



Cost-Benefit Analysis for Human Factors Integration: A Practical Guide

The investigation which is the subject of this Report was initiated by the Research Programme Leader Human Capability.

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Contents

0	Executive Summary	1
1	Purpose	3
1.1	Why this guidance is needed	3
1.2	What this guidance contains	3
1.3	How to read this guidance.....	4
1.4	Background and Outlook.....	5
2	Introduction	7
2.1	Arguments for HFI.....	7
2.2	Process overview	7
2.3	Varying depth depending on project stage	11
2.4	Measuring successful HFI.....	14
2.5	HFI cost and risk factors	14
2.6	HFI costs during the Lifecycle	15
A	Establish objectives.....	17
A.1	Establish variables and constraints.....	17
A.2	Derive analysis needs	17
B	Identify and quantify project risks	21
B.1	Identify and assess risk areas.....	21
	B.1.1 PRE-PROJECT PLANNING	21
	B.1.2 ONGOING PROJECT SUPPORT	25
B.2	Identify cost impact	28
C	Specify HFI influence	33
C.1	Specify the role that HFI takes in the project	33
C.2	Specify target design areas.....	36
D	Quantify required HFI effort.....	39

D.1	Review project variables	39
D.2	Specify HFI activity costs or cost proportions	39
D.2.1	Method 1: Cost calculation as a percentage of project budget	39
D.2.2	Method 2: Breaking down the budget into components	43
D.2.3	Method 3: Cost calculation by study type	46
D.2.3.1	Investigate and Evaluate (elements 1 and 3)	46
D.2.3.2	Create (element 2)	48
D.2.3.3	Manage (element 4).....	49
D.2.4	Using the methods together.....	49
E	Specify options	50
E.1	Define suitable HFI expenditure variables	50
E.2	Define suitable ways to assess success.....	51
E.3	Relate spending variables and success	52
E.4	Assess confidence factor	53
E.5	Specify HFI process options	53
F	Choose preferred option.....	55
F.1	Compare options.....	55
F.2	Nominate preferred option and present case	55
Appendix A	Resources	56
Appendix B	Proposed Guidance for Overview Booklet.....	66
Appendix C	Proposed Quick Sheet/Flyer.....	90
References	92
Acronyms	95

0 Executive Summary

The Human Factors Integration (HFI) Cost-Benefit Analysis guidance provides methodological aids for how to make the cost case for HFI for a specific project or programme, based on a risk analysis. Its aim is:

- to achieve a pro-active approach based on a sound analysis of needs at the early project stages,
- to avoid reactive situations with late damage control.

It also provides methods that help ensure that the right activities are conducted in the right areas, with the right amount of effort. They help in specifying suitable HFI efforts in relation to problem potential and in generating data to support the planning and justifying of HFI activities as part of projects or programmes.

This guide is aimed at any stakeholder concerned with having to make judgements about how much project budget should be spent on HFI (and how), based on predicting the potential concrete cost benefits of such activities as opposed to none. Whereas the full cost-benefit guidance provides a level of detail more suited to HFI practitioners, the overall process itself is suitable to any stakeholder in a project planning role.

HFI Cost-Benefit Analysis provides help for how to estimate costs both for potential problems and for HFI mitigation activities. It supports the cost-justification of HFI, in order to define and demonstrate its benefits in financial terms. It identifies how HFI can affect overall project costs, in relation to the efforts that need to be spent to achieve cost reductions.

Building on earlier work on Cost-Justifying HFI (Bruseberg & Linsell 2006; HFI DTC 2006), the Cost-Benefit Analysis for HFI put forward in this report aims to provide a more practical perspective through a step-by step guide and detailed methodological resources supporting the practical use.

This report includes guidance at three levels of detail, including the full guidance, a more hands-on reduced version, and a 'quick sheet' flyer. The full guidance is provided in the main text. A shortened version, proposed for publication as a printed booklet, is included in Appendix B. A draft quick guide that introduces HFI Cost-Benefit Analysis to MoD stakeholders as a desk guide is included in Appendix C.

The HFI Cost-Benefit Analysis is first applied at the conception of projects or programmes and then revisited and refined as the project progresses and uncertainty decreases. The analysis approach required differs depending on the project stage – due to varying levels of uncertainty for cost predictions. Three levels of detail are distinguished:

1. Initial justification of HFI (e.g. early concept phase, and pre-concept).
2. Justification of HFI effort for specific risk areas (e.g. during concept phase).
3. Detailed planning and option selection (e.g. assessment and subsequent phases).

The cost-benefit assessment methodology consists of six steps (A to F). All of these steps need to be conducted – with varying depth and focus depending on circumstances. The process is initiated following the recognition that there may be a need for HFI involvement in the project. The process then establishes the extent and focus of HFI activities needed to mitigate potential risks. It may be necessary to iterate between the steps, and revisit some of them later, since they closely relate. Initially, the analysis may need to draw on some assumptions. Later, more detailed analyses need to be conducted to substantiate the plans.

The steps are answering the following questions: For this project,

1. What are the aims, constraints, and priorities of the analysis, what will be the outputs, and for whom? (Step A)
2. What can go wrong without HFI, and what are the potential cost effects of the risks? (Step B)
3. Which HFI activities are needed to reduce the risks as far as possible, and how should HFI get involved? (Step C)
4. What are the costs for the required HFI activities? (Step D)
5. What if a full and optimal implementation of HFI activities needs to be traded off against other cost priorities? (Step E)
6. Which is the most suitable HFI implementation option based on a trade-off analysis, and how to present it best to decision makers? (Step F)

When moving from one stage to another in the course of the project, the results of the top-level approach can feed into the next stage, including ongoing reviews and updates (e.g. calculations, plans). Since projects vary with size and budget, it needs to be noted that the level of depth and scrutiny allocated for the cost-benefit analysis may vary.

Besides the overall assessment process, the guidance provides a series of optional methods that help instantiate the steps. The techniques and examples specifically developed for this guide appear in a specific formatting, in order to identify them better.

Moreover, the text identifies various resources including methods and data explained in full elsewhere, which are included as a summarised version in a Resource section (Appendix A).

1 Purpose

1.1 Why this guidance is needed

Human Factors Integration (HFI) is critical to ensure that system performance is safe, effective, and efficient. However, HFI is often considered a costly process. The cost benefits of HFI are frequently perceived as intangible. The potential losses due to not applying HFI are rarely assessed early enough for adequate consideration in budget allocations. The financial value of HFI through cost savings is often poorly understood. HFI professionals often find it difficult to express HFI cost benefits and produce early budget plans when uncertainty is still high. Thus, project budget plans often do not allow sufficient resources for HFI.

To be able to argue against the various preconceptions that prevent the practical application of HFI, a sound cost-benefit analysis is needed to express both HFI efforts and benefits in business terms. Cost-benefit analysis for HFI technical and management activities is often recognised as a difficult task. This is especially so for larger HFI projects, and during early project stages. It is not always easy to argue that there are situations where it is necessary to spend money in order to save money.

1.2 What this guidance contains

This report offers guidance on cost-benefit analysis to support the cost-justification of HFI, in order to define and demonstrate its benefits in financial terms. The approach taken identifies how HFI can affect overall project costs, in relation to the efforts that need to be spent to achieve cost reductions.

The guidance material provided here is intended to be applied mainly by HFI practitioners. It provides a detailed task breakdown, as well as heuristics¹ for cost estimation and assessment. Additional resources (methods, data) are referenced for further elaboration and examples are provided. The heuristics draw on initial experience values, in the absence of reliable data. The figures provided throughout have not been validated and need to be applied with care.

Since the provision of actual cost figures is often problematic for HFI, this guidance material takes the approach of showing cost relationships to present benefits. This is based on project risk assessments and cost estimation techniques, drawing on an understanding of the paths through which HFI can create value.

¹ Heuristics are understood here as using 'rules of thumb', experience-derived knowledge, practical deduction techniques, informal rules of good judgement, or shortcuts without full analysis that are not necessarily perfect.

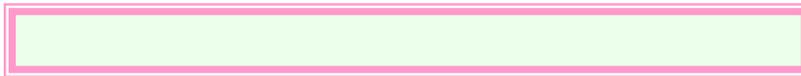
1.3 How to read this guidance

The cost-benefit analysis method is broken down into six steps that can be identified through the chapter headings using capital letters instead of a numbering system (i.e. A through to F). Each main chapter section representing a step in the method is broken down further into individual task steps (e.g. E.1, E.2).

Some illustrations given in the main text represent techniques and examples that have been specifically developed for this guide in support of the suggested methodology. They appear in a specific formatting rather than the usual formatting for tables and figures, in order to identify them better.

Supporting **Techniques** are highlighted in the text in the following format: **Table A1**.

They can be identified through the following colour and formatting:



Examples are referred to in the text in the following format: **EXAMPLE 1**.

They can be identified through the following colour and formatting:



Additional **Resources** referenced in the text are explained further in a separate Resource section at the end of the report. They appear in the text as: **Resource 1**.

In the resource section, they are further distinguished by **Methods and Data** through the following formatting:

Methods - including techniques, processes, approaches and methodological guidance.

Data - including example descriptions and applications found in the literature, as well as case studies and example proportions.

1.4 Background and Outlook

The provision of practical support for planning and justifying HFI budget at the outset of projects or programmes is widely recognised. It links closely to trade-off decisions, both in terms of ‘product’ (i.e. what is to be achieved, and through which changes) and ‘process’ (i.e. what to do to achieve the changes).

The need for this work was originally identified following stakeholder consultations that established barriers and enablers for HFI (Newman & Tatlock 2004). It highlighted the need for being able to make a business case for HFI to show its costs benefits in relation to efforts. The resulting work package on ‘cost-justifying HFI’ from Phase 1 of the HFI DTC (Bruseberg & Linsell 2006) had focussed on the overall cost arguments and evidence for the benefits of HFI (i.e. a retrospective perspective), but had also identified initial resources and approaches conducting cost-based HFI planning (i.e. a prospective perspective). A public printed booklet was issued that made a high-level case for the cost benefits of HFI (HFI DTC 2006). This was received very well, with a high demand for copies.

Building on this earlier work, the Cost-Benefit Analysis for HFI put forward in this report aims to provide a more practical perspective through a step-by step guide and detailed methodological resources supporting the practitioner. The need for such guidance has been confirmed repeatedly (e.g. Leonard & Maddock-Davies 2008). Additionally, the overall technical approach is in line with the new Def-Stan 00-250 which also states that the justification of HFI needs to follow a risk-based approach.

The Cost-Benefit Analysis for HFI addresses the following objectives identified through the original Barriers and Enablers Report (Newman & Tatlock 2004):

- Present HFI risk and consequence in business terms;
- Indicate benefits in financial terms;
- Show the value of HFI to projects with a clear statement of value to individual projects;
- Provide a concise statement of value, improved integration with COEIA;
- Cost prediction should demonstrate how cost could be reduced by meeting requirements;
- Investigate cost implications of re-work required to remedy operational problems;
- Benefits need to be expressed in terms of money saved or increased capability;
- Firmly link business goals to usability benefits;
- Human performance issues need to be linked to costs impact;
- Provide aids to determine HFI expenditure for projects.

Following the success of the printed Arguments and Evidence Booklet (HFI DTC 2006), the provision of another booklet along those lines with a focus on hands-on predictive HFI cost planning is likely to be very beneficial to stakeholders. Whereas the full cost-benefit guidance provides a level of detail more suited to HFI practitioners, the process underlying the analysis may be applied by any stakeholder concerned with having to

make judgements about how much project budget should be spent on HFI (and how), based on predicting the potential concrete cost benefits of such activities as opposed to none.

This report presents the full guidance in the main text and also proposes a shortened ('lean') version of the guidance, for publication as a printed booklet, as an Appendix (Appendix B). Moreover, the report includes a draft 'Quick Sheet' that introduces HFI Cost-Benefit Analysis to MoD stakeholders as a desk guide (Appendix C). This three-tier approach to guidance was proposed by Leonard & Maddock-Davies (2008) to account for the different levels of detail needed by different stakeholders, depending on their role.

It needs to be noted that the process, the techniques proposed, and the heuristics included, have not yet been tested and validated. Thus, the guidance presented here would benefit from an update once it has been made available to stakeholders for practical application. They can be encouraged to provide feedback for an update, depending on whether such an update is deemed beneficial. This, however, would be a little more in the future, since some time needs to be allowed for wider application.

However, the clearance and publication of the printed booklet put forward under Appendix B is recommended in the short-term. Moreover, this booklet consists primarily of the analysis process, which has less of a need for detailed validation, since grounded well in the review of literature with related approaches, and is of a more logical nature than the specific techniques suggested in the full guidance.

2 Introduction

2.1 Arguments for HFI

The material presented in this report follows on from the arguments made in the accompanying Case Study Booklet (HFI DTC, 2006), which provides a high-level case for HFI using a set of arguments to demonstrate how HFI creates value. The arguments presented there are supported by example case studies – including successes due to the application of HFI, as well as failures due to a lack of HFI. The generic arguments for HFI include:

1. HFI can reduce major cost areas. Costs may be incurred due to both operational and development risks.
2. HFI is increasingly required due to developments in technology.
3. HFI plays a critical role in identifying and mitigating operational risks. It has an essential support function throughout the product lifecycle.
4. HFI can draw on resources that enable an efficient development process.
5. HFI requires early, complete and close project involvement to ensure greater success.

Having established the need for HFI, this HFI Cost-Benefit Analysis report provides a methodological aid for how to make the cost case for HFI for a specific project or programme, based on a risk analysis. It provides help for how to estimate costs both for potential problems and for HFI mitigation activities.

Based on the generic arguments for HFI, an assumption can be made that every project that is affecting humans in some way will develop a certain number of HFI issues that need to be identified and mitigated. The methods described in this report help in specifying suitable HFI efforts in relation to problem potential, and in generating data to support the planning and justifying of HFI activities as part of projects or programmes.

The overall aim of the cost-benefit analysis is to achieve a pro-active approach based on a sound analysis of needs at the early project stages, to avoid reactive situations with late damage control. It also provides methods that help ensure that the right activities are conducted in the right areas, with the right amount of effort.

2.2 Process overview

The cost-benefit assessment methodology consists of the steps shown in Figure 1. All of these steps need to be conducted – with varying depth and focus depending on circumstances. The process is initiated following the recognition that there may be a need for HFI involvement in the project. The process then establishes the extent and focus of HFI activities needed to mitigate potential risks. It may be necessary to iterate

between the steps, and revisit some of them later, since they closely relate. Initially, the analysis may need to draw on some assumptions. Later, more detailed analyses need to be conducted to substantiate the plans. The steps are answering the following questions:

For this project,

- What are the aims, constraints, and priorities of the analysis, what will be the outputs, and for whom? (Step A)
- What can go wrong without HFI, and what are the potential cost effects of the risks? (Step B)
- Which HFI activities are needed to reduce the risks as far as possible, and how should HFI get involved? (Step C)
- What are the costs for the required HFI activities? (Step D)
- What if a full and optimal implementation of HFI activities needs to be traded off against other cost priorities? (Step E)
- Which is the most suitable HFI implementation option based on a trade-off analysis, and how to present it best to decision makers? (Step F)

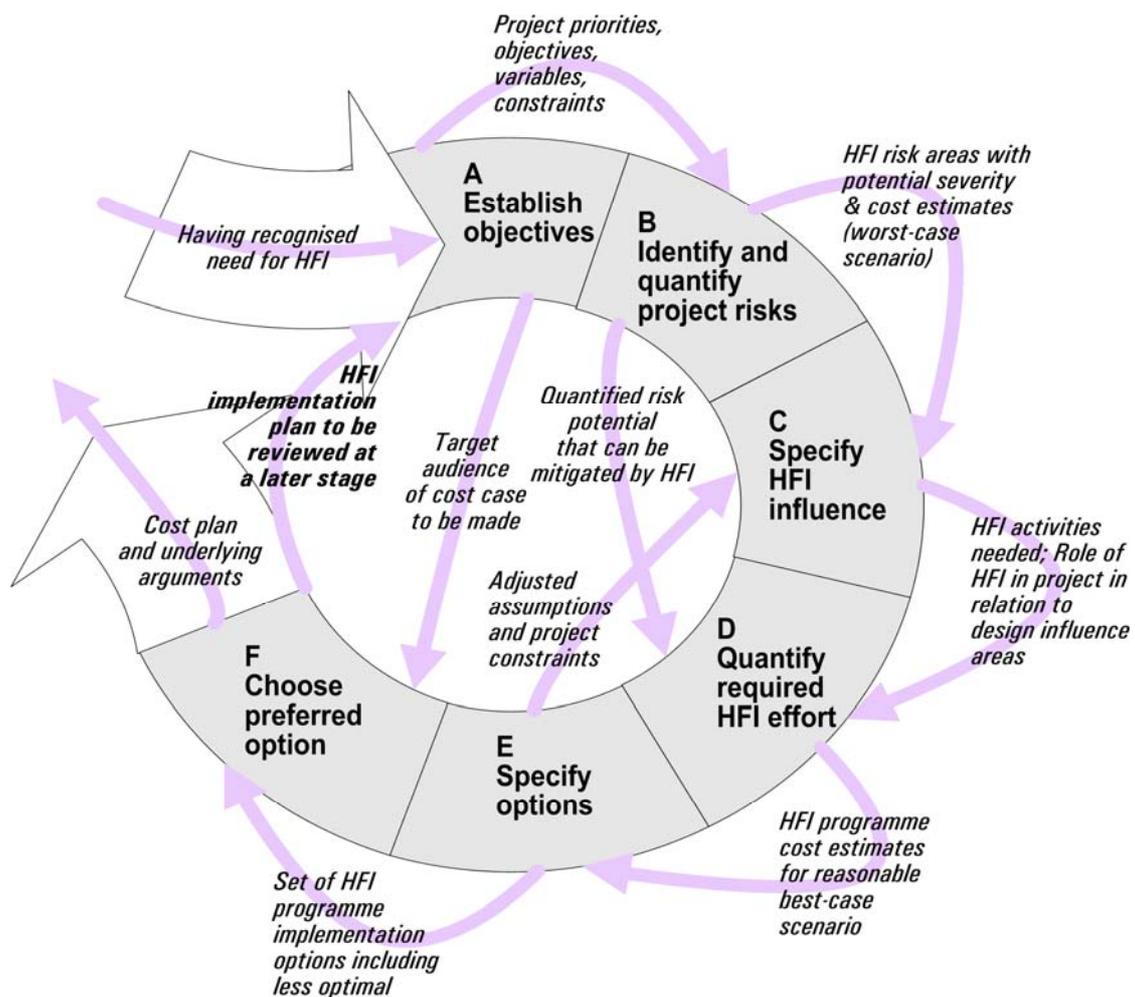


Figure 1: HFI Cost-Benefit Analysis process steps.

Each step is broken down further and detailed with specifically tailored techniques, as well as resources and examples. Figure 2 provides an overview of what can be found in this report.

	Steps	Techniques	Examples	Resources
A Establish objectives	A1. Establish variables and constraints.	Table A1: PROJECT VARIABLES CHECKLIST		Quality Function Deployment (QFD)
	A2. Derive analysis needs.			
B Identify and quantify project risks	B1. Identify and assess risk areas.	Table B1: RISK POTENTIAL CHECKLIST	EXAMPLE 1: example risk assessment, applied to NEC for Close Combat.	Human Factors Integration Plan (HFIP) Expert Rating Techniques Early Human Factors Analysis (EHFA) Work Domain Analysis
	B2. Identify cost impact.	Table B2: COST TYPE CHECKLIST	EXAMPLE 2: Example calculations for HFI cost impact due to design flaws	Example calculations Experience values Case studies
C Specify HFI influence	C1. Specify the role that HFI takes in the project.			
	C2. Specify target design areas.	Table C1: DESIGN AREA CHECKLIST	EXAMPLE 3: Example Matrix for Specifying HFI Activities	Value Chains and Influence Diagrams
D Quantify required HFI effort	D1. Review project variables.	HFI functions, potential roles, and level of direct design influence		
	D2. Specify HFI activity costs or cost proportions.	Table D1: COST ASSESSMENT METRICS (translating risk potential from Table B1 into cost percentages)	EXAMPLE 4: Example ratings and calculation	Value breakdown per project stage/design area (from FAA)
		Table D2: PROPORTIONAL HFI COST BREAKDOWN		Example breakdowns (from FAA)
		Table D3: COST ASSESSMENT HEURISTICS BY NUMBER OF STUDIES.		Aviation-specific heuristics (from FAA)
E Specify options	E1. Define suitable HFI expenditure variables.	Types of HFI implementation deficiencies		
	E2. Define suitable ways to assess success.	Potential success in mitigating design flaws		
	E3. Relate spending variables and success.	Relationships between 'implementation factor' (time and effort) and success		Typical lifecycle cost distribution Minimum spending levels discussion
	E4. Assess confidence factor.	Potential need for revisions in HFI planning		
	E5. Specify HFI process options.	Further implementation scenarios and cost estimates		QFD (Quality Function Deployment)
F Choose preferred option	F1. Compare options.	Trade-off analysis		
	F2. Nominate preferred option and present case.	Present preferences		

Figure 2: Overview of steps, techniques (in tables), examples, and resources.

