	identify HF related product variables and constraints	(e.g. existing training system; interface supplied; HF standard compliance)	identify relevant HF areas, depending on variables and constraints	(e.g. product type: hardware, software, combinations; project type; supply type; task and operational context)	develop and detail HF requirements specification	(e.g. buttons operable with gloves)	identify if COTS solution is feasible at all	trade-off for using COTS as such
starting point	(e.g. finding technology for need; or use for technology (blue-sky)		research original use and existing operational context of product	(e.g. established conditions, tasks and system context)	identify scope of implications due to product use and system integration issues	initial risk assessment	identify potential system design areas and costs	(e.g. maintenance costs, training costs)	narrow product options	
perspective of assessment	(e.g. audit or design)	*Identify specific HF risks*	identify variables and constraints for solutions	(e.g. scope for modification, scope of supply, impact of updates) - may require further market search	predict potential performance/ safety problems (through stages of implementation, use, disposal)	identify risks and risk factors	fix and clarify HF requirements and assessment criteria		cost-benefit trade-off analysis for product rating, based on benefits and drawbacks of product options	(e.g. using risk ratings, variables)
		assess risks and compare options	identify supplier options	(e.g. ease of contact, proof of HF standard compliance, provision of product details)	identify mitigation strategies for HF risks and associated cost	(e.g. training needs)	identify HF assessment criteria	(e.g. what is acceptable, metrics)	supplier negotiations where applicable	
			conduct HF field studies and tests where applicable	(e.g. use studies in adverse conditions)					choose options for purchase/ contract	

Figure 6 - Activity elements leading to process model

ANNEX B

B.1 Case study 1: Identifying COTS and MOTS equipment for urban operations

- Two Engineers were interviewed.
- Procurement recommendations of equipment for urban operations – to be used by individuals prior to, and during, combat situations in built-up environments (e.g. towns, villages);
- Task is to find any suitable products that fill capability gaps; involves processes of identifying, initial assessment, purchase, assessment through product handling and trials, capturing data in database (standard entry fields), making recommendations for purchases, making training recommendation based on health and safety issues identified;
- Focus is on identifying large number of suitable products involving much compromise – only major HF issues are of concern;
- Often involves issues of carrying, use in combination with other equipment, being part of a set of things assembled together, putting on and taking off, setting up and taking down, handling product, on some products: operating buttons and displays;
- Main issues for HF assessment: weight, time, compatibility, functionality (form, fit, function);
- Equipment may be out of date and depending on old hardware after relatively short period; once hardwired into system it cannot be changed without redesigning system.

B.2 Case study 2: Systems engineering – integration of COTS hardware components

- Two Engineers were interviewed.
- Two examples were demonstrated:
  - o Meteorological observation system providing weather charts to be used on navy ships – COTS equipment include frames, flat screen, keyboard,

mountings with slide-out shelves, internal components, CD writer and floppy drive. Software was developed by external contractor as a new version of existing COTS equipment ('half way').

  - Training system simulating function of sonar system to be used on-board submarines (since deploying real system is costly, but needs to be trained in real setting in relation with other tasks) – COTS equipment include frame, some internal hardware components (e.g. power supply), and a laptop with windows platform to be used by training instructor to program and concurrently update training scenarios.

- COTS characteristics

  - COTS always part of a larger system being designed, requiring adaptations and some custom-made components;

  - need to deal with a range of technical requirements, HF issues emerge naturally from requirements of use and technical constraints;

  - requirements are usually fixed at beginning by customer (MoD) – solution with COTS components being proposed, and implemented if successful (it may turn out later that COTS equipment cannot be implemented due to unforeseen constraints, then losses due to higher development cost;

  - constraints in military can be stringent – e.g. need to cope with shock waves on ships after under-water explosions – COTS equipment not designed to those standards, but may still be proposed where acceptable due to cost reductions ;

  - COTS equipment often encouraged by customer;

  - Some type of COTS equipment come with proven use, and compliance with HF standards;

  - None of the COTS equipment are certified for military, need to make case based in trade-offs against advantages;

  - cost issues central, COTS equipment is cheap; COTS often have a variety of constraints – the decision is whether they are acceptable in relation to cost saving – i.e. always somewhat sub-optimal, but at acceptable level. The question is what is acceptable!