Step (A), *Establish objectives*, captures the purpose and strategy for the argument to be made, and how it is to be presented. It is essential to be clear about the focus of the analysis, about specific project circumstances, and about applicable values and priorities. A checklist is provided that guides through the different areas of concern.

Step (B), *Identify and quantify project risks*, looks at where problems could occur without sufficient HFI, and which cost impact they may have. This is specifying areas of concern for the worst-case scenario of no HFI implementation. The underlying question is: ‘how badly could it go wrong?’ A checklist is provided to help quantify the risk potential for early project stages. Relationships to cost are aided by a checklist detailing the types of cost that may be incurred. Simple metrics are provided such as predictions based on the number of users affected.

Step (C), *Specify HFI influence*, looks at what HFI can do to prevent such costs. The roles that HFI may take vary with the type of project. To help specify the most suitable set of HFI activities, a generic set of HFI functions is discussed. The necessary HFI effort to be spent may be estimated as a percentage of the overall project budget. This depends on the role HFI takes in relation to design. A checklist of how HFI can be related to ‘design influence areas’ is provided, as well as an example outlining how these categories can be used to specify HFI activities.

Step (D), *Quantify required HFI effort*, provides aids for estimating the actual cost of the HFI activities needed. This specifies a (reasonable) best-case scenario for risk mitigation where HFI budget constraints are minimal. Depending on the stage of the project, and the associated level of uncertainty, three different methods are suggested for how to assess the necessary HFI spending:

1. *Method 1* estimates HFI cost as a percentage of the overall project budget, assuming a typical range between 2 % and 10%. This is based on the high-level HFI risk assessment conducted under Step B. This approach is most suited to early project stages, when detailed project risk areas are not yet known.
2. *Method 2* further details the estimate from Method 1 and can be used to verify its high-level approximation when more project understanding becomes available. It is based on breaking the overall percentage down into budget components using broad categories for which proportional volumes can be estimated. This is based on experience values. The components draw on the HFI functions discussed under Step C (i.e. Investigate, Create, Evaluate, Manage) and a distinction of Productive Time, User Access, and Resources. Example Heuristics are provided to estimate cost elements.
3. *Method 3* provides an alternative approach to Methods 1 and 2. It is more precise but requires extra information. It uses a parametric cost estimation approach that cumulates component costs. It provides heuristics for the types of studies to be conducted under the Investigate and Evaluate HFI functions. Using these, the cost components for the functions Create and Manage are then based on proportional relationships and a number of variables.

Step (E), *Specify options*, discusses the variables and relationships that help determining HFI budget requirements to be proposed after considering external constraints. It discusses how insufficient HFI may impede risk reduction, and how successful HFI can be estimated through the reduction of design flaws. Predictions may need to be adjusted depending on confidence values. A set of less optimal options may need to be prepared besides the best-case scenario requiring the highest budget. It brings together all the elements from Figure 4.

Step (F), *Choose preferred option*, compares and presents the options based on practical constraints and needs. Priorities and assumptions may need to be reviewed. This step involves a trade-off analysis. A final presentation and documentation of options and evidence is critical in influencing decision-makers as intended.

Guidance material from other sources may be referred to for [complementary details on cost-benefit analysis methodologies](#) (see [Resource 1](#)).

2.3 Varying depth depending on project stage

The analysis approach required differs depending on the project stage – due to varying levels of uncertainty for cost predictions. Three levels of detail are distinguished here:

1. *Initial justification of HFI*: Making the business case for investing in HFI at the inception of a programme of work, for justifying fundamental HFI activities. This specifies initial overall resource requirements when there is a high level of uncertainty. This is largely drawing on generic insights about HFI benefits.
2. *Justification of HFI effort for specific risk areas*: Further specifying risk and value factors and initial allocation of HF effort to HFI plans. This concerns early project stages when uncertainty is still high but gradually being reduced.
3. *Detailed planning and option selection*, based on informed assessments of contributory factors. This is specifying efforts for detailed HFI requirements, for an ongoing mapping of resources to needs. This applies throughout the project at increasing levels of detail².

When moving from one stage to another in the course of the project, the results of the top-level approach can feed into the next stage, including ongoing reviews and updates (e.g. calculations, plans).

Guidance is provided for all levels – whilst only particular project types and examples can be covered at the lower levels. Depending on the project stage and levels of detail available, approaches may vary as shown in Table 1. It provides a top-level summary of the information described in subsequent chapters. It also shows that some process steps (B1, B2, C2, D2) specify different methods for different levels of detail.

² In terms of the CADMID lifecycle, ‘Initial justification of HFI’ may apply at the very beginning of the Concept Phase. ‘Justification of HFI effort for specific risk areas’ applies from the Concept Phase to early stages of the Assessment Phase. ‘Detailed planning and option selection’ may need to be addressed during all remaining phases.

The level of depth and scrutiny allocated for the cost-benefit analysis may vary, since projects vary regarding their size and available budget. The less effort is spent on substantiating the assessments with data, the more uncertainty remains, and the higher the unknown risk. On the other hand, smaller projects tend to carry less financial risk. The overall process suggested here (i.e. steps A to F) applies to projects of any type and size. However, the individual techniques used, and the level of substantiation with data, may vary³. For smaller projects, the approaches suggested under ‘Project Conception’ may be sufficient. For larger projects, all stages may need to be considered. The differentiation for method options applies primarily to steps B1 and D2.

Table 1: Approach variations for different project stages.

	Project Conception	Project Specification	Project Detailing
(A) Establish objectives A1. Establish variables and constraints. A2. Derive analysis needs.	▶ Establish variables, constraints, and values for the project and analyses to be conducted (e.g. safety, cost efficiency, system performance, re-use of processes and knowledge) to determine depth and focus of the analysis, as well as business case presentation and documentation requirements.		
(B) Identify and quantify project risks	▶ Assess the applicability of risk factors to the project, to assess the magnitude of HF-related risks. Specify likely cost types.	▶ Further assess the magnitude of risk through identifying particular risk areas. Provide impact ratings, and quantify cost effects (e.g. through likelihood of occurrence, number of users affected).	▶ Identify particular risks and problems to be mitigated. Assess potential impact and cost proportions for selected risks.
B1. Identify and assess risk areas.	▶ Table B1: RISK POTENTIAL CHECKLIST ▶ Resource: Expert Rating Techniques	▶ EXAMPLE 1: Example risk assessment, applied to NEC for Close Combat ▶ Resource: Human Factors Integration Plan (HFIP) ▶ Resource: Early Human Factors Analysis (EHFA) ▶ Resource: Work Domain Analysis	
B2. Identify cost impact.	▶ Table B2: COST TYPE CHECKLIST	▶ EXAMPLE 2: Example calculations for HFI cost impact due to design flaws ▶ Resource: Example calculations ▶ Resource: Experience values ▶ Resource: Case studies	
(C) Specify HFI influence	▶ Based on an understanding of the main functions provided by HFI, specify the desired role of HFI, and target design activities.	▶ Identify influence areas for HF activities to inform design decisions, in relation to risk areas (i.e. what effort is needed where). Specify activities across the lifecycle.	▶ Identify target design activities in relation to particular risks.
C1. Specify the role that HFI takes in the project.			
C2. Specify target design areas.	▶ Table C1: DESIGN AREA CHECKLIST	▶ EXAMPLE 3: Example Matrix for Specifying HFI Activities ▶ Resource: Value Chains and Influence Diagrams	

³ For example, some of the heuristics provided assume a typical, medium to large, multi-disciplinary system development project.

	Project Conception	Project Specification	Project Detailing
(D) Quantify required HFI effort D1. Review project variables. D2. Specify HFI activity costs or cost proportions.	▶ Estimate HFI spending as a proportion of the overall project budget, based on the assessment of risk influence factors. Assess proportional distributions across project stages, and between HFI functions.	▶ Estimate total HFI spending based on an approach that specifies and cumulates the number of HFI studies needed, and the volume of design effort required. Actual cost figures may be specified based on heuristics.	▶ Specify costs for specific studies, by breaking down the effort needed into time, resources and user access.
	▶ Table D1: COST ASSESSMENT METRICS (translating risk potential from Table B1 into cost percentages) ▶ EXAMPLE 4: Example ratings and calculation ▶ Resource: Value breakdown per project stage/design area (from FAA⁴)	▶ Table D2: PROPORTIONAL HFI COST BREAKDOWN ▶ Resource: Example breakdowns (from FAA)	▶ Table D3: COST ASSESSMENT HEURISTICS BY NUMBER OF STUDIES ▶ Resource: Aviation-specific heuristics (from FAA)
(E) Specify options E1. Define suitable HFI expenditure variables. E2. Define suitable ways to assess success. E3. Relate spending variables and success. E4. Assess confidence factor. E5. Specify HFI process options.	▶ Specify alternative options and variables for HFI spending in addition to the best-case and worst-case scenarios already specified. Based on defining suitable variables and measures of success, relate potentially inadequate HFI spending to shortcomings in risk reduction. Specify a set of alternative options, and alternative cost predictions.		
(F) Choose preferred option F1. Compare options. F2. Nominate preferred option and present case.	▶ Clarify decision criteria for risk acceptance. Review assumptions, constraints, and trade-off priorities to present the most reasonable option.		

⁴ Federal Aviation Administration

2.4 Measuring successful HFI

Successful HFI prevents operational problems and reduces development risks. HFI has a well-defined process and can draw on many methods, tools, standards and data to support its technical activities to achieve this. HFI activities can only reduce project risks by influencing design decisions (e.g. team structure). Figure 3 shows a generic HFI value chain, which illustrates the relationships between (1) HFI activities, (2) Design features, and (3) Problem Prevention.

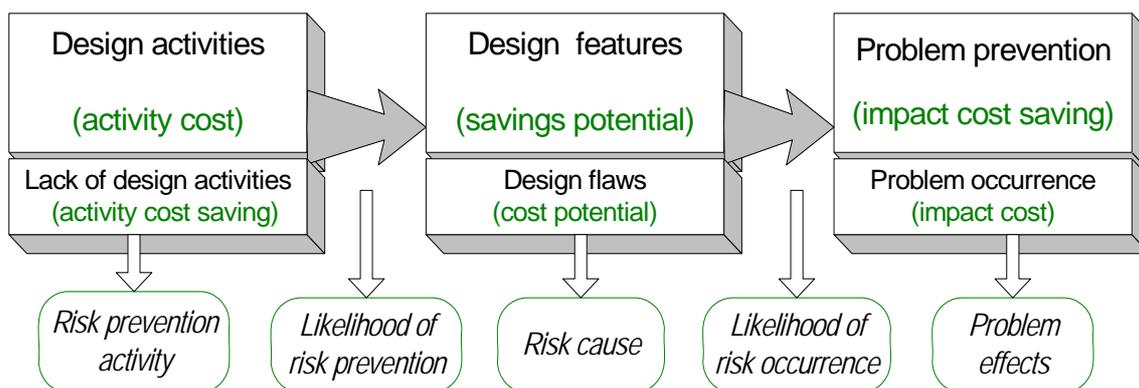


Figure 3: The HFI value chain.

It can be difficult to determine retrospectively the extent to which HFI has contributed to the success or failure of past projects. Whilst the ‘non-occurrence’ of costly problems after preventative HFI activities can be used as a final measure for success, it does not provide an understanding as to how they have been avoided, i.e. how HFI may have influenced the results. Moreover, there is usually a delay between the process stage at which HFI has been applied, and the occurrence of associated cost effects. This makes it difficult to express direct relationships clearly.

It is useful to draw on the concept of ‘design flaws’ to be prevented or mitigated through HFI. A design flaw can be understood here as a property of the design (i.e. the designed socio-technical system) that is likely to cause an operational problem. The concept of design flaws links HFI risks with the absence of HFI activities. The presence of design flaws can be linked to omitted or excluded HFI effort. Deficiencies may occur due to a lack of design decisions, delayed decisions, or ‘wrong’ decisions. It can be assumed that a certain number of potential HFI design flaws are always emergent as part of any design process without HFI intervention (which may vary by design domain).

2.5 HFI cost and risk factors

Figure 4 shows an overview of the elements that are part of the HFI cost calculation. Whilst the left side of the graphic deals with the *risk estimation*, the right side deals with the *risk mitigation* through Human Factors (HF) activities. Cost can be specified for hypothetical risks, and assumptions can be made about the likelihood of them occurring. The risk mitigation side includes two aspects. One is the *cost of HF activities*; the second is the *risk reduction* through HF activities (depending on the extent to which necessary HFI activities are being implemented – i.e. ‘how well’). Some of the factors (shown in a

grey shade) may be expressed as a percentage (experience-based or assumed estimates) that can modify risk or cost estimates.

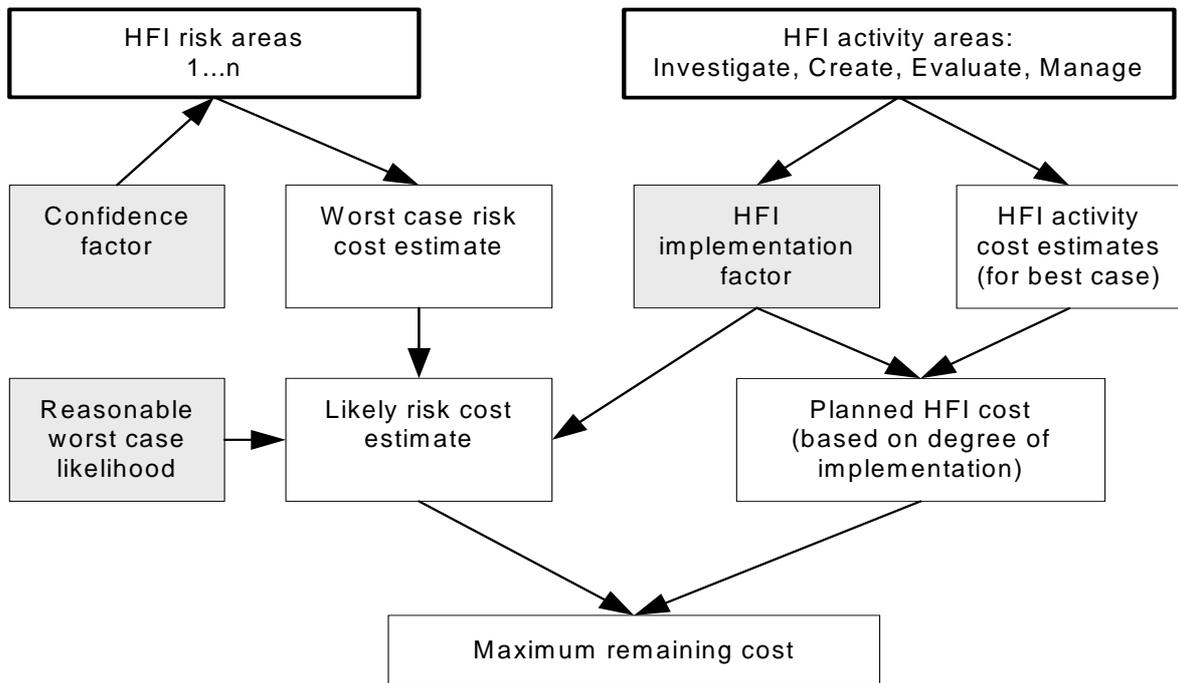


Figure 4: Components of HFI cost-benefit calculations.

2.6 HFI costs during the Lifecycle

When determining HFI needs and cost impact, it is essential to consider the entire system lifecycle (e.g. CADMID⁵). It is important to differentiate between ‘actual spending’ at each lifecycle phase and ‘locked-in’ costs (see Figure 5). Locked-in costs describe investment commitments made through design decisions. At early project phases, design decisions have a high impact. At later stages, cost reduction efforts have a limited potential. Around 70% of the total budget for development has usually already been allocated before the detailed design stage (see [Resource 2](#) for further references).

This has several implications. First, the need for HFI costs varies with each stage. Second, HFI activities conducted at an earlier stage may affect cost savings at a later stage. Third, a significant proportion of the HFI budget needs to be spent during the early project stages. Fourth, influencing HFI design decisions is central.

⁵ CADMID stands for Concept, Assessment, Demonstration, Manufacture, In-Service, Disposal.

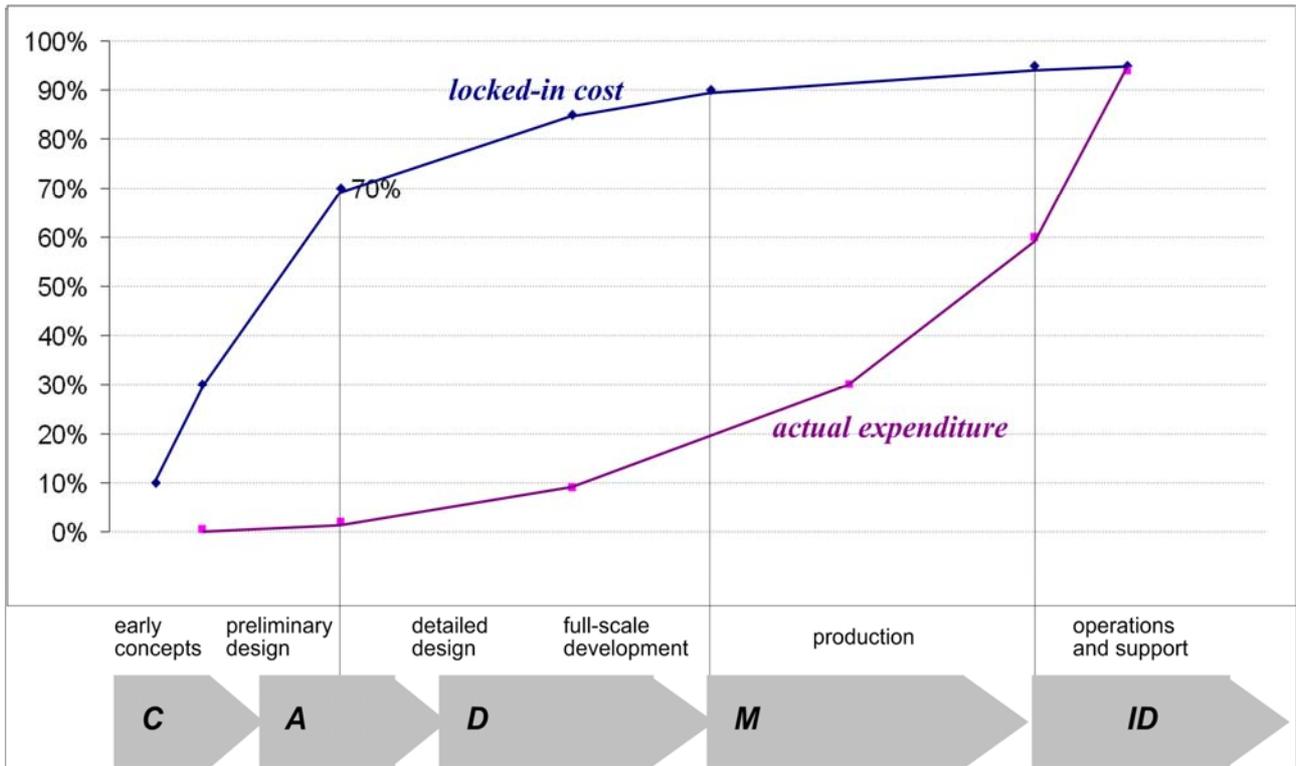


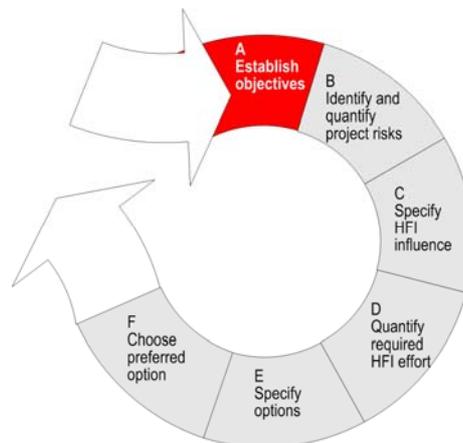
Figure 5: Locked-cost during the lifecycle.

A Establish objectives

At the outset of cost-benefit analysis, the purposes and constraints need to be established to determine the intended focus, breadth and depth of the analysis, and to specify documentation needs.

Main steps:

1. Establish variables and constraints.
2. Derive analysis needs.



A.1 Establish variables and constraints

The type of project, and central purposes and objectives can have a major influence on HFI spending requirements and budget decisions. It is important to define the target audience to whom the cost arguments are to be made.

Table A1 provides a PROJECT VARIABLES CHECKLIST that can be used to identify relevant issues to be considered at the outset. It includes advice on their implications.

A.2 Derive analysis needs

With an understanding of objectives, variables and constraints, the requirements for detail and content of the analysis can be derived. Depth and focus of the cost-benefit analysis can then be determined. An initial understanding of the scope of the HFI work can be gained, by matching it to major project requirements. A list of central values to be achieved should be produced at this stage. Moreover, presentation and documentation requirements for the business case can be determined. **Table A1** also provides recommendations on this.

Where project values have not been established yet, the [Quality Function Deployment \(QFD\)](#) method may be useful (see [Resource 3](#)).

Table A1: PROJECT VARIABLES CHECKLIST

Category	Variables	Advice: requirements for detail and content
Purpose of analysis	The argument to be made by the analysis	<p>The argumentation strategy depends on the objective of the analysis, such as:</p> <ul style="list-style-type: none"> • Make the case for the HFI budget to be increased; • Make the case for full HFI against no HFI; • Make the case for some level of HFI against no HFI; • Specify optimum spending level where the need for an HFI budget is already well accepted.
Central purposes and objectives	Type of organisation (and source of business)	<p>The perspective of the organisation (e.g. contracting/auditing vs. designing/selling) influences the values to be achieved and targeted. The argument for HFI may depend on who owns the cost of HFI activities, and the cost of HFI benefit, and where it is mandated, or accepted, as a cost worth the value. The focus of the organisation may be on, e.g.:</p> <ul style="list-style-type: none"> • Selling products or services: for commercial profit (sales revenue); • Buying products or services: to establish capability (or process efficiency) at low cost; • Auditing (e.g. safety authorities; insurance organisations). <p>For example, from a selling perspective, HFI may add cost to a product, which may or may not be purchased depending on the value the acquirer assigns to having extra utility and usability achieved through HFI. Extra HFI effort may be mandated through requirements, standards and policies put forward by the organisation looking for a purchase (e.g. UK MoD). If these values are not defined they cannot be addressed or achieved.</p>
Central purposes and objectives	Risk type and application area (i.e. what are the main issues to be addressed)	<p>Depending on the application area of new products or processes, the types of risks that can be addressed through HFI can vary. The nature of the risk may affect:</p> <ul style="list-style-type: none"> • Project priorities and criteria for success. • Cost calculation approaches. For example, in safety-critical domains, few operators may take a key role where the potential of human error can lead to significant losses. In applications where large numbers of users depend on the ease and reliability of interaction with equipment, minor design flaws can have large effects.
Central purposes and objectives	Criteria for project success (performance objectives; values)	<p>Criteria for success include:</p> <ul style="list-style-type: none"> • Performance objectives. To specify the criteria for success, the objectives of the development need to be clarified. For example, the focus of effectiveness calculations is often on peacetime operations (i.e. the presence of the capability); when primarily ensuring effectiveness for wartime operations, additional factors have to be taken into account more intensely (e.g. mission achievement, resource availability, survivability). • Priorities for values to be achieved – e.g. quality vs. quantity of performance; development time vs. effectiveness of system being developed; safety vs. cost/productivity.
Type of project	<p>Novelty:</p> <ul style="list-style-type: none"> • New product/technology • New process/operation • New task • New users • New environment/context • New constraints • New organisation 	<p>HFI usually targets processes of change – by improving product or process effectiveness and efficiency.</p> <p>The HFI effort depends on the magnitude of change envisaged – i.e. the level of novelty for one or several aspects of change – where the level of change may be somewhere between evolutionary and revolutionary.</p> <p>Novel systems or processes often require more HFI effort than smaller improvements to existing systems. Novelty increases uncertainty, and therefore increases the need to spend more resources on identifying and mitigating potential problems of use and operation.</p> <p>For example, civil aviation safety regulations often use assessments of novelty to determine HF scope and effort required.</p>
Type of project	<p>Content/objective of change:</p> <ul style="list-style-type: none"> • Support of new product/system <i>development</i> 	<p>The cost-benefit analysis needs to be tailored to the type of change that HFI is intended to support. In many cases, HFI is intended to support the new product/system <i>development</i>. For new product development, the engineering design process (e.g. CADMID) can be taken as the basis for showing where HFI benefits may occur, and where efforts need to be spent. As part of product/system design, HFI can significantly reduce (one-off) costs for system</p>

Category	Variables	Advice: requirements for detail and content
	<ul style="list-style-type: none"> • <i>Purchase</i> of new product/system for operations (e.g. COTS) – including software system; hardware; service • Designing a new <i>process</i> for operations. 	<p>development, by increasing the process efficiency.</p> <p>HFI benefits, however, are not limited to the development of new products/systems. HFI can also provide essential support to the <i>purchase</i> of equipment or services (e.g. COTS acquisition). Moreover, processes of change include the re-design of In-Service <i>processes</i> for manufacturing and operations. Designing a new process for operations, may include, for example:</p> <ul style="list-style-type: none"> • Reorganisation (e.g. new jobs, new work layout); • Implementing new equipment (e.g. databases); • Training and recruitment change (e.g. additional training).
Type of project	Timing of case being made (e.g. initial planning stage vs. ongoing resource allocation)	<p>Ideally, HFI should be applied through all product development and operational stages (i.e. the CADMID system lifecycle). Early HFI involvement in this process is usually not only cheaper, but also more effective. There may be situations where involvement in the late development stages is of no value at all, other than confirming the need for re-designing, or providing accurate re-design requirements. The usefulness of HFI, however, often extends much beyond the development process.</p> <p>Depending on the scope of work, the case for HFI needs to be made as comprehensively as possible. Risks across all development stages, and for all stakeholders, need to be identified to establish the full range of cost benefits. The later the HFI involvement, the fewer the savings possible, and the higher the focus on cost mitigation rather than prevention. However, at later stages, specific risk areas may be more readily understood for more accurate quantification and mitigation. HFI plans need to be updated at every stage.</p>
Type of project	<p>Proactive vs. Reactive approach:</p> <ul style="list-style-type: none"> • <i>Proactive</i> (e.g. early involvement in new product/system design; continuous operational improvement programme) • <i>Reactive</i> (e.g. addressing operational problems after product/system implementation) 	<p>Where HFI is only employed after problems become apparent (e.g. through accidents, high injury numbers, lowered performance, mission failures, high maintenance cost), usually In-Service or shortly after initial implementation, HFI can only contribute through a <i>reactive</i> approach. This is a high-risk approach that lowers the cost of HFI efforts, but can be costly in other ways.</p> <p>The alternative is a <i>proactive</i> approach, based on the assumption that HF problems are unavoidable for any activity of change that affects human stakeholders in some way. An HFI process and sufficient HFI resources need to be available in order to identify, investigate, and mitigate emergent design issues in relation to user requirements. This proactive approach is not only applicable to development processes. At the operational (In-Service) stage it may be achieved by implementing a programme for continuous improvement that identifies specific HFI improvement opportunities to mitigate potential HFI shortfalls, again assuming and accepting a certain number of emergent HFI issues (e.g. an ergonomics programme to measure and mitigate work health problems).</p> <p>Whether a proactive or reactive approach is adopted depends on project and budget constraints. Whilst the cost-benefit analysis should clearly identify the savings of a proactive approach, it may have to be accepted that the options available are only of a reactive nature. In this case, the maximum benefit of such an inefficient approach may need to be specified clearly.</p>
Type of project	<p>Role of HFI in the change process:</p> <ul style="list-style-type: none"> • Raising the need for change • Offering services to support the envisaged design programme • Efficiently conducting a specified HFI task 	<p>The objective of the cost-benefit analysis depends on the role that HFI takes in how it drives and supports the process of change:</p> <ul style="list-style-type: none"> • If the need for HFI has largely not been recognised, then much of the focus needs to be on the risk analysis to raise the need for design or process changes based on the potential of costly HF problems. • Where a project or programme is being conceived, based on having identified a requirement for change (that may or may not be HF specific), then the potential contribution of HFI to that process of change needs to be demonstrated. • Where the need for HFI has been already clearly identified and a task specified, the focus is mostly on effective resource allocation to achieve the required objectives. Detailed reasoning for key spending areas needs to be provided. Identifying a minimum HFI cost

Category	Variables	Advice: requirements for detail and content
		<p>level is instrumental in this case.</p> <p>The primary demonstration aim of the analysis needs to be identified: (a) whether HFI is needed, (b) what HFI is needed, (c) how much HFI is needed, (d) what HFI activities are needed for what task. The role taken by HFI often depends on the design stage at which HFI is being considered.</p>
Type of project	Project size	Project size influences the breadth and depth of reasonable HFI efforts, the options to be specified for HFI involvement (e.g. training engineers in applying basic HF methods and principles vs. establishing entire HFI programme that employs full-time HF specialists). The minimum HFI investment to ensure a financial return may vary between small and large projects.
Type of project	Project pace	Project pace (e.g. the 'tightness' of the project schedule, the margins for slippage on delivery) influences the priorities for spending – and the amount to be committed.
Target audience of argument	Management level to be addressed	<p>Cost-benefit analysis is a trade-off analysis that requires an optimisation process. Once a favourite option has been identified in relation to identified values, the option needs to be presented through a suitable argument. The target audience of the argument may depend on the project stage at which the case is being made (e.g. higher management vs. project manager), as well as the level of detail to be addressed (i.e. project conception, specification, detailing).</p> <p>Distinctions need to be made regarding the management level to be addressed. (Eurocontrol, 2000), suggests distinguishing the following management levels for making HFI arguments:</p> <ol style="list-style-type: none"> (1) Higher-level strategic capability management; (2) Project management; (3) Systems engineering; (4) Software and hardware construction itself.
Target audience of argument	Cost responsibilities and target audience objectives	<p>The arguments to be made depend not only on the specific characteristics of the project (although many of the cost areas are fairly generic), but also on who is making the argument to whom. For example, the cost of accepting something that is not fit for purpose is a cost to the procurer (i.e. Customer 1), the cost of failing to meet requirements is a cost to the supplier, and the cost of operational difficulties may be a cost to the user (i.e. Customer 2). Whilst a single HFI issue could actually be a cost to all three parties, it may not need presenting to all.</p> <p>It is therefore essential to identify the main business goals of the decision makers. Their perspective depends on their role, responsibilities, and influence. For example, the case is more difficult to make if the organisation designing a product may never have to deal with the consequences of it failing due to, for example, human error. Likewise, some HFI effects are long-term and may fall outside the decision-makers' role – for example, by establishing new methods to be re-used in the field, or wider-reaching benefits for society. In this case, standards and regulations may need to be considered.</p>

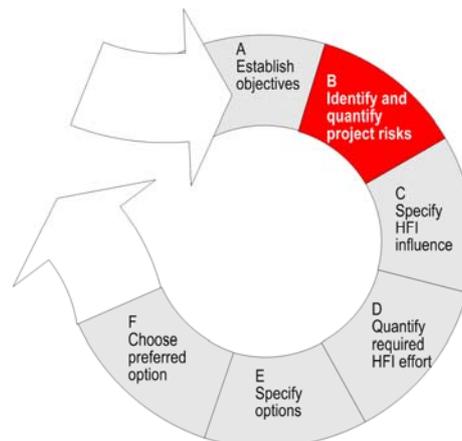
B Identify and quantify project risks

To estimate the effort required for HFI, the potential for HF-related risks needs to be assessed. Risks need to be identified in relation to the overall values that need to be achieved by the project. Based on this, opportunities for savings through HFI can be identified. They may be expressed either as project risks avoided (e.g. lowered performance avoided) or value added (e.g. efficient training design).

This step essentially specifies the worst-case scenario – i.e. the effects of no HFI involvement.

Main steps:

1. Identify and assess risk areas.
2. Identify cost impact.



B.1 Identify and assess risk areas

B.1.1 PRE-PROJECT PLANNING

To be able to specify the need for HFI, the extent to which the project may lead to HFI-related risks needs to be assessed. A risk refers here to the likelihood of the occurrence of an undesired event or situation that leads to costs. The concept of risk is always predictive, with a probability and an impact level assigned to it. The impact level may be expressed through a severity rating or a cost figure.

The foundation for any risk assessment is to establish the values and priorities to be achieved, as described in section A (e.g. resource spending during development, mission effectiveness and performance, productivity gain, safety, societal benefits, conforming with regulations). Such a list of values is the basis for assessing the extent to which they may, potentially, not be achieved.

The analysis approach changes with the project phase and the level of uncertainty. When making predictions at the earliest project stages, the exact risk areas, likelihood and severity are often unknown until more detailed investigations have been conducted. Thus, only an initial best guess can be made.

With an understanding only of the type of project and the main constraints and objectives, the scope of potential problems can be measured using a set of generic risk factors that HFI can have a particular effect on. **Table B1** shows a RISK POTENTIAL CHECKLIST that provides such risk influence factors (2nd and 3rd columns).

The list combines two types of factors:

- HFI-specific factors such as the level and focus of human involvement in the operation of new system/equipment, providing an initial prompt as to potential areas of concern (e.g. level of expected cognitive demand) – items 1 to 7;
- Generic cost factors (e.g. project uncertainty, novelty, and complexity) with an effect on the HFI effort needed for prevention and rectification – items 8 to 15.

This risk assessment is the first part of a method that is completed under step D with **Table D1**, where the risk levels are translated into the amount of HFI effort needed as a proportion of the overall project budget (that covers other disciplines as well). The risk assessment, however, is a valuable resource in itself since it points towards areas of concern that can be linked to their cost impact.

The first step in quantifying the extent to which financial penalties can be expected is to identify the risk potential on a severity scale, based on the likelihood and impact of problem occurrence. The checklist in **Table B1** provides a rating facility (the columns under ‘severity rating’) to estimate the potential impact of each factor (where ‘1’ is very low and ‘5’ is very high). It shows a completed example assessment. Impact ratings need to be based on experience values and expert judgements. To make the ratings more objective, **Expert Rating Techniques** may be used (see **Resource 5**).

The level of risk for each factor does not provide actual cost figures, but it can be implied that a cost can be expected. Step B2 identifies the relationships to costs – both generically (when details are unknown) and more specifically.

The assessments for each risk factor provide a qualitative overview as to where problem areas may lie. The ratings can also be used to derive a figure for an overall risk level. It may be expressed using the same rating scale as for each individual factor (1 to 5). There are 15 factors, so each contributes 6.67% to the overall risk. Since their contribution may vary, the risk influence factors in **Table B1** have been given a predetermined weight (e.g. presence of health hazards: 5%). These proportions may need to be adjusted according to the type of project. The sum of all risk factor percentages should be 100.

For the example rating given in **Table B1**, the overall risk level could therefore be determined as **3.6** on a scale of 1 to 5. This is derived by multiplying the rating for each (e.g. 5) with the weight (e.g. 0.05) and then accumulating them all ($0.25+0.05+0.50+0.05+0.25+0.75+0.15+0.30+0.25+0.25+0.50+0.05+0.25=3.6$).

Table B1: RISK POTENTIAL CHECKLIST (completed example).

	Risk influence factor	Explanation	Weight	Severity Rating					
				0 - None	1 - Very Low	2 - Low	3 - Medium	4 - High	5 - Very High
1	Estimated cognitive complexity of operation	The level of complexity for the interaction between people and technology, and the complexity of the operational environment, potentially leading to cognitive workload (e.g. decision-making tasks in dynamic environments; operation of complex equipment with many variables; time pressure; anxieties).	5%						X
2	Expected physical difficulty of operation	The severity and number of adverse operating constraints that may reduce operator performance and task achievement due to physical stressors and workload factors (e.g. extreme thermal discomfort, moving heavy loads, limited visibility).	5%	X					
3	Mission-critical operation	The extent to which the operation of the system affects the success of the mission, and the criticality of mission or task failures.	10%						X
4	Presence of health hazards	Presence of potentially harmful conditions due to the operating environment, technology interaction, or task demands (e.g. toxic substances, moving parts, prolonged operation under physically or psychologically strained conditions).	5%	X					
5	Expected operation under safety critical conditions	Risk of large-scale accidents due to human error (e.g. possibility of excessive cognitive workload, lack of situational awareness).	5%						X
6	Direct interaction scope	Extent to which people are directly affected by the equipment (e.g. number of users affected; occasional vs. continuous use) – not limited to operators, but including, for example, maintenance personnel, users directly benefiting from function of product/system, and people transporting and installing equipment.	15%						X
7	Expected change of manpower and skill levels	Likelihood of changes to personnel issues including manpower availability and requirements, and skill needs – potentially requiring manpower planning, recruitment, and/or training activities.	5%			X			
8	Extent of HF problems in predecessor systems	Extent of HF problems in existing systems, giving an indication of the amount of design change required to overcoming them and assessing improvements.	5%			X			
9	Scope of effects	The extent to which the new product/system affects related system design areas through the consequences of changes required. For example, new technology such as NEC information networks may require new organisational and information flow structures, re-training, re- recruiting, new maintenance schedules, new documentation. The lifetime of the product/system may come into the equation here.	5%				X		
10	HFI design scope in relation to project focus	If the purpose of the project is the design of a new user interface only (e.g. for an existing helicopter), then the HFI effort is proportionally much higher than, for example, the design of an entire new helicopter (where, for example, ensuring technical airworthiness will take on a much larger proportion than HFI activities).	10%				X		
11	Level of novelty	The extent to which the newly designed working system is novel (e.g. first-of-a kind) and produces sources of uncertainty (e.g. novel technology, new task and operating conditions, new organisational constraints). This affects design, implementation, and operation.	5%						X
12	Number of design constraints	The extent to which the design process needs to conform with external limitations that require optimisation of operational variables (e.g. need to comply with safety regulations, need to follow specific design standards).	5%						X
13	Project uncertainty	Amount of (not yet) available understanding of operational needs and system requirements (e.g. agreements on operational concepts, understanding of user constraints, definition of tasks and expected task performance, clarity of high-level human-equipment interface requirements, envisaged use of technologies). Technology Readiness Levels may be referred to here.	10%						X
14	Product purpose directly fulfils a Human Factors need	The purpose of the design is in itself fulfilling a user need, i.e. support to humans is the objective of the project (e.g. transporting them, housing them, providing them with information).	5%	X					
15	Absence of conducive design organisation conditions	The ease with which an effective HFI process can be integrated depends not only on the acceptance level of HFI, but also on the presence of conducive processes such as an iterative design process, efficient project management, effective communication, documentation, and information sharing processes.	5%						X

Instead of a detailed risk analysis, a simple metric relating human and equipment cost may be useful for up-front assessments to determine the relative value of the human cost element as a percentage:

$$H = [P * M^y / ((C^o * N + C^y) + P * M^y)] * 100\%$$

Where:

H = Relative value of the human cost element (as a percentage)

P = Average number of simultaneous users

M^y = Average cost per man/year of the users

C^o = Capital cost of equipment purchase

N = Number of equipment units purchased

C^y = Annual support costs of the equipment/system

This calculation provides a percentage of what the human in the system may cost, based on the number and types of users affected. This provides an early estimate of associated cost risk for situations where problems may affect the human element. It provides a percentage in a rough order of magnitude of how much HFI investment may be needed in relation to the overall project budget – without a detailed notion of actual risk or risk areas, however.

For example, a Ship Command System will have major human interaction at all levels, a very large user community across differing demographics and critical HMI dependencies, while a Flight Control System will cost the same order but have a much reduced target audience with more selective users.

This calculation may also be used to assess item 6 in [Table B1](#), ‘Direct interaction scope’, expressing the extent to which people are directly affected by the equipment (e.g. number of users affected; occasional vs. continuous use).

B.1.2 ONGOING PROJECT SUPPORT

Later, at the stage of project specification, when specifying the first [Human Factors Integration Plan \(HFIP\)](#), more specific project risk areas need to be identified. [Resource 4](#) briefly describes the contents of an HFIP. An [Early Human Factors Analysis \(EHFA\)](#) can be taken as the basis for producing an HFIP. [Resource 6](#) provides a brief description of EHFA.

One of the main outputs of an EHFA is an initial risk register where specific risk areas are identified and assessed. The risk areas should be specified for major project stages or elements. Cost candidates can be established based on consideration of the risk influence factors (from the checklist in [Table B1](#)), and the interplay between technology, operating conditions, users, and tasks. Risk assessments involve developing a combined impact rating (i.e. the extent to which the problem may decrease mission performance) and likelihood rating (i.e. novelty, and extent to which technology is proven and performance goals are understood). More detail on EHFA can be found, for example, in the Practical Guide for IPTs (MoD, 2001).

The risk identification for an EHFA relies not only on identifying human-related constraints that may affect system performance, but also on an understanding of the functions (that are to be supported by the new system) that may or may not be achieved, or not achieved efficiently. A useful method for establishing system functions, purposes and values is [Work Domain Analysis](#) (see [Resource 7](#)).

[EXAMPLE 1](#) provides an EXAMPLE RISK ASSESSMENT, as may be derived from an EHFA, applied to the domain of Network Enabled Capability (NEC) for Close Combat. It presents a list of potential HFI risks. They were identified based on the presence of human-related constraints, the needs for change, and an understanding of the functions, values, and purposes of the socio-technical system being designed. The system functions were established through a Work Domain Analysis. The potential ‘non-achievement’ of these functions due to HFI deficiencies can be understood as a risk.

During later phases of project detailing, the analysis focuses on specifying particular risks in relation to contextual factors, where original risk assessments from the HFIP are being reviewed.

EXAMPLE 1: EXAMPLE RISK ASSESSMENT based on sources of risk due to functional changes – applied to NEC for Close Combat.

Due to operational constraints	Due to change (wider implications) - problems due to incorrect predictions	Due to information use - to maintain and use Situational Awareness (SA)	Due to networking, communication and coordination needs as part of team interaction
<ul style="list-style-type: none"> ❑ Operational characteristics (task, mission, context, operators) ❑ Equipment weight and portability <ul style="list-style-type: none"> ◇ physical strain ◇ reduced physical flexibility ◇ decreased protection and increased vulnerability ◇ unsuitable trade-offs between data gathering equipment on soldier and need for information on command level ❑ Manual/physical limitations <ul style="list-style-type: none"> ◇ having to use different parts of NEC equipment in parallel ◇ having to operate NEC equipment in parallel with other devices (e.g. guns, gloves) - hands-free vs. simple operation ◇ integration with other elements of combat suit, weapons, sensors etc. (e.g. access problems) ◇ having to fit information on small screens given weight and portability limitations ◇ characteristics of equipment increasing vulnerability (e.g. bright screens visible to enemy at night) ◇ performance reductions with thermal comfort variations due to equipment weight, clothing, protection 	<ul style="list-style-type: none"> ❑ Impact of technology on operations - effects of change ❑ Need for evolution of networks and technologies ❑ Need for changed roles and jobs ❑ Need for changed organisational structures to support technologies and new operating demands ❑ Need for more complex/expensive/ recurring training <ul style="list-style-type: none"> ◇ existing personnel unable to deal with new task requirements ◇ training efforts, and potential (continuous) re-recruiting, adds significant costs ◇ need for substantial updates in equipment documentation, manuals etc. ◇ creating reliance on user documentation due to complexity of use ❑ Need for changes in operating procedures, doctrines, basic strategies etc. ❑ Need to overcome older habits, structures, established processes 	<ul style="list-style-type: none"> ❑ Information and data provision relevant to task and role <ul style="list-style-type: none"> ◇ provision of irrelevant information for task ◇ expectation to deal with NEC data becoming a hindering factor in task execution ◇ integrated use of databases and expert systems introduces new types of interaction ◇ decision support tools that keep operators 'in the loop' ❑ Attention requirements and mental workload <ul style="list-style-type: none"> ◇ having to deal with too much information - causing overload, confusion, and lowered SA ◇ having to filter and assess what information is most important - additional task ◇ having to integrate information from different devices (or screens) for complete understanding ◇ head-down time increasing vulnerability (e.g. need for data entry, reading information, watching for updates) - risk for survivability ◇ delays due to operating the devices, slowing down reaction times - reduced action flexibility 	<ul style="list-style-type: none"> ❑ Operation of multiple devices and information sources <ul style="list-style-type: none"> ◇ automated support can mask understanding of raw data ◇ using electronic data from semi-autonomous devices (e.g. UAVs) ◇ use of semi-autonomous devices (e.g. UAVs) that may need some level of control ❑ Need to match qualitatively different types of network <ul style="list-style-type: none"> ◇ integration of different technology networks may not follow operational information requirements but technical feasibility ◇ local networks (e.g. elements of action deployment) may not match global networks (e.g. command information structures) ◇ human-machine interaction framework may interrupt collaboration networks ◇ information flows may not map onto power/responsibility structure ◇ NEC making communication more complex rather than simple ◇ NEC structures may impose organisational changes that need to be coordinated with other elements of social networks ❑ NEC (in itself) does not solve existing organisational/social/team work problems <ul style="list-style-type: none"> ◇ NEC may be embedded into ineffective (existing) organisational structures (e.g. complex reporting lines through too many instances)

Due to operational constraints	Due to change (wider implications) - problems due to incorrect predictions	Due to information use - to maintain and use Situational Awareness (SA)	Due to networking, communication and coordination needs as part of team interaction
<ul style="list-style-type: none"> ❑ Inadequate support of human senses <ul style="list-style-type: none"> ◇ screens need to be bright enough/dark enough/non-reflective for all lighting conditions ◇ understandability of voice communication in noisy environments ❑ Data availability, redundancy options and procedural flexibility - dependence on reliability and availability of equipment <ul style="list-style-type: none"> ◇ equipment robustness requirements for demanding environments (e.g. moisture, temperature) ◇ availability of trained back-up options and procedures for situation of missing data (e.g. black screen) ◇ implications of procedure switching due to technical failures for individual and team performance ◇ power sources - weight, availability, reliability constraints ◇ impact of maturity, functional fit, adaptability, and upgrade options on operations (e.g. COTS requiring inefficient workarounds) ❑ Usability issues <ul style="list-style-type: none"> ◇ physical interaction and button operation, manipulation ◇ physical manipulation ◇ physical interaction, operation, manipulation ❑ Compatibility and consistency issues across related equipment and interfaces 	<ul style="list-style-type: none"> ❑ Increasing reliance on new equipment creates complete mission failures when they become unavailable (where traditional processes, and the ability to switch back to them, have not been maintained) ❑ Maintenance and logistics implications due to increased dependence on physical objects with power and technical support requirements ❑ New distributions of functions between people and machines <ul style="list-style-type: none"> ◇ automation/computer technology solves some problems but shifts them elsewhere (e.g. ironies of automation; short-sightedness of office automation) ◇ the human element should/cannot be eliminated (e.g. UAVs still need to be controllable from the ground) ❑ Need for information management roles ❑ Network development and growth - e.g. ability to upgrade ❑ Implementing organisational change throughout organisation (e.g. training, motivation, doctrines) 	<ul style="list-style-type: none"> ◇ too many information-processing tasks added that cannot be fulfilled in parallel to combat tasks ❑ Insufficient consideration of human cognitive characteristics - causing lowered SA provision of understanding/sense making ensuring situational awareness <ul style="list-style-type: none"> ◇ not fast enough (e.g. information presentation, media use, unsuitable pre-calculations and assessments, central information easily accessible) ◇ risk of wrong or incomplete understanding (e.g. presentation/visualisation, attention focus, need for mental calculation and assimilation) ◇ poor support of action planning (e.g. lack of predictions/ presentation of change/suitable time references, information presentation with no correlation to action requirements) ◇ need for provision of simple interfaces that provide immediate understanding for personnel with basic training and computer expertise 	<ul style="list-style-type: none"> ◇ social issues (e.g. trust issues) not resolved through technology alone ◇ right type of network needed for each type of task (centralised vs. distributed) ❑ Relationships between networks - network of networks perspective <ul style="list-style-type: none"> ◇ feeding plan/tactical/assessment/decision/ status information to higher command - e.g. overhearing voice communication vs. digitally transformed data requiring input ◇ local network in relation to global network (e.g. UAV-soldier-commander interaction in relation to headquarter decision-making) ◇ remoteness issues (e.g. 'long screwdriver') ❑ Team work support (collaboration amongst all elements of operational network) <ul style="list-style-type: none"> ◇ difficulties of communication between many different entities: individual soldiers, weapons, sensors and vehicles ◇ shared information resources cannot be navigated/shared/mutually understood ◇ shared references cannot be established ◇ communication breakdowns ◇ lack of mutual understanding ◇ focus on sharing information on screen reduces visibility of actions/understanding for other team members ◇ inability to form dynamic grouping and flexible organisational structures due to rigid constraints and structures

B.2 Identify cost impact

To further understand the risks, and their associated impact, it is necessary to specify the types of cost that can be associated with problem occurrence. There is not always a one-to-one relationship between risks and costs. Risks may cause cost not only through adverse events and situations (e.g. performance reduction, failed task, accident damage), but also process-based cost such as the consequences of wrong investments and re-design needs. The potential benefits of HFI, to which a financial value can be assigned, also include wider-reaching benefits and savings outside the direct project scope (e.g. long-term effects of well-established HFI over many projects; established methods, processes and expertise).

When specifying savings, It is important to consider the effects throughout the CADMID lifecycle because HFI costs at one stage can create savings in a later stage. The overall argument for HFI can be presented as contrasting a typical best-case situation (Figure 6) with a worst-case situation (Figure 7).

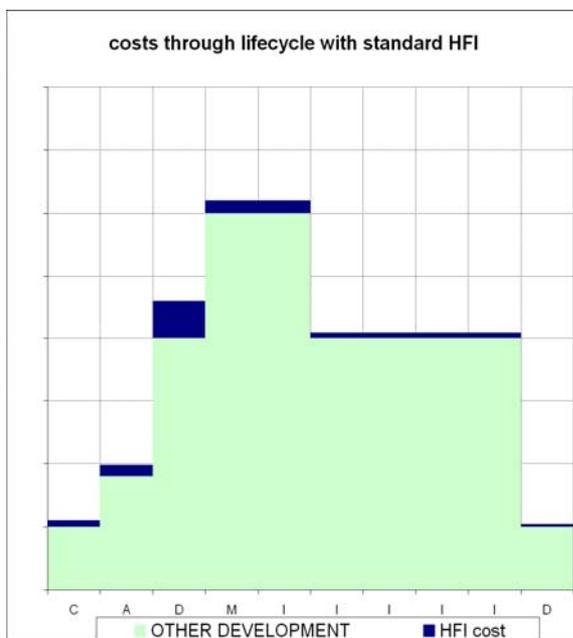


Figure 6: Example project situation where HFI is being applied.

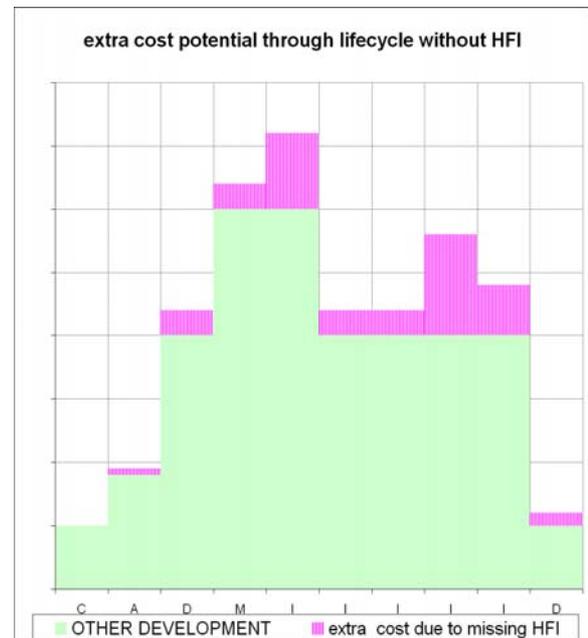


Figure 7: Example project situation where required HFI is not applied.

Table B2 provides a COST TYPE CHECKLIST to identify the variety of costs that can be associated with HFI oversights. This is a qualitative approach that can be used as the basis for subsequent quantitative analyses. Identifying the different types of possible costs gives a basic understanding of the magnitude of the risks identified. Once the savings potential has been identified, cost areas may be prioritised to establish particular target savings across lifecycle stages.

Table B2: COST TYPE CHECKLIST.

		Effects that can be linked to costs	Cost effects	Influential factors and example problems
C A D M	System delivery is overspent	Increased development cost for effective and efficient system	<ul style="list-style-type: none"> • Delays (investments locked, system benefits unavailable) • Losses due to wasted financial commitments • Re-design costs to deal with consequences of system design errors • Additional resources needed (e.g. training design, requirements analysis) • Manufacturing productivity 	<ul style="list-style-type: none"> • Operational problems identified in late testing stages • Misunderstood user requirements identified late in design stages (e.g. expensive product functions are identified as unwanted by users in the final assessment phases) • Unsuitable design focus adopted • Unanticipated support costs (e.g. more complex training to be delivered) • Manufacturing slowed by HFI oversights (e.g. complicated manual assembly, exposure to hazardous substances) • Late design changes due to oversights in HF regulations that need to be adhered to • Development resources (e.g. additional design iterations) needed to overcome implications of inefficient design decision-making (late, incorrect, missing decisions due to lack of HFI data) • Type of productivity: one-time (few products only produced) or recurring (larger numbers produced over longer period)
I	System is not efficient (i.e. overspending to achieve effective system after acceptance into service)	Unexpected implementation effort	<ul style="list-style-type: none"> • Partial re-designs or additional equipment design • Reorganisation need (e.g. role changes) • Higher initial training effort • Higher cost of personnel change • Grounding systems due to unresolved issues: equipment downtime • Wasted personnel time when equipment unavailable • Support systems need to be purchased • Managing resistance to change 	<ul style="list-style-type: none"> • More resources than expected needed for implementation • System initially inoperable without spending additional unanticipated resources (e.g. delays, re-design), e.g. <ul style="list-style-type: none"> ◊ Skilled people not available (e.g. training not effective; personnel not recruited) ◊ Supplies not available (e.g. required batteries fail too frequently) ◊ Operational instructions not available (e.g. manuals not printed) ◊ System not maintainable/serviceable (e.g. part to be replaced is physically difficult to access) ◊ Organisational structures not supportive • Complexity of implementing change in existing systems (i.e. more constraints, more commitments made) – requiring changes of larger magnitude • Constraints of organisational culture and nature of relationships among management, user, provider, unions, industry, and other stakeholders who may have differing perspectives on the benefits of changes
I D		Unexpected resources needed for system operation In-Service (i.e. more spending to achieve effective system)	<ul style="list-style-type: none"> • System to be replaced sooner by more effective/efficient solution • System support required exceeds that planned in current policies • Small-scale performance improvement measures needed frequently to keep up with demands • Equipment downtime in case of operational shortcomings 	<ul style="list-style-type: none"> • Expensive training design and delivery (e.g. expensive simulator time needed, long period of initial training, frequent refresher training, more training personnel needed) • Ensuring continued and effective servicing/maintenance (e.g. long downtimes due to physical accessibility problems, complex maintenance routines, more servicing personnel needed) • Expensive recruitment (e.g. new operators required, rare skills required, skills required do not match profile/image of traditional task) • More, or more expensive, manpower required (e.g. higher-paid operators needed, more people needed elsewhere) • More materials, spares needed • Safety culture processes needed • Organisational and management processes needed

		Effects that can be linked to costs	Cost effects	Influential factors and example problems
I D		Wider organisational problems causing additional cost later (i.e. 'knock-on' effects)	<ul style="list-style-type: none"> • Organisational re-design • Re-building lost structures and resources • Recruitment/ training • Disposal cost • Problem recovery • Re-building and re-learning efforts when having to repeat processes for which resources have not been maintained 	<ul style="list-style-type: none"> • High staff turnover due to low job satisfaction (e.g. lack of control; mundane jobs) • New social structures do not support trust, communication and collaboration needs • Cutting existing structures may increase future deficiencies (e.g. less training effort may result in future accidents) • Organisational structures and command hierarchies that do not support effective information flows • Having to repeat inefficient design processes in later projects (e.g. knowledge gained not captured in new methods and processes) • Resources spent to achieve effective HFI process not maintained for future projects • Demand for provided services lowered
I	System is not effective (mission achievement and performance flaws)	Mission or task failure under operating conditions (e.g. major functions not achieved, critical assignments fail)	<ul style="list-style-type: none"> • Operational resources wasted • Task not achieved • Having to repeat mission • Collaborators' resources wasted 	<ul style="list-style-type: none"> • User interface has major flaws that prevent reliable task completion under operating conditions (e.g. task achieved too slow to achieve purpose) • Equipment inappropriate for physical constraints in operating environment (e.g. body armour too hot for environment temperature and length of time it will be worn) • Equipment cannot be handled (e.g. too heavy for carrying over distances required) • Ineffective support leading to task failures
I		Limited achievement (e.g. low operator/user performance)	<ul style="list-style-type: none"> • Operational resources wasted • Delays • Support resources needed (e.g. refresher training) • Re-work 	<ul style="list-style-type: none"> • High fatigue rates (e.g. time stress, high attention requirements, physical overload, high task demands) • Task completion time unsuitably high (e.g. frequent response delays) • Frequent operator error (e.g. data entry in wrong field, wrong button pressed) • Low skill retention after period of not using system • Additional effort needed since human limitations were not taken into account (e.g. physical reach and strength; vision; effects of tendency towards recognition primed decision making) • Ineffective support leading to lowered performance
I D	System is not safe (health and accident risks)	Exposure to health hazards leading to injuries, illness, or death	<ul style="list-style-type: none"> • Absence/unavailability • Re-recruitment • Re-training • Insurance • Liability • Rehabilitation 	<ul style="list-style-type: none"> • Presence of hazards in proximity to people (e.g. moving parts, toxic materials, flammable materials, exposure to heights) • Environmental conditions unsuitable for people (e.g. noise, heat, insufficient light) • Repetitive actions that are unsuitable for human physique (e.g. frequently working in confined spaces) • Job constraints (e.g. time pressure, stress, workload, demands) • Unnecessary exposure to hostile forces (survivability issues)
I D		Risk of major accidents that can be linked to operator workload and human error (including operator and maintenance errors)	<ul style="list-style-type: none"> • Equipment replacement and repair • Equipment downtime • Absence/unavailability of people • Rehabilitation • Re-recruitment • Re-training • Insurance losses • Liability/ legal costs in establishing blame • Loss of image 	<ul style="list-style-type: none"> • Safety-critical domain – operational hazard prediction incomplete • Dynamic, complex systems – operational implications not completely understood • New technology, new applications – changes not investigated sufficiently • Critical role of human operator/maintainer – role underestimated • Ironies of automation (i.e. new roles, new demands, new errors) – effects underestimated

Detailed quantitative assessments are project-specific and are not further elaborated here. The literature provides some examples that help to estimate risk costs, including:

- [Example calculations \(Resource 8\)](#);
- [Experience values \(Resource 9\)](#);
- [Case studies \(Resource 10, Resource 11\)](#).

For the stage of specifying initial HFI plans, the emphasis can be shifted more from identifying cost areas to specifying and quantifying them (likelihood and volume) for particular process stages. Cost impact calculations may vary depending on how the effects can be measured – such as:

- *One-Off effects* (non-recurring, unique), applying to development costs; implementation costs; responsibility costs; loss of sales or customers.
- *Rare effects*, applying to risk of accident, or other exceptional (infrequent, irregular) events, usually associated with very high costs. Design in safety-critical domains relies heavily on prediction techniques using probability measures.
- *Intermittent effects*, applying to cost effects that have an element of frequency that can be counted and valued, including costs associated with:
 - ◊ ‘*Non-achievement*’ of task or mission success. The cost of not achieving an important task can be measured through the importance of the task, and to some extent through the frequency of occurrence.
 - ◊ ‘*Non-availability*’ of people (e.g. due to personnel turnover, injury, health) and/or equipment (e.g. due to failure, maintenance need, logistics problems, inoperability). The immediate cost effects of lost productive time and recovery expenses are usually easily measurable. This category closely relates to the concepts of survivability and personnel retention, affecting recruitment and training costs. Moreover, subsequent lack of expertise can affect mission success.
- *Continuous effects* (i.e. uninterrupted, permanent, regular), applying to productivity, effectiveness and performance costs (e.g. costs of running system, maintenance). These are ongoing effects that can be measured and compared to a theoretical (or past) alternative. A major factor is the number of people affected.

The cost of risks may be estimated based on assuming a certain number of design flaws as a cause of risks. The concept of a design flaw can be understood here as a property of the designed system that is likely to cause an operational problem.

Design flaws can be linked to cost effects through measures including:

- Total number of emergent design flaws (e.g. per design area, per project stage);
- Confidence/likelihood factor as a measure of probability of problem occurrence;
- Impact/damage/severity (e.g. minor to catastrophic) as a measure of potential cost magnitude;
- Impact severity proportions (e.g. 40 minor flaws, 10 major flaws) to specify actual figures, after assigning figures to impact categories.

EXAMPLE 2 provides two hypothetical EXAMPLE CALCULATIONS that draw out different types of variables for cost impact calculations. The example shows that the calculation depends on how the effects may occur (e.g. the effects of rare events such as human error vs. effects of overall human performance reduction). Note these are approximations only, using simplifications.

EXAMPLE 2: EXAMPLE CALCULATIONS for HFI cost impact due to design flaws.

- Accident occurrence due to human error:
 - ◊ 5 design flaws with the potential of causing human error;
 - ◊ Likelihood of occurrence (i.e. error occurs and leads to an accident): 0.001% ⁶ (over 1 year);
 - ◊ Magnitude of one accident: major (e.g. cost of £2,000,000);
 - ◊ 100 aircraft of this type will be in service;
 - ◊ $5 \times 0.00001 \times 100 \times £2,000,000 = £10,000$ per year of operation;
 - ◊ 20 years of operation expected: £200,000 total.
- Usability problems causing lowered performance:
 - ◊ 5 flaws on interface present;
 - ◊ 80% likelihood of lowering performance (for each flaw present);
 - ◊ Cost due to performance reduction over 1 year for 1 user: £500 (minor);
 - ◊ 10 users likely to be affected directly;
 - ◊ $5 \times 0.8 \times 10 \times £500 = £20,000$ costs of problems per year of operation;
 - ◊ 10 years of operation expected: £200,000 total.

A “reasonable worst-case scenario” can be established that combines cost estimates for worst-case scenario risks with likelihood factors.

⁶ Note that type of operation and the type of aircraft would play a role here, as well as the complexity of the design and the types of users. There may be statistics that help with the estimation. Also note that the errors are assumed to occur independently of each other. Moreover, the extent of use (e.g. flying hours per day) has not been considered here.

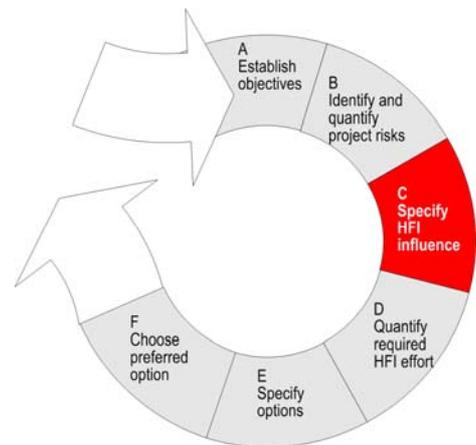
C Specify HFI influence

To specify how HFI can reduce project risks, the paths through which HFI can influence design decisions need to be clarified. Understanding the functions that the HFI process contributes to the design process is crucial to comprehending how HFI creates value.

To assess the scope of HFI needed, it needs to be shown how design decisions in different design domains can be influenced. Likewise, these areas need to be targeted specifically to initiate support through HFI.

Main steps:

1. Specify the role that HFI takes in the project.
2. Specify target design areas.



C.1 Specify the role that HFI takes in the project

To be able to link HFI activities to benefits, the role HFI is to take in the project needs to be clarified. As part of this, the types of activities through which HFI can affect design decisions need to be understood.

For example, product development activities involve major cost investments. If unsuitable investments are discovered during tests and assessments after development efforts have been spent, re-design costs can be significant. Accurate requirements specifications that users have agreed to are crucial. Translating user needs into system specifications is a non-trivial task where HF expertise can be critical. Moreover, regular assessments of part solutions in an iterative design approach are essential for effective project risk management.

In order to show the benefits of HFI, it is necessary to demonstrate what functions HFI provides and how they can affect the design choices and ultimately prevent problem costs. In this context design is considered here as a solution-generating activity that includes requirements specification, concept generation, prototyping and final product design.

It is essential to establish that HFI takes effect through a set of standard functions (i.e. typical component activities). They include (1) Investigate; (2) Create; (3) Evaluate; (4) Manage. Table 2 provides more details on these HFI functions.

Table 2: Main HFI functions with explanations.

INVESTIGATE	Seeking understanding of constraints and resources	<p>Researching:</p> <ul style="list-style-type: none"> • Conditional factors such as human capabilities and limitations for selected situations; • Motivational factors due to organisational processes; • Effects of environmental constraints on human performance and health; • Users' current and envisaged tasks and procedures.
CREATE	Active generation of requirements and design solutions	<p>Providing design guidelines, principles and means of compliance with regulations and standards to meet HF needs;</p> <p>Translating needs and constraints into envisaged functionality and solutions.</p>
EVALUATE	Assessment and testing of ideas, concepts, solutions and prototypes	Understanding the effects of new designs (e.g. technology, equipment, interfaces) on, for example, human behaviour, cognition, capacities, skills, jobs content and structures, human interactions, social structures, information flows, distribution of responsibilities.
MANAGE	Process management	Ensuring implementation of information; ensuring HF design involvement; ensuring HF mediation role; planning and timing; defining assessment criteria; defining roles and responsibilities; assigning tasks; assessing progress; project risk management etc.

All of these functions, or component activities, are needed to prevent or mitigate risks. They interact closely, as visualised in Figure 8. They apply to every stage of the CADMID process. They are not to be equated directly with design process steps such as design phase or testing phase.

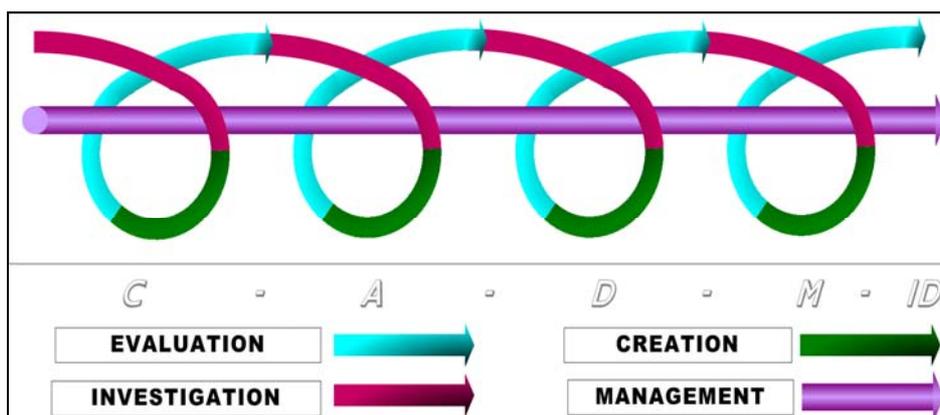


Figure 8: The functional elements of HFI.

The effects of HFI on risk reduction may be measured through:

- Design decisions influenced proactively (i.e. flaws prevented);
- Good design solutions generated (i.e. flaws prevented);

- Design decisions influenced reactively (i.e. flaws identified and rectified).

Based on the assumption that knowledge of operational and user constraints are required to provide effective designs (efficiently), HFI reduces risks through:

- Retrieving and communicating information;
- Applying information/findings to inform design decisions.

HFI creates value through services such as:

- Raising potential issues – by providing essential information (e.g. through observations of operations, identifying current problems);
- Establishing validated insight (e.g. through experimentation, models);
- Providing HF tools, methods, processes, data, standards, and expertise;
- Enabling user involvement and translating user views into requirements;
- Undertaking a design mediation and communication role.

HFI reduces risks through influencing design decisions. However, HFI does not always have direct involvement in solution-generating activities with decision-making power. HF specialists tend to have more direct access to generating solutions in larger projects.

HFI takes a central role in providing information to the design process (i.e. through the Investigation and Evaluation functions). For example, HFI identifies and validates insight on:

- Operational conditions (constraints and existing resources);
- Operational implications of designs;
- User characteristics (physical, psychological, knowledge, skill).

The total budget typically assigned to HF activities has been estimated to be between 2% and 10% during development phases for a medium to large multidisciplinary programme (Kopardekar & Hewitt 2002). This estimate depends partly on how the boundaries of the project are defined (e.g. the project output itself may be defined as an HF product such as a new HF method, where HF activities may contribute up to 100%). The estimate also depends on the role that is assigned to HF specialists.

Figure 9 shows how projects may vary in terms of the role of HFI in direct creative involvement. Typically, in a large multi-disciplinary project, HFI may be estimated to take control over about 1.5 to 3% of project design decisions (given that most specifications tend to be of a technical engineering nature). It may be appropriate, however, to assign higher proportions, depending on the design areas to be covered and the overall HFI strategy to be adopted. For example, the proportion may be higher when HF engineers are employed directly for specifying the user interface.

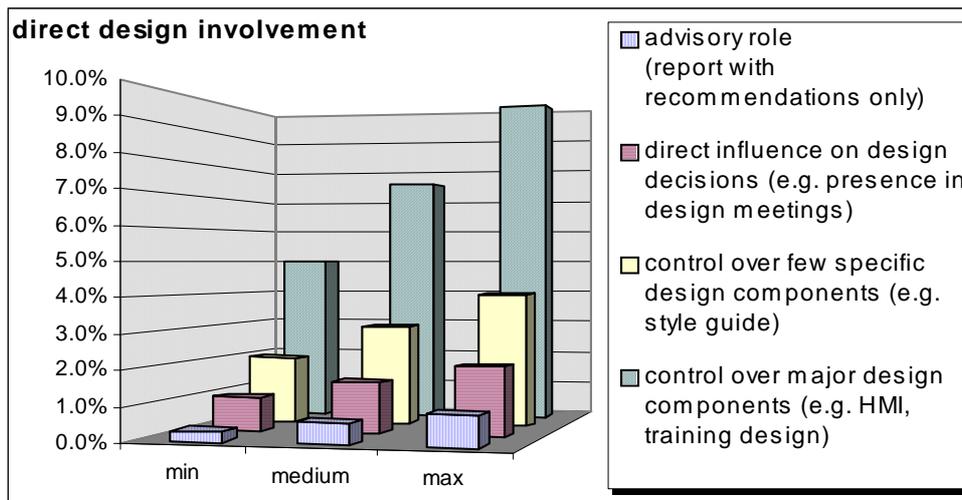


Figure 9: Variations in direct HFI design involvement – as a proportion of the total project budget.

C.2 Specify target design areas

To identify where HFI efforts need to be spent, it is necessary to specify and target design decision areas through which HFI can reduce project risks (e.g. user interface design, organisational specification, infrastructure design, training design).

Table C1 provides a DESIGN AREA CHECKLIST to identify HFI influence areas. It lists typical design areas and the relationships between (i) design decision areas, (ii) typical design activities, (iii) HFI roles in design areas, and (iv) risks mitigated. Many design areas are not always considered as areas where HFI can make a crucial contribution. They are not explicit HFI areas, but HFI can contribute a certain percentage of the work directly (e.g. in some domains, 30 to 50% of requirements engineering may be carried out by HF specialists). Note that the figures given are examples only and have not been validated.

When writing early project plans, activities need to be specified for each of the HFI functions, for each of the target design areas, and across all CADMID process stages.

EXAMPLE 3 provides an EXAMPLE MATRIX FOR SPECIFYING HFI ACTIVITIES.

To create an understanding of how cost effects can be linked to the HF efforts, [Value Chains and Influence Diagrams](#) may be of use. [Resource 12](#) provides further information on these techniques.

Table C1: DESIGN AREA CHECKLIST

(Relationships between design decision, design activities, HFI role in design areas, and risks mitigated). Figures provided are examples only. Note the percentage given expresses how much HF effort might be spent per design area – thus the HF column not intended to add up to 100%.

Design decision areas related to HFI (by overall system components to be defined)	Standard design areas (activity)	HF part	Associated HF activity examples (causing cost)	Example HF risk types affected
Functional specification (e.g. what should the system do; what technologies should be used; what facilities do the users require)	requirements engineering	30%	user needs analysis	inefficient support of human characteristics and needs
User interface (visual look and feel)	software design	50%	HMI	number of user interface issues (e.g. lack of simplicity; lack of control; potential for error)
Automation/software (behaviour, detailed functionality, structure, allocation of functions)	software design	20%	engineering psychology	workload/human error leading to lowered performance
Hardware interface (e.g. physical handling, location and handling of control interfaces, screen properties, aural interface design)	equipment hardware design	20%	physical ergonomics design	usability and handling problems leading to lowered performance; physical strains
Designed physical environment (spaces, visual angles, temperature control, lighting, vibration, working height, exposure to health hazards, ergonomics and comfort, layout/workflow/workspaces)	equipment surroundings hardware design	20%	workspace design	health hazards; operating conditions leading to lowered performance and task failures
Technology system structure (e.g. networking links, component interaction)	hardware system design	5%	various	technical network not matched to organisational structure
Number, skill, and availability of people needed to operate system	human resources	70%	training design, recruitment, manpower optimisation	lack of skill in existing personnel leading to additional training cost and/or performance problems
Manufacturing process (e.g. efficient part production and system assembly)	production design	5%	production flow design; workspace design	moving machine parts cause health hazards
Structure and processes of organisation/human interaction (responsibilities, collaboration needs, reporting structures, information flows)	organisational design	60%	organisational design; job design	lack of motivation; high personnel cost; ineffective information exchange
Designed operational processes , including: <ul style="list-style-type: none"> ● Equipment support activities (logistics, maintenance); ● Personnel support (recurrent training, health support); ● 'Management of change' plan; ● Product documentation design (user manuals); ● Procedure design. 	design of operations for: <ul style="list-style-type: none"> ● implementation ● early use ● late use 	30%	various	psychological strains; maintenance errors; implementation delays

EXAMPLE 3: EXAMPLE MATRIX FOR SPECIFYING HFI ACTIVITIES.

The matrix shown below provides an example for how to specify HFI activities for HFI design influence areas across the CADMID lifecycle. The numbers expand to example activities below. Activities are specified for each of the main HFI functions. Note that this is not comprehensive. To specify activities, the reader may also refer to other resources, such as ISO13407; Def Stan 00-25; The Practical Guide for IPTs (MoD, 2001).

	C	A	D	M	I	D
Requirements specification and management	1	2				
Design of hardware			3			
Production design				4		
Implementation and operations planning					5	
Maintenance design						6

(1) Requirements specification and management (Concept Phase)

Influencing design decisions at the level of specifying the URD:

- Manage: where to spend which development effort, e.g. facilitating design collaboration.
- Investigate: e.g. current best practice of system use; operational conditions; current improvement needs; current skill levels; user-expressed needs.
- Create: e.g. focus design process on essential user requirements and product functionality.
- Evaluate: e.g. user feedback on requirements prioritisation.

(2) Requirements specification and management (Assessment Phase)

Influencing design decisions at the level of specifying the SRD:

- Manage: adjust plans according to emerging constraints.
- Investigate: e.g. identify human constraints informing allocation of function issues.
- Create: e.g. produce concept of operations; specify functionality.
- Evaluate: e.g. user surveys to provide validated insight where requirements are unclear.

(3) Design of hardware (Demonstration Phase) – Influencing decisions leading to solution options:

- Manage: Adjust plans according to emerging constraints.
- Investigate: e.g. collect relevant anthropometric data.
- Create: e.g. specify sizes and shapes of product handling elements.
- Evaluate: e.g. ergonomics assessment of reach, vision, force (on computer model or mock-up).

(4) Production design (Manufacturing Phase) – Ensure efficient part production and manual assembly support

- Manage: e.g. productivity management.
- Investigate: e.g. study health and safety statistics.
- Create: e.g. ensure the same type and size of screws are used on all product parts for efficient manual assembly.
- Evaluate: e.g. measure time on task for production component.

(5) Implementation and operations planning (In-Service Phase) – Continuous process improvement

- Manage: e.g. establish and maintain suitable collaborative links.
- Investigate: e.g. identify remaining human factors risks.
- Create: e.g. input of HFI principles and processes into corporate standards and customer-centred business plans.
- Evaluate: e.g. assess success of HFI process.

(6) Maintenance design (Disposal Phase)

- Manage: e.g. allocate tasks to specialists.
- Investigate: e.g. analyse problems with similar previous products in other domains.
- Create: e.g. specify disassembly/ recycling/ discarding procedures.
- Evaluate: e.g. record feedback from operators.

D Quantify required HFI effort

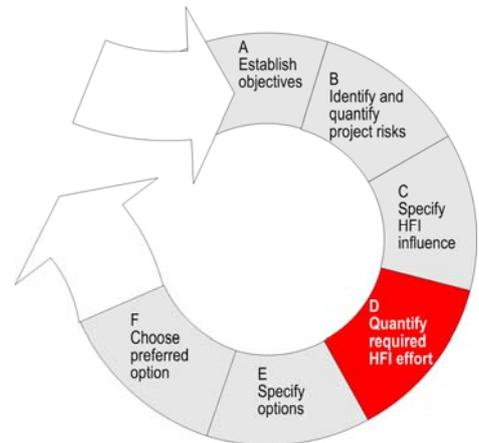
The HFI spending needed to prevent and mitigate risks can be assessed based on the severity of risk factors and resulting risk potential. Where no exact cost figures can be calculated, measures of magnitude can be used as a basis to estimate the appropriate effort of mitigation.

Initially, a (reasonable) best-case scenario for risk mitigation should be assumed. This implements a full HFI process with sufficient resources to have a significant impact on project risks.

The cost effort may be assessed either as a total cost figure, or as a proportion in relation to other quantifiable activities that are specified elsewhere.

Main steps:

1. Review project variables.
2. Specify HFI activity costs or cost proportions.



D.1 Review project variables

The same influence factors that were used in section B to assess project risks can also be used to assess the required HFI effort based on heuristics. The project risk ratings identified through the checklist in [Table B1](#) can be translated into HFI budget needs. This assumes a typical, medium to large, multi-disciplinary system development project.

During the Project Specification and Detailing Phases, the risk influence factors can be updated and further specified. Likewise, the role of HFI with regard to its involvement in direct solution generation activities needs to be defined. Factors such as project size, complexity and uncertainty have a direct impact on time and resource requirements. The level of fidelity required for simulators and prototypes has a high impact on cost requirements.

D.2 Specify HFI activity costs or cost proportions

Depending on the level of uncertainty for different project stages, three alternative options for cost estimation are outlined below.

D.2.1 Method 1: Cost calculation as a percentage of project budget

At stages of high uncertainty, obtaining detailed cost figures is often not practicable. Instead, sufficient HFI spending may be estimated as a proportion in relation to other costs specified elsewhere. At this stage, HFI costs may be calculated as a percentage of

the overall project budget, based on the project risk assessment conducted earlier, and experience values.

Table D1 provides COST ASSESSMENT METRICS that translate risk influence factors into cost percentages, to calculate the proportion of the overall project budget that needs to be allocated to HFI activities. The calculation is derived as follows:

- The HFI cost proportion is calculated by adding up the percentage elements for each risk influence factor.
- The higher the risk severity rating (chosen in section B) for each element, the higher the percentage element.
- For example, if each HFI factor is assessed at a very low intensity, they all add up to a total of 2% of total project cost. If all factors would be assessed at the highest severity, they add up to 12%.
- If some factors are assessed to have no impact, they contribute nothing to the total – so the total may be below 2%.
- Risk influence factors with a higher weight contribute more to the total, relative to each other. The weights must always add up to 100% of influence. For example, the first risk factor with a weight of 5% contributes at the lowest rating (2%) a total of 0.1% to the total budget ($2\% * 5\% = 0.1\%$).
- **EXAMPLE 4** shows example ratings, for which the factors add up as follows:
 $0.6\% + 0.1\% + 1.2\% + 0.1\% + 0.6\% + 1.8\% + 0.225\% + 0.225\% + 0.35\% + 0.7\% + 0.6\% + 0.6\% + 1.2\% + 0.1\% + 0.6\% = 9\%$ of the total budget to be spent on HFI.

The method suggested in **Table D1** has been derived modifying an approach suggested by an FAA study, as summarised in Resource 13. The modifications include adding the weighting, and producing a new list of risk influence factors that are more generic. The underlying metrics draw on experience values. They have been derived as follows:

- The maximum HFI proportion of project cost has been assumed as 12%. The contribution added by each factor is a breakdown (by weight) based on this total.
- The minimum has been assumed as 2% – based on a fairly even distribution across the five severity rating levels (i.e. 2%; 4.5%; 7%; 9.5%; 12.0%).
- 12% as maximum HFI budget may be a fairly high figure – however, it cannot be assumed that only totalling all risk factors leads to the highest amount – hence the typically assumed maximum of 10% was slightly increased.
- This is assuming a typical medium to large, multi-disciplinary, engineering-based project. The weightings, and the assumed budget maximum and minimum, may need to be adjusted as needed.

Table D1: COST ASSESSMENT METRICS.

Weight of influence factors:		Budget elements depending on factor severity				
100%		Very Low	Low	Medium	High	Very High
1	Estimated cognitive complexity of operation 5%	0.100%	0.225%	0.350%	0.475%	0.600%
2	Expected physical difficulty of operation 5%	0.100%	0.225%	0.350%	0.475%	0.600%
3	Mission critical operation 10%	0.200%	0.450%	0.700%	0.950%	1.200%
4	Presence of health hazards 5%	0.100%	0.225%	0.350%	0.475%	0.600%
5	Expected operation under safety critical conditions 5%	0.100%	0.225%	0.350%	0.475%	0.600%
6	Direct interaction scope 15%	0.300%	0.675%	1.050%	1.425%	1.800%
7	Expected change of manpower and skill levels 5%	0.100%	0.225%	0.350%	0.475%	0.600%
8	Extent of HF problems in predecessor systems 5%	0.100%	0.225%	0.350%	0.475%	0.600%
9	Scope of effects 5%	0.100%	0.225%	0.350%	0.475%	0.600%
10	Project scope regarding design focus 10%	0.200%	0.450%	0.700%	0.950%	1.200%
11	Level of novelty 5%	0.100%	0.225%	0.350%	0.475%	0.600%
12	Number of design constraints 5%	0.100%	0.225%	0.350%	0.475%	0.600%
13	Project uncertainty 10%	0.200%	0.450%	0.700%	0.950%	1.200%
14	Product purpose directly fulfils Human Factors need 5%	0.100%	0.225%	0.350%	0.475%	0.600%
15	Absence of conducive design organisation conditions 5%	0.100%	0.225%	0.350%	0.475%	0.600%
<i>Maximum budget per severity:</i>		2.0%	4.5%	7.0%	9.5%	12.0%

EXAMPLE 4: HFI BUDGET ESTIMATION BASED ON RISK FACTORS.

Weight of influence factors:		Budget elements depending on factor severity				
	100%	Very Low	Low	Medium	High	Very High
1	Estimated cognitive complexity of operation 5%					✓ (0.600%)
2	Expected physical difficulty of operation 5%	✓ (0.100%)				
3	Mission critical operation 10%					✓ (1.200%)
4	Presence of health hazards 5%	✓ (0.100%)				
5	Expected operation under safety critical conditions 5%					✓ (0.600%)
6	Direct interaction scope 15%					✓ (1.800%)
7	Expected change of manpower and skill levels 5%		✓ (0.225%)			
8	Extent of HF problems in predecessor systems 5%		✓ (0.225%)			
9	Scope of effects 5%			✓ (0.350%)		
10	Project scope regarding design focus 10%			✓ (0.700%)		
11	Level of novelty 5%					✓ (0.600%)
12	Number of design constraints 5%					✓ (0.600%)
13	Project uncertainty 10%					✓ (1.200%)
14	Product purpose directly fulfils Human Factors need 5%	✓ (0.100%)				
15	Absence of conducive design organisation conditions 5%					✓ (0.600%)
Maximum budget per severity:		2.0%	4.5%	7.0%	9.5%	12.0%

The factors add up as follows:
 $0.6\%+0.1\%+1.2\%+0.1\%+0.6\%+1.8\%+0.225\%+0.225\%+0.35\%+0.7\%+0.6\%+0.6\%+1.2\%+0.1\%+0.6\%$
 = 9.00% of the total budget to be spent on HFI.

D.2.2 Method 2: Breaking down the budget into components

Having identified the overall HFI effort needed in relation to project risk influence factors and cost impact ratings, the resources required can be broken down for a more detailed estimation. For example, an [FAA report](#) provides such values [per project stage](#) (see [Resource 14](#)), and [by design area](#) (see [Resource 15](#)).

Likewise, the size of the budget may be built up from the HFI functions as component activities (i.e. Investigate; Create, Evaluate, Manage). Figure 10 shows an example of that. Experience values can be used to assess proportional breakdowns of budget needs.

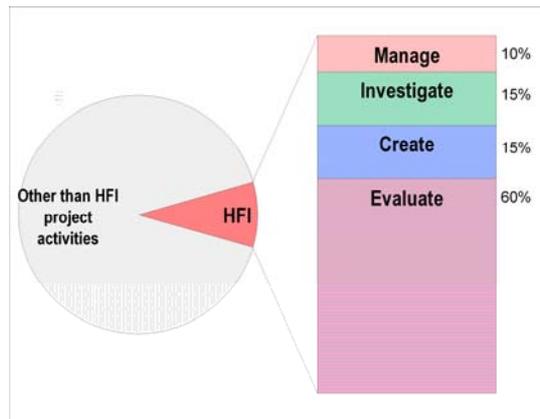


Figure 10: Breaking down the HFI budget.

Similarly, The HFI process, or each of its HFI function components, may be broken down by the main elements that cause HFI costs (see Figure 11): Productive time; Resources; User Access.

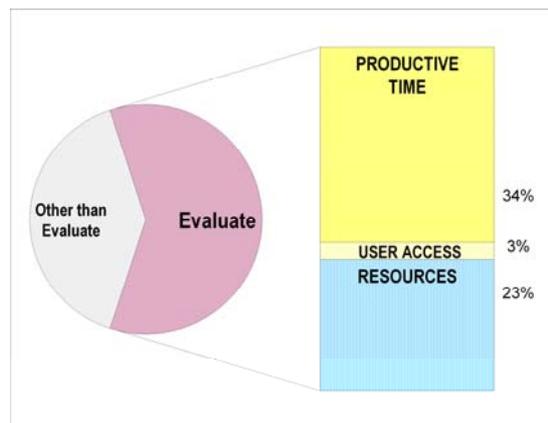


Figure 11: Breakdown of HFI function Evaluate into cost components.

Productive time refers here to labour time, i.e. time spent by HF practitioners. Resources may include producing simulations, mock-ups, and prototypes. They may also be understood here as access costs such as hire fees, travelling, or assistance. User Access

includes user fees, travel costs to access users, time of users not spent on their usual activities etc.

Cost element proportions may vary for different HFI tasks, as shown in Figure 12.

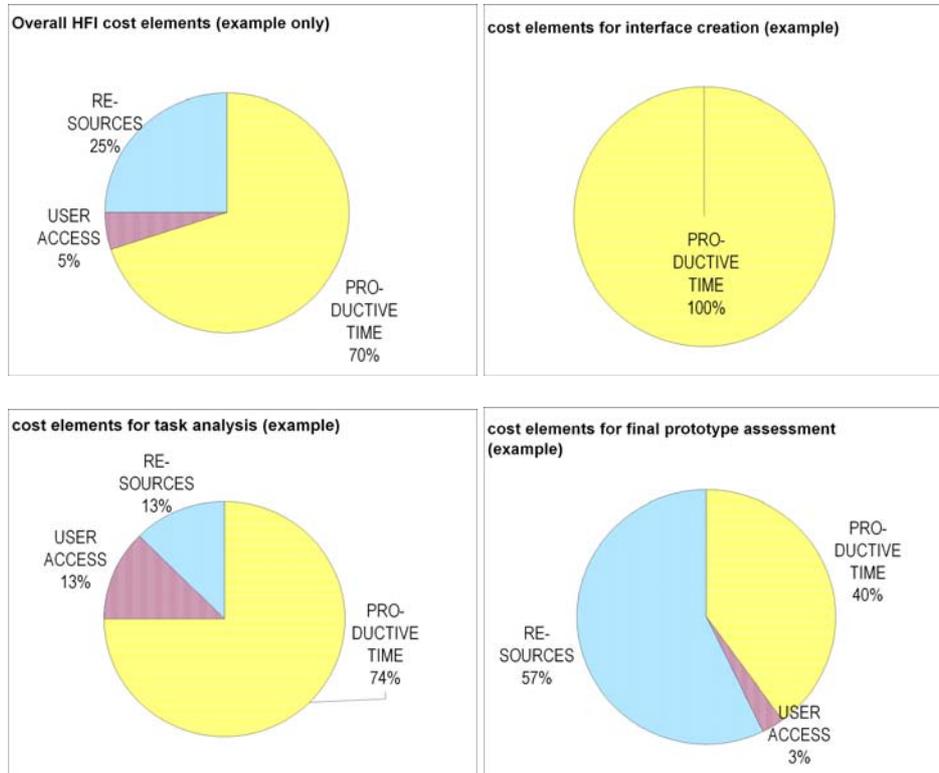


Figure 12: Variations of cost breakdowns for different HFI tasks.

Table D2 provides a PROPORTIONAL HFI COST BREAKDOWN into major cost components, which suggests proportions based on experience values. They have not been validated and should be treated as an example, to be adjusted based on project-specific requirements. They may vary with HF risk areas identified, and the domain (e.g. design for aviation vs. design of handheld devices). They may also vary depending on the overall approach to implementing HFI (e.g. through employing permanent HFI staff, employing HFI contractors, employing engineers trained in using HFI methods and resources, or combinations of these). Experience values from previous projects within a domain should be recorded to aid estimation.

Table D2: PROPORTIONAL HFI COST BREAKDOWN (HFI functions, tasks, and proportional effort). Data are not validated; to be used as an example only.

	TOTALS 100%	PRODUCTIVE TIME 70%	USER ACCESS 5%	RESOURCES 25%
INVESTIGATE	15.00%	11.00%	2.00%	2.00%
user characteristics and needs	5.00%	3.00%	1.00%	1.00%
current task practice	4.00%	3.00%	0.50%	0.50%
task/use/operational conditions	4.00%	3.00%	0.50%	0.50%
regulations/standards/design guidelines	2.00%	2.00%		
CREATE	15.00%	15.00%	0.00%	0.00%
user requirements/functional specification	1.00%	1.00%		
physical equipment specification	1.00%	1.00%		
infrastructure specification	1.00%	1.00%		
software/interface specification	2.00%	2.00%		
system component interaction design	1.00%	1.00%		
personnel/training specification	3.00%	3.00%		
organisational specification	2.00%	2.00%		
documentation	1.00%	1.00%		
implementation specification	1.00%	1.00%		
operational and support specification	2.00%	2.00%		
EVALUATE	60.00%	34.00%	3.00%	23.00%
user requirements/functional specification	3.50%	3.00%	0.50%	
concepts and ideas	4.00%	3.00%	0.50%	0.50%
early prototypes	9.00%	7.00%	0.50%	1.50%
intermediate prototypes	12.50%	7.00%	0.50%	5.00%
late prototypes	17.50%	7.00%	0.50%	10.00%
finished product	13.50%	7.00%	0.50%	6.00%
MANAGE	10.00%	10.00%	0.00%	0.00%
process/procedures	3.00%	3.00%		
issues log	2.00%	2.00%		
planning	3.00%	3.00%		
communication	2.00%	2.00%		

These cost components may be broken down further, or in other ways. Figure 13 shows an example of a different breakdown of components. The component activities can either be used to further specify an overall budget figure proportionally, or to derive an overall figure from its components by estimating them separately based on experience values and then cumulating them.

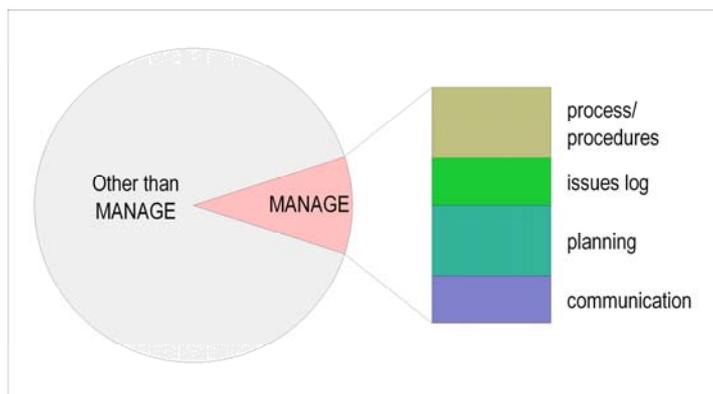


Figure 13: Example breakdown of ‘Manage’ into more detailed activity types.

D.2.3 Method 3: Cost calculation by study type

An alternative approach to identifying HFI cost as proportions of the overall project budget is a parametric cost estimation approach that defines cost figures for constituents first, and then cumulates them.

The components are defined here again as the main HFI functions: Investigate, Create, Evaluate, and Manage. Heuristics are used to generate cost figures. The four elements then need to be added up, to come to a total HFI budget figure.

D.2.3.1 Investigate and Evaluate (elements 1 and 3)

For the elements *Investigate* and *Evaluate*, the cost can be assessed based on the number of studies needed. **Table D3** provides COST ASSESSMENT HEURISTICS BY NUMBER OF STUDIES.

Table D3: COST ASSESSMENT HEURISTICS BY NUMBER OF STUDIES.

Categories	Examples	HFI scope		
		minimum	typical	large
analytical studies	literature search, risk analysis with updates (e.g. EHFA), task modelling study	0.3	1	1.5
empirical study/ concept assessment study	interview study, observational field study, survey study, performance modelling study, user workshop/focus group, study to assess ideas on paper	0.6	2	3
low fidelity product element testing study	part-task simulator concept assessment studies	1	3	5
medium fidelity partial product testing study	rapid prototyping, fast-time simulation	2	6	9
high fidelity full product testing study	real-time test with simulator of entire system, product test in field or under simulated conditions	4	10	14

The heuristics are to be used as follows:

- The cost estimates are calculated based on ‘points’ – where one point can be equated with a defined cost figure (e.g. £9000). For example, a typical observational field study for a medium-scale project may be calculated as 2 points * £9000 = £18000.
- Project size is expressed through the value that is assigned to 1 point.
- The point values vary for different study categories. They have been chosen depending on cost impact. For example, an analytical study such as an EHFA is clearly much cheaper than a full-scale assessment using high-fidelity prototypes.
- For each study category, different values have been suggested for the conditions ‘minimum’, ‘typical’, and ‘large’ – based on the expected scope of effort needed (depending on risk severity and overall intended HFI budget commitments).
- Figure 14 shows example cost distributions for the different categories defined.

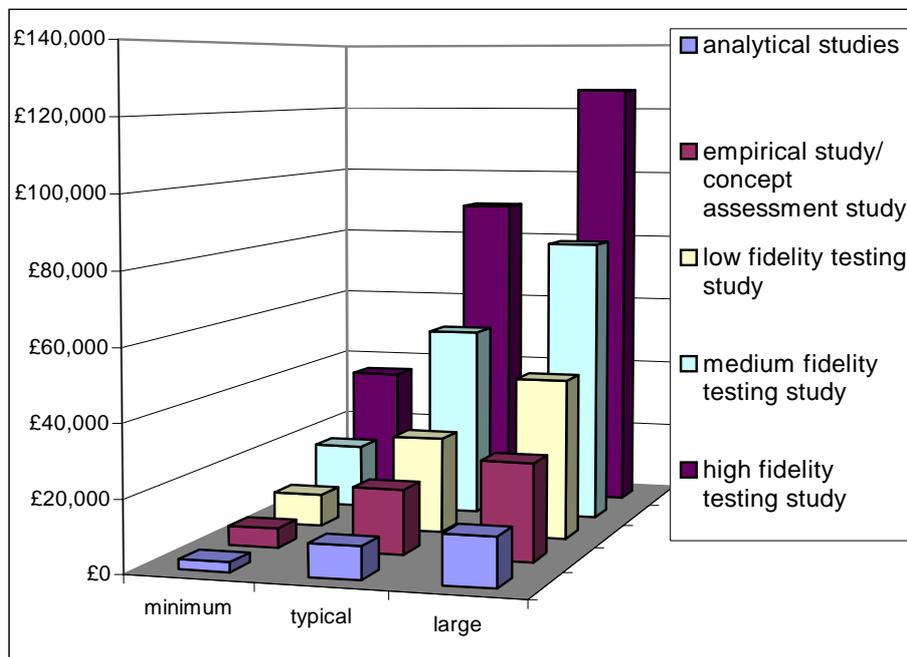


Figure 14: Example costs for different types of studies, based on cost assessment heuristics (example only).

Table 3 shows an example calculation for heuristics by study type. One point has been defined here as £9,000, and the category ‘typical’ was used. A total of £198,000 was calculated.

The approach has been adapted based on an approach suggested by an FAA study (see [Resource 16](#)). Aviation-specific heuristics can be found there.

The point values suggested here assume considerable effort needed for prototype and simulation creation as the basis for concept and solution assessments. In domains where such resources are not required, the cost for assessment studies can be estimated as much lower. In contrast, for domains where prototyping is highly complex and requires high fidelity (e.g. due to safety concerns), the values may be even higher.

A general rule of thumb is to add an extra 30% to such predictive parametric calculations since they frequently do not cover all elements (i.e. emergent requirements often cannot be foreseen).

Table 3: Calculation example for cost estimation by study type.

Categories	Translation of points into costs based on £9,000 per point – for condition ‘typical’	Example number of studies	Totals
Analytical studies	£9,000	3	£27,000
Empirical study/ concept assessment study	£18,000	2	£36,000
Low fidelity product element testing study	£27,000	3	£81,000
Medium fidelity partial product testing study	£54,000	1	£54,000
High fidelity full product testing study	£90,000	0	£0
		SUM:	£198,000

Alternatively, when more project details can be anticipated, study costs may be built up of estimates for Resources, Time (e.g. preparation, conducting, data analysis), and User Access. For example, a medium scale Focus Group study with 5 sessions and 8 participants per session may be estimated at around £15,000 including personnel, room and equipment hire, participant fees and refreshments, preparation and analysis.

D.2.3.2 Create (element 2)

The component *Create* can be assessed based on the role HFI takes in the generation of solutions. Figure 9 (page 36) outlined the extent to which HFI input may vary regarding direct creative decision-making involvement. When assuming that the solution-generating element is around 15% of HFI activities, as estimated in the last section, it can be calculated as a fixed proportion based on the cost of studies needed. For example, if Investigation and Evaluation is assumed to be 75% of the HFI budget (see Figure 10, page 45), and 10% needs to be allocated to HFI Management – then the unknown proportions can be calculated as follows:

- Total HFI cost = (Total of ‘Analysis’ and ‘Evaluation’ study costs) / 75%
e.g. £198000/0.75 = £264000
- Cost of ‘Create’ Activity = Total HFI cost * 15%
e.g. £264000 * 0.15 = £39600
- Cost of ‘Manage’ Activity = Total HFI cost * 10%
e.g. £264000 * 0.10 = £26400

For a calculation independent of the effort already calculated for studies, the project size, and the associated total design effort for the project as a whole needs to be taken into account.

For this approach, again, the level of HFI participation in solution-generating design activities is a question of definition (e.g. HFI in minor advisory role, HFI taking part in HMI solution generation).

The volume of work required can be estimated based on the number and scope of system elements to be designed (e.g. by design areas, design components), taking into account factors such as:

- Complexity/volume of each component;
- Extent to which they are unknown;
- Extent to which they have already been prototyped;
- Extent to which resources can be drawn on (e.g. use cases developed).

D.2.3.3 Manage (element 4)

The component *Manage* can be assumed as an overhead figure of around 5 to 10% of the HFI budget, depending on factors such as:

- Project size;
- Number of collaboration partners;
- Presence of iterative design approach;
- Level of acceptance of HFI;
- Quality of organisational structure and information management resources.

D.2.4 Using the methods together

The different methods suggested here for estimating HFI effort should be used with one another. By triangulating the results, and by reviewing the earlier estimates in relation to later ones, more accurate estimates can be achieved.

Moreover, trade-offs between HFI efforts in influencing design decisions may need to be considered (e.g. interface design option affecting required training effort). Some ideas can be taken from Table C1.

Step D.2 has provided approaches for how to calculate an HFI budget as a whole, without specifying how it is to be distributed over the lifecycle. However, the best-case scenario is based on the assumption that sufficient effort is to be spent during the early project stages (i.e. concept and assessment, before detailed design). This does not necessarily result in disproportionately higher cost up-front (see [Resource 14](#) for an example of how costs may be distributed over the lifecycle). This is because earlier HFI activities are often less resource-intensive.

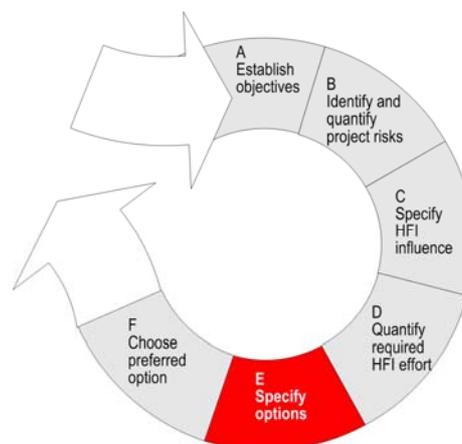
E Specify options

Typically, project resources are constrained. To be able to justify the specified HFI effort in relation to other project cost constraints, the effects of alternative options to the suggested approach need to be demonstrated and assessed. Suitable approach variables need to be specified, and their effects calculated.

Measures of HFI success and effectiveness need to be specified. Confidence values and success factors may be attached.

Main steps:

1. Define suitable HFI expenditure variables.
2. Define suitable ways to assess success.
3. Relate spending variables and success.
4. Assess confidence factor.
5. Specify HFI process options.



E.1 Define suitable HFI expenditure variables

If resources are constrained, the best-case scenario for HFI expenditure specified earlier may need to be assessed regarding the suitability of other planning options. These may include spending resources at different project phases, spending resources on different aspects, and/or spending fewer resources. The following main variables may be considered:

- Timeliness of HFI implementation;
- Completeness of HFI functions;
- Sufficiency of resources.

Resource spending options should be specified based on an understanding of the variables that affect HFI success (Bruseberg, 2006). For example, an efficient HFI process requires early involvement, to ensure spending on the right developments. Likewise, HFI needs to be applied and resourced as a complete process including the main functions:

- Investigate, Create, Evaluate (e.g. having validated information, having user contact, knowing design principles and standards, predictions of use);
- Manage (e.g. HFI risk management, acceptance management, resource management, process implementation): HFI requires close involvement of HF practitioners to address emerging design issues.

A minimum level of resources for each function is needed to achieve its purpose.

The following types of HFI deficiencies may be considered:

- HFI functions are applied with limited resources (e.g. not enough depth, limited validity, information remaining uncertain);
- HFI functions are applied too late (missing involvement during Concept, Assessment, Demonstration, and/or Manufacturing phase);
- HFI functions are missing (e.g. analysis without implementation; design and assessment based on limited knowledge of use; limited design involvement);
- HFI functions are not applied to all design activities/domains;
- Missing/ineffective/inefficient process integration (e.g. activities carried out in isolation; Investigation function and Evaluation function not joined to design decision making; limited acceptance of HF contribution).

This is assuming a correct risk analysis, and a suitable assignment of HFI activities to risk areas.

E.2 Define suitable ways to assess success

To be able to assess planning options, ways to assess HFI success need to be established. It was discussed earlier that the concept of 'design flaws' is a useful way to express the effect of HFI on risk mitigation (see Figure 3). The primary influence of HFI activities is through design decision areas that affect how future systems will behave. Design flaws are properties of the designed system that are likely to cause an operational problem.

The number of design flaws to be expected depends on the risk level (due to risk factors) as identified earlier. Such a quantification approach can be taken as the basis for mitigation targets. The larger the number of flaws, the higher the retrospective mitigation effort needed.

The impact magnitude of design flaws may be measured through potential cost effects, based on:

- Development process performance measures (e.g. delays, number of iterations, unexpected human resources needed);
- Operational performance measures (e.g. unexpected training and maintenance, unexpected failures, unachieved performance).

It needs to be noted, however, that concepts such as the number of design flaws, or the number of design decisions, are theoretical concepts that cannot easily be measured practically. The number of design flaws sometimes becomes apparent when an HF study categorises a number of design deficiencies that may cause problems when assessing design solutions during the later stages of a project. It may be measured through the number of design changes made retrospectively. However, measurable prospective influence on design decisions is less tangible. The occurrence of a certain number of design flaws needs to be assumed for any project, to be prevented and mitigated by HFI efforts.

E.3 Relate spending variables and success

To be able to assess the effects of planning options on risk reduction success, we can draw on heuristics that show the relationships between implementation variables and success measures. This may also be termed the ‘implementation factor’ – i.e. the extent to which HFI is to be employed (e.g. fully, reduced, none).

Figure 15 shows relationships between the times at which HFI is applied (with varying effort), and the risk cost potential – which may be measured through the percentage of design flaws remaining. This is based on experience values only. Relationships are shown for basic options including late implementation, incomplete implementation, and insufficiently resourced implementation, in comparison to an option of full HFI implementation and no HFI implementation across the system lifecycle. The higher the remaining percentage of flaws is, the higher the potential of associated risks and costs at the same or later project stages.

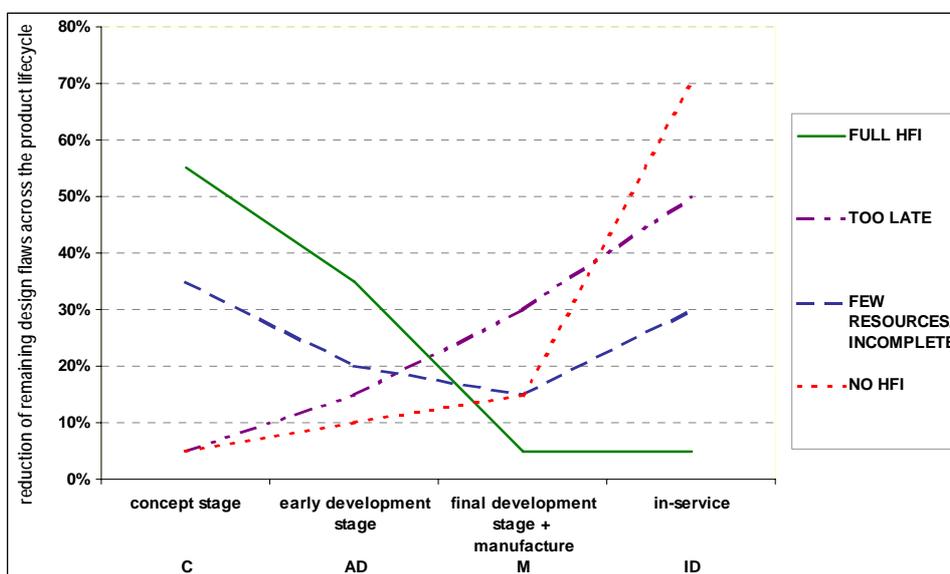


Figure 15: Relationships between HFI implementation options and reduction of remaining emergent design flaws across the product lifecycle.

Such an assessment may be established for different tasking options. Specific cost effects may be attached separately. For example, the cost of not identifying a design flaw early is higher since it results in higher failed investment, due to the **cost ‘locked in’ when commitments to investments have been made** (see also Figure 5 and Resource 2 for further explanations). Moreover, the cost effect of design flaws may differ with types of risks.

It is important to establish a minimum (and maximum) level of activity to achieve an acceptable level of risk reduction. Figure 16 further specifies the relationship between the volume of resource spending on HFI and the effectiveness that can be expected. It shows that there are two cut-off points. Below a certain spending volume, the insight gained through HFI is likely to be incorrect, or invalid. This may be, for example, due to insufficient data, or not enough analysis effort to come to valid conclusions. From a

certain spending volume onwards, no further useful information is likely to be gained, other than confirming already known facts. The challenge is to define the optimum at which most effect can be gained. The minimum effort may vary with project priorities. For example, in safety-critical domains, reducing the likelihood of human error may be regarded as paramount, requiring more scrutiny and higher effort. In other domains, less certainty for the risk reduction achieved may be more acceptable. Resource 17 provides a discussion on [minimum spending levels in the usability domain](#).

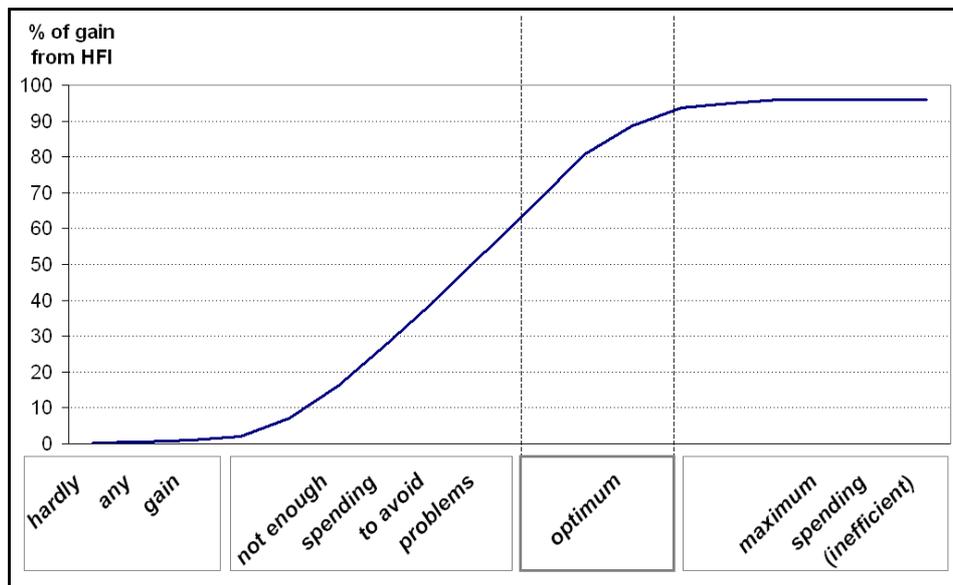


Figure 16: Relationship between spending volume and gain in value from HFI.

E.4 Assess confidence factor

A factor that may be useful for consideration here is the Confidence Factor, expressing the extent to which the specified ‘ideal’ HFI process can achieve the savings specified. No project planning is perfect. Thus, it has to be acknowledged that the assessments of resources required may need to be revised during the course of the project, as the scope of risks and design challenges becomes clearer. Likewise, the confidence regarding the extent to which the right activities have been linked to the right problems needs to be assessed. This may include an assessment of the expected quality of the HFI process (e.g. effectiveness of communicating and implementing information into design).

When uncertainty is high, [Sensitivity Analysis](#) (see [Resource 18](#)) is often used to identify the extent to which project outcomes may react to changes in the underlying assumptions.

E.5 Specify HFI process options

Having reviewed project-specific constraints, a suitable set of distinct options for HFI implementation needs to be specified – to have a basis for comparison. Moreover, with the insight gained, the specification of both a best-case and a worst-case implementation scenario may be updated (i.e. complete and efficient HFI process vs. no HFI process). This may include, for example, a task list and budget estimate for a minimum spending

option (e.g. reduced number of users, no observational studies, minimum prototype fidelity) vs. a project outline for a fuller implementation option.

To specify distinct scenario options, it is necessary to:

- Determine the scope of potential budget constraints;
- Include potential trade-off options (e.g. in-service vs. development costs; performance/achievement/safety vs. improved processes and methods);
- Identify expected high-spending activities – to re-assess prime HFI activity areas (e.g. significance of information);
- Assess effectiveness factors (e.g. which HF activities have the highest benefits in which circumstances);
- Using a model of HFI benefit mechanisms, determine potential areas for HFI spending cuts.

Each option can be calculated based on the relationships summarised earlier in Figure 4, showing the cost-benefit calculation elements and their interaction.

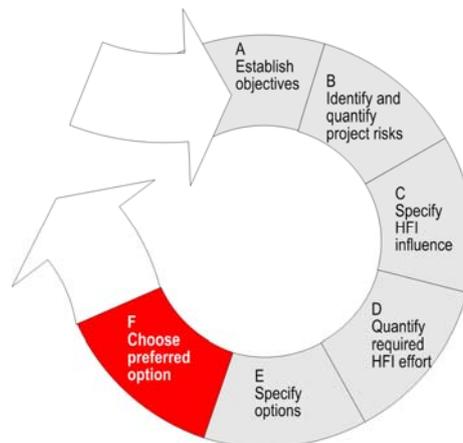
Cost assessments for alternative options need to be produced. Using the same approaches as suggested in Sections B and C, the activity and risk costs for the specified alternative options may need to be reassessed.

F Choose preferred option

Having established options, variables, constraints, and priorities, the specified scenarios need to be compared. Assumptions need to be reviewed. Trade-off options for spending priorities need to be assessed. A commitment to a preferred option needs to be expressed with underlying reasoning, and presented in an appropriate format.

Main steps:

1. Compare options.
2. Nominate preferred option and present case.



F.1 Compare options

Having specified the variations for costs and benefits across the product lifecycle for the specified options, they need to be compared in relation to priorities, constraints, and assumptions. This process includes tasks such as:

- Record any assumptions made.
- Review priority values and business goals.
- Establish constraints and cost boundaries, for example can the cost (of risk) be accommodated or not (e.g. Could the cost of an accident close down the design organisation? Is public acceptance likely to be low, and is it of importance?).
- Assess trade-off options.

QFD (Quality Function Deployment) technique (Resource 3) is a widely used method that can also be employed for option comparison. Similarly, Expert Rating Techniques may be applied (see Resource 5).

F.2 Nominate preferred option and present case

A commitment to a preferred HFI implementation option needs to be made. The case needs to be documented and presented including the underlying reasoning. Suitable format options need to be considered, including the use of diagrams, suitable structure, or the depth of detail required.

Appendix A Resources

Resources are distinguished by **Methods and Data** through the following formatting:

Methods - including techniques, processes, approaches and methodological guidance.

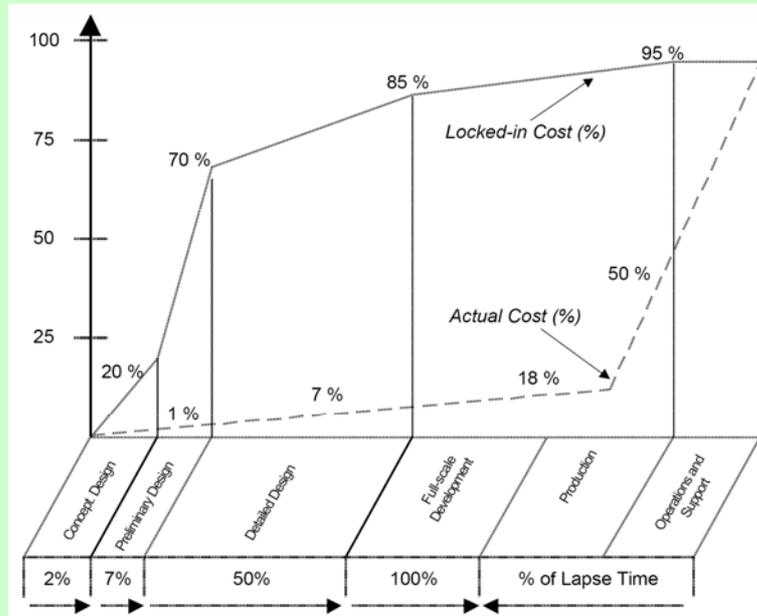
Data - including example descriptions and applications found in the literature, as well as case studies and example proportions.

Further guidance materials are available for cost-benefit analyses that may be useful in an HFI context, including:

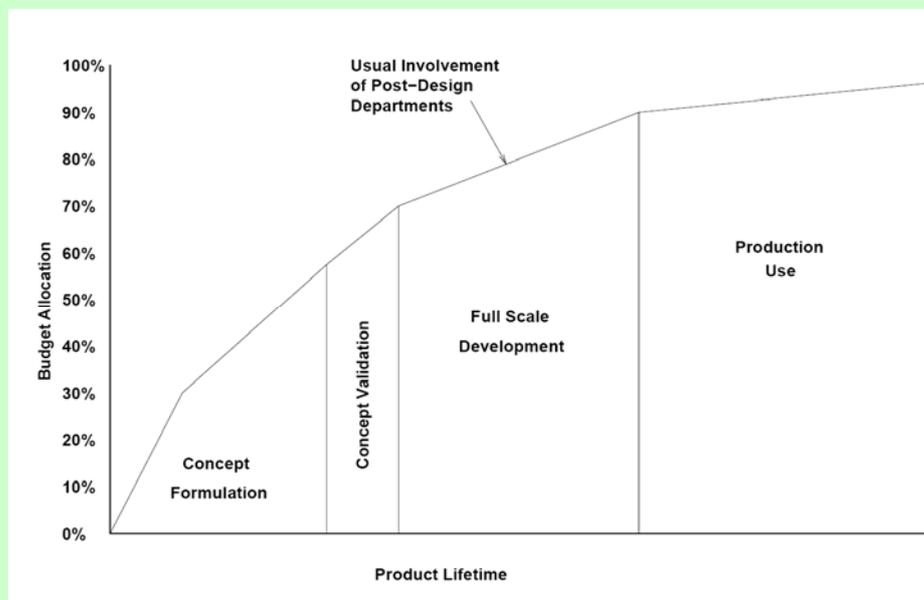
Document	Source and domain	Comments
Creating and Using A Business Case for Information Technology Projects	Treasury Board of Canada Secretariat (1998); military	Well-structured methodological guidance for making business cases (not specific to HF, but with many HF references); Expands on process of options generation and selection; Draws out links to costing, risk assessment, option analysis, cost-benefit analysis, making a case, and ongoing project management.
A Business Case for Human Factors Investment	Eurocontrol (1999); civil, ATC	Overview of HF cost-justification; mainly high level arguments; Focus on importance, design process, methods; classifies types of benefit; examples of life-cycle cost models; Example of HF cost vs. reliability calculation.
Operational Concept Validation Process	FAA (1999); civil, ATC	Collection of validation and assessment processes throughout the system lifecycle.

Resource 1: Further Reading.

The graph shows the **relationship between actual cost and locked-in cost throughout the lifecycle** (Eurocontrol 1999), based on (Gawron et al 1996). The dashed curve shows the 'current cost' that is actually being spent. It shows that the most significant spending occurs during the implementation and operation phases. The solid curve shows the so-called locked-in cost. It represents decisions made leading to commitments in spending. The graph shows that typically 70% of the committed cost is generated before the Detailed Design phase, after only about 10% of the total system life-cycle time.



A similar relationship is shown by the Westinghouse Curve (Bralla, 1996):



Resource 2: Typical lifecycle cost distribution.

Quality Function Deployment Method (QFD) is a method typically used for requirements engineering and design option comparison. In this function (where it is also referred to as the 'House of Quality'), it is a systematic tool to define user needs by translating the 'voice of the customer' into product requirements and solution options.

QFD uses a special matrix approach to distinguish, and then relate, user requirements (i.e. the 'why') and technical design parameters (i.e. the 'how'). It establishes the strength of relationships between the 'why' and 'how', and attaches various attributes such as weights, relationships between options, benchmarking through ratings, target cost values etc. Thus, it helps to decide between design options by better understanding the values to be achieved. In the context of cost-benefit analysis, where costs are traded off against added worth, Fujita & Nishikawa (2001) suggest QFD for establishing the 'worth' - i.e. the values to be achieved by a product or system.

QFD is a type of multi-criteria analysis that draws on matrix techniques to establish values to be achieved in relation to design options. Requirements specification ties in closely with project planning. Whilst QFD has been conceived for product design, there is no reason why QFD cannot also be applied to the 'design' of projects - e.g. by establishing project values and budgeting options.

For example, Chao & Ishii (2004) suggest an adaptation of QFD to 'Project QFD', where in House 1 the organisation's Project Requirements are mapped against Project Metrics like project budget and time-to-market. In House 2, the Project Metrics are mapped against Project Resources. Similarly, Hutchison et al (2006) suggest the use of QFD to inform HFI design trade-off decisions.

QFD is intended as a team process that uses matrixes as a communication tool. This however, is not strictly necessary to gain the benefits of option selection. One of its aims is to bring together perspectives from various disciplines. It is intended for application in four phases over the course of the system development process. In practice, however, often only phase 1 is used.

Further information of QFD may be obtained, for example, from
<http://www.npd-solutions.com/qfd.html>; <http://www.ifm.eng.cam.ac.uk/dstools/control/qfd.html>.

Resource 3: Quality Function Deployment Method (QFD).

The **Human Factors Integration Plan (HFIP)** outlines the HFI activities to be carried out based on an understanding of project boundaries, potential risk areas and HFI issues, and resources available. It may include the following information:

1. Background information, including:

- ⇒ Project and document scope (e.g. purpose and objectives, time of plan, issue number, context information, relevant work to date, input from URD);
- ⇒ Relationships with other documents (e.g. plans, risk analyses);
- ⇒ Basic objectives, principles, processes, and strategy of HFI.

2. Understanding the project requirements, including:

- ⇒ System purpose and requirements, and constraints;
- ⇒ Key HFI risks (e.g. main results of the EHFA), including assumptions and dependencies;
- ⇒ Constraint management approach including registers for initial assumptions, decisions, and constraints;
- ⇒ Resources available (e.g. budget, facilities, HF expertise, access to users);
- ⇒ Relevant HF understanding to date, including results of earlier work, applicable standards, reference materials.

3. Work plan, including:

- ⇒ Key HFI success criteria; guiding principles of the work plan;
- ⇒ HFI technical activities, including work breakdown, deliverables, timeframes, milestones;
- ⇒ HFI management mechanisms and activities - including approaches to project risk management, progress assessments, managing trade-offs, ensuring design involvement etc.;
- ⇒ Responsibilities, team organisation and reporting structures.

Further information may be found in MoD Publications (MoD 2001, 2006a, 2006b).

Resource 4: HFIP.

An **Expert Rating Technique** is a method to add validity to subjective ratings. After providing a template that allows a limited set of issues to be rated using a standardised rating scale (e.g. 7-point Likert rating scale), which has been assigned a certain set of meanings (e.g. 1: Very Low Risk; 7: Very High Risk), several domain experts can provide ratings. By averaging the results, higher validity of the subjective ratings can be achieved. Additionally, the experts may be asked to weigh the issues being rated in relation to each other.

Resource 5: Expert Rating Technique.

Early Human Factors Analysis (EHFA) is used to drive project plans, requirements, and the project's HFI Risk Register. EHFA identifies initial risk reduction strategies. "Based on established risk management techniques, EHFA helps define and track key human related issues at an early stage when there is limited information about potential solutions. It contributes directly to project requirements and risk management" (MoD, 2001).

The main stages include:

1. Establish HFI Baseline: Record initial knowledge of facts, assumptions, constraints, options, objectives, issues, and HFI activity needs.
2. Identify HFI issues: Agree on key issues that can be identified as risks.
3. Assess impact of HFI risks: Prioritise risks to derive tasking requirements and HFI plans.

Outputs of the Baseline analysis include:

- Background information records (e.g. objectives, constraints, variables);
- Records of the reasoning, including initial elements of the Assumptions Register;
- Initial elements of the Issues Log (listings of issues, risks, requirements, design options), to feed into the Risk Register.

To identify HFI issues, the potential for problem areas needs to be assessed within each HFI domain. Subsequently, key issues and risk areas are agreed, rated, and recorded, preferably organised by HFI domains. It is helpful to subdivide issues into:

- Concerns - issues that cannot be dismissed, but need not be resolved now;
- Risks - Key issues representing risk that must be managed.

To assess the impact of HFI concerns and risks, they may be rated and potential cost implications specified. Requirements for design properties or actions may be derived. Mitigation options need to be specified for those risks with high probability and impact. This provides the basis for producing an HFIP.

EHFA benefits from an iterative process where knowledge evolves. At certain points, the current understanding should be recorded and agreed. Subject Matter Experts (e.g. representative users) should be consulted.

Further information may be found in MoD Publications (MoD 2001, 2006a, 2006b).

Resource 6: Early Human Factors Analysis (EHFA).

Work Domain Analysis (WDA) is the first step of Cognitive Work Analysis, (CWA). A major component of WDA is creating an Abstraction Hierarchy that describes the work domain through the following categories at different levels of means-ends abstraction:

- 1: Functional Purpose: the reasons for the system's existence;
- 2: Abstract Function (Priorities and Values): the criteria for ensuring that purpose-related functions meet system objectives;
- 3: Generalized (purpose-related) function: basic work functions of the system;
- 4: Physical Function (Object-related processes): functionality afforded by the physical objects of the system;
- 5: Physical Form (Objects): physical objects of the system.

By specifying the purposes, values and functions through various levels of abstraction, the Abstraction Hierarchy identifies system constraints and 'affordances', in order to capture what is possible/impossible, and what resources are available, or can be made available. Further reading is suggested for more detail - e.g. Lintern & Naikar (2000), Vicente (1999), Naikar & Saunders (2002).

Resource 7: Work Domain Analysis (WDA).

A good example for the calculation of a Return on Investment (ROI) for an HF programme in the domain of medical device development is provided by Wiklund (2005). The Return on Investment gives an indication of value gained for effort spent in financial terms. Wiklund (2005) provides example calculations for various savings potentials, for example one-time benefits due to the extended life of an interface: "Suppose a great user interface extends a product's life just one year, resulting in withdrawal at the end of year six instead of year five. In effect, this reduces design costs. A \$2 million design effort spread over five years costs \$400,000 per year (disregarding the time value of money for simplicity's sake). Spread over six years, the design effort costs \$333,333 per year. In this case, the savings over the course of multiple design cycles amount to \$66,667 each year."

Several of such savings elements are then added up and a total is calculated for an entire product lifecycle (e.g. six years), taking into account factors such as the 'time value of money'. With the most conservative view applied, a ROI of no less than 7:1 can be expected. A maximum of 35:1 has been identified.

Resource 8: ROI calculation example.

Landauer (1995) estimates that "**The average User Interface has some 40 flaws.** Correcting the easiest 20 of these yields an average improvement in usability of 50%. The big win, however, occurs when usability is factored in from the beginning. This can yield efficiency improvements of over 700%."

Based on experience, Nielsen (1998) suggests the following baseline for assumptions about **typical numbers of design problems** without professional usability input from some example statistics:

- the average website has 11 'usability catastrophes' (design elements that prevent users from completing test tasks);
- on average, users are only able to complete 42% of the test tasks;
- users' average subjective rating of websites is 4.9 on a 1-7 scale.

Resource 9: Experience values for risk assessment.

Case studies reporting the lack of HFI cite the following costs of subsequent failures:

- Aviation accidents cost the U.S. Navy and Marine Corps \$4.3 billion between 1997 and 2002. The \$4.3 billion in losses only include the direct costs, such as the actual aircraft. The Navy additionally incurred at least \$20 billion to \$30 billion in other "indirect" costs related to aviation accidents, such as litigation, investigations and program delays. Most of the aviation mishaps during that period - about 85 percent - were attributed to human error (Erwin, 2002).
- The SA80 Rifle and Light Support Weapon (British Army) was beset by a series of problems over a period from 1985 to 1992. The overall estimated cost for the modifications to fix these problems was £24 million (House of Commons, 1993). A significant proportion of the problems were related to operability/fitness for purpose.
- Ergonomics problems can cause significant losses in personnel time. The US Department of Defence (DoD) provides figures for the effects of lost time and associated medical and compensation costs due to injuries and illnesses incurred to the DoD (DoD, 2004): "Between 2001 and 2003, the Military Services lost 4.6M hours of productive work time to occupational injuries and illnesses."
- Operational problems with the Remote Control Mine Disposal System that became apparent soon after accepting the first of five Single Role Minehunters into service, caused a cost of £1.9 million associated with design changes to overcome these difficulties (Public Accounts Committee, 2000).

Resource 10: Example costs for HFI failures.

Case studies reporting the HFI successes cite the following savings:

- Design changes due to usability work at IBM resulted in an average reduction of 9.6 minutes per task, with projected internal savings at IBM of \$6.8 Million in 1991 alone (Karat, 1990).
- Booher and Minninger (2003) claim that the adoption of MANPRINT on the programme for the development of the Comanche Helicopter programme (U.S. Army) avoided costs totalling \$3.29 billion against a cost of implementing MANPRINT of \$74.9 million.
- "At one company, end-user training for a usability-engineered internal system was one hour compared to a full week of training for a similar system that had no usability work. Usability engineering allowed another company to eliminate training and save \$140,000. As a result of usability improvements at AT&T, the company saved \$2,500,000 in training expenses." (Bias & Mayhew, 1994).
- Booher and Minninger (2003) report that the estimated cost of the modelling and verification for workload assessments for the U.S. Army Fox M93A1 (a Nuclear, Biological and Chemical Reconnaissance System) was US\$60,000. The savings achieved on operational testing were estimated at between US\$2 and \$4 million.
- Kirwan (2003) reports multiple benefits of a major HF programme for the design of a new plant (a Thermal Oxide Reprocessing Plant). It identified a number of HF safety issues that, had they remained in the design plans, would have caused costs leading to the economic ruin of the design organisation.

Resource 11: Example cost savings for HFI successes.

Value chains (or benefit chains) express cause-effect relationships. These may express relationships of various types. They may be used to express the ways in which HFI activities can affect costs through system performance attributes. This is usually difficult. Alternatively, they may map relationships between system elements, from which cause-benefit relationships can be inferred. Likewise, value chains may map relationships between complementary activities to map trade-off effects. **Influence diagrams**, for example, are a way of mapping complex value chains that branch out in the shape of a hierarchy or network. Lastly, value chains may make predictions about event chains leading to costs (e.g. events potentially leading to accidents, or human error), each of which may be influenced by HFI activities.

Only one cost modelling approach could be identified that aims to provide a comprehensive approach to quantifying the impact of HFI on project costs (Milk 2001). It is based on influence diagrams that aim to reflect the relationships between HF activities as part of the six HFI domains. Whilst it is able to provide actual cost implications for different HFI application variables, it was developed as a 'proof of concept' model, due to lacking access to historical evidence of HFI benefits.

Resource 12: HFI cost models based on Influence Diagrams and Value Chains.

The HF budget calculation method provided by an FAA study calculates the size of HF budget as a percentage of the overall project budget. It is based on a risk assessment using 18 factors, each of which contributes an element to the total.

	No	Very Low	Low	Medium	High	Very High	
Percentage of Developmental Budget:	0%	0.11% per element rated in this category. Adding up to a maximum of 2%.	0.22% per element rated in this category. Adding up to a maximum of 4%	0.33% per element rated in this category. Adding up to a maximum of 6%.	0.44% per element rated in this category. Adding up to a maximum of 8%.	0.55% per element rated in this category. Adding up to a maximum of 10%.	total
Risk areas that may need to be assessed include:	0	0.11	0.22	0.33	0.44	0.55	5.83%
1. Workload: Operator and maintainer task performance and workload.				✓			0.33
2. Training: Minimized need for operator and maintainer training.			✓				0.22
3. Functional Design: Equipment design for simplicity, consistency with the desired human-system interface functions, and compatibility with the expected operation and maintenance concepts.					✓		0.44
4. CHI: Standardization of computer-human interface (to address common functions employ similar user dialogues, interfaces, and procedures).				✓			0.33
5. Staffing: Accommodation of constraints and opportunities on staffing levels and organizational structures.					✓		0.44
6. Safety and Health: Prevention of operator and maintainer exposure to safety and health hazards.		✓					0.11
7. Special Skills and Tools: Considerations to minimize the need for special or unique operator or maintainer skills, abilities, tools, or characteristics.			✓				0.22
8. Work Space: Adequacy of work space for personnel and their tools and equipment, and sufficient space for the movements and actions they perform during operational and maintenance tasks under normal, adverse, and emergency conditions.				✓			0.33
9. Displays and Controls: Design and arrangement of displays and controls (to be consistent with the operator's and maintainer's natural sequence of operational actions).					✓		0.44
10. Information Requirements: Availability of information needed by the operator and maintainer for a specific task when it is needed and in the appropriate sequence.					✓		0.44
11. Display Presentation: Ability of labels, symbols, colours, terms, acronyms, abbreviations, formats, and data fields to be consistent across the display sets, and enhance operator and maintainer performance.					✓		0.44
12. Visual/Aural Alerts: Design of visual and auditory alerts (including error messages) to invoke the necessary operator and maintainer response.					✓		0.44
13. I/O Devices: Capability of input and output devices and methods for performing the task quickly and accurately, especially critical tasks.					✓		0.44
14. Communications: System design considerations to enhance required user communications and teamwork.			✓				0.22
15. Procedures: Design of operation and maintenance procedures for simplicity and consistency with the desired human-system interface functions.			✓				0.22
16. Anthropometrics: System design accommodation of personnel (e.g., from the 5th through 95th percentile levels of the human physical characteristics) represented in the user population.		✓					0.11
17. Documentation: Preparation of user documentation and technical manuals (including any electronic HELP functions) in a suitable format of information presentation, at the appropriate reading level, and with the required degree of technical sophistication and clarity.					✓		0.44
18. Environment: Accommodation of environmental factors (including extremes) to which it will be subjected and their effects on human-system performance.			✓				0.22

Resource 13: FAA proportional HF cost assessment method (Kopardekar & Hewitt 2002).

Typical cost distributions by acquisition phase, as suggested by FAA study (Hewitt 2003).

Program Cost Category	Relative Human Factors Cost Distribution
Mission Analysis	10%
Investment Analysis	15%
Solution Development and Implementation	60%
In-service Management	10%
Disposition and Service Life Extension	5%
<i>TOTAL</i>	<i>100%</i>

Resource 14: FAA metrics for HFI cost by design stage.

Typical cost distributions by design activity (Solution Development Category), as suggested by an FAA study (Hewitt 2003).

Program Cost Category	Relative Human Factors Cost Distribution
Program Management	10%
System Engineering	15%
HW/SW Design, Development, Procurement, and Production	50%
Facilities and Physical Infrastructure Design and Development	5%
Test and Evaluation	10%
Documentation	5%
Logistics Support	5%
<i>TOTAL</i>	<i>100%</i>

Resource 15: Experience values for cost distributions by design influence area.

A method of HF effort estimation was suggested by an FAA study (Kopardekar & Hewitt 2002):

***Cost estimate = a1X1 + a2X2 + a3X3 + a4X4 + a5X5 + a6X6 + a7X7**

Where a1, a2, a3, a4, a5, a6, and a7 are constants, and

- X1 = number of user needs assessment studies that need to be performed.
- X2 = number of concept studies that need to be performed.
- X3 = number of fast-time simulation studies that need to be performed.
- X4 = number of prototyping studies that need to be performed.
- X5 = number of real-time human-in-the-loop simulation studies that need to be performed.
- X6 = number of test and evaluation/validation studies that need to be performed.
- X7 = number of hours of training required by each user.

Values of Constants (Points) by Fidelity Requirements

	--Constants --	-----Initial Constant Values -----		
		(Low Fidelity)	(Medium Fidelity)	(High Fidelity)
user needs assessment studies	a1	1	1	1
concept studies	a2	1	N/A	N/A
fast-time simulation studies	a3	2	4	6
prototyping studies	a4	7	9	11
real-time human-in-the-loop simulation studies	a5	12	14	16
test and evaluation/validation studies	a6	12	14	16
hours of training required by each user	a7	\$75/Hr	\$150/Hr	\$200/Hr

These heuristics are for guidance only, based on a subjective assessment, and may have to be adjusted for other domains than aviation, where prototyping and simulations are complex and therefore especially expensive. One point is suggested to be about \$40,000. However, this figure needs to be adjusted for the project at hand.

Resource 16: Parametric HF cost estimation suggested by FAA study.

Minimum HF involvement may still create savings. Nielsen (1994) argues for the utility of 'Discount Usability Engineering' that uses HF methods at a reduced scale to save cost, whilst still receiving essential benefits. The approach is discussed as a response to overcome barriers for the use of usability techniques for smaller-scale projects. Whilst the validity of the results is reduced, Nielsen argues that the insight is still highly valuable as a means to reduce the chances of operational problems (i.e. small insight is better than no insight).

He argues that the high usability cost figures often published typically only apply to large-scale projects. By choosing methods that compromise on the validity of the results in favour of inexpensiveness, the cost may be more acceptable for inclusion into project budgets. 'Discount Usability Engineering' is suggested as a reduced method that combines three techniques: (1) Scenarios; (2) Simplified thinking aloud; (3) Heuristic evaluation.

Nielsen (1994) discusses the following example: "Consider the problem of choosing between two alternative interface designs (Landauer, 1988). If no information is available, you might as well choose by tossing a coin, and you will have a 50% probability of choosing the best interface. If a small amount of user testing has been done, you may find that interface A is better than interface B at the 20% level of significance. Even though 20% is considered "not significant," your tests have actually improved your chance of choosing the best interface from 50/50 to 4-to-1, meaning that you would be foolish not to take the data into account ... In other words, even tests that are not statistically significant are well worth doing since they will improve the quality of decisions substantially."

Resource 17: Identifying the minimum HFI spending levels.

Sensitivity Analysis is used to identify the effects of changes to the underlying assumptions used for decision-making. It may be used to check the accuracy of project risk predictions, or the cause-effect mechanisms between potential operational problems and prevention strategies. It "tests variations in costs and benefits, especially in the assumptions used to derive them, and sees how those variations will affect an option's value to the organisation. It provides insight into the risks of each option. It can identify the factors that must be carefully managed throughout the life of the investment if it is to deliver the expected benefits. A cost-benefit analysis should be tested by recalculating performance using high, optimistic values and low, pessimistic values. Test assumptions by systematically increasing and decreasing rates. Conduct the sensitivity analysis on one variable at a time so that the impact of that one variable can be assessed" (Treasury Board of Canada Secretariat, 1998). When many variables need to be tested, especially for small variations, **Monte Carlo Simulation** may also be used.

Resource 18: Sensitivity Analysis.

Appendix B Proposed Guidance for Overview Booklet



Cost-Benefit Analysis for Human Factors Integration



December 2008
HFI