- HF issues from examples:

  - HF issues part of initial requirements (functionality), but rarely as a risk, more likely as a selling point showing an advantage;

  - Many HF requirements emerge as part of overall system design. For example, issue of locking into position was resolved with adaptation. Issue of CD drive sometimes interfering with screen was accepted;

- many hardware components do not have HF issues, mainly basic, rarely a factor that decides for or against COTS – but example: number of COTS to be used in small room generated heat – this was an HF issue requiring to develop system rather than use COTS;
- main issue is physical fit of components that people may interact with in relation to task requirements;
- some COTS products have own interface;
- flat screen sitting in move-out casing, standard keyboard and trackball are used on most products – minor variation regarding fold-out mechanisms, size, quality, positions of buttons, etc. – this is a question of choosing the most appropriate available.

B.3 Case study 3: Integration of hardware components for submarine messaging system

- The main task is the technical integration of the hardware components according to a set of technical constraints, including constraints of software requiring particular software components (developed/supplied by BAe);
- Systems usually include a screen, main unit, and some buttons (one-off, reset) that need to be chosen and assembled according to a range of constraints – mainly space, how to manipulate things in small space (folding out screens), functional quality (display size and clarity), software requirements – most given in initial requirements specification, but not all;
- Most components are hardware with no HF issues (also not servicing and training since delivered and serviced as whole unit externally); integration issues are mainly of a technical nature, rarely HF implications;
- HF considerations come in regarding the operational constraints to be dealt with in finding optimal selection and integration of components;
- Some feed-forward of technical issues into user documentation provided;
- Some reliability/safety issues may have implications for operating/modes of use;
- Some of the HF issues do not fall within responsibilities of engineers assembling the system (e.g. training implications, consistency issues);
- HF standards were not usually an issue;
- Interesting note – there was a need to disable reset button since operators get extremely bored when no information exchange needed (just switch machine off),

and damage other buttons – need some distraction! – such an issue, however, is difficult to be identified before in-service;

- In the future, operators may operate several workstations – consistency issues.

B.4 Case study 4: Integration of hardware components for submarine messaging system

The Swedish Navy have a surveillance sonar mounted on HMS Orion. This vessel is mainly used for electromagnetic monitoring, but they also need to monitor surface and sub-surface traffic. The main addition to the functionality of the existing sonar console is to support the acquisition and processing of data from sonobuoys. This project comprised a complete re-design of the sonar processing element of the system, based on COTS PC technology. The MMI was designed in-house.

The operator is provided with a standard Windows interface, using keyboard and mouse/trackerball. Two PC cards are supplied. These provide an Input subsystem and an MMI subsystem respectively. The MMI computer supports two screens via a standard monitor interface, and provides the outputs to printers, tape recorders and headphones. The MMI (man-machine interface) and display task includes menus, data displays, etc. The program was designed in such a way that the layout and properties of the display windows can be selected by individual users, and stored to file for re-use.

HF impact areas were identified for most categories in the checklist – mainly showing a positive effect (e.g. reduced training effort due to familiarity, high constancy due to standard equipment), with only few or minor risk areas (e.g. effects of fit into space, need for new documentation).

B.5 Case study 5: COTS software

The final version of the questionnaire was assessed by a COTS software expert. Questionnaire usability was found to be good. Regarding COTS software, all questionnaire items were assessed regarding their applicability to common software-related issues. The items in the questionnaire were commented on as such:

part a) 1. Often COTS s/w has an impact on requirements - cost savings from using COTS often mean compromising on less important system requirements; 2. N/A; 3. COTS s/w usually has a big impact on safety criticality - work often needs to be done to show that using COTS s/w will not impact safety of system; 4. n/a.

part b) 5.-8. hugely important for COTS s/w.

part c) 9 - 11. again important for COTS s/w, mostly extra interface s/w will need to be written to integrate COTS S/W with rest of system.

part d) 12, 14. not so applicable. 13. quite possibly applicable to COTS s/w.

part e) 15. 16., 20. n/a; 17., 18., 19. applicable since COTS s/w can often undermine reliability - if there are problems with the COTS s/w you have to go back to the manufacturer and a fix is not always fast or straightforward (or even possible).

part f) 21. - 24. very applicable to COTS s/w - customisation of COTS s/w is important as is maturity (similar as reliability). COTS s/w will often have a negative impact on performance. 25. is really the reliability issue.

part g) if the COTS s/w has a user-interface then this will be very relevant, if not then n/a.

- End of Document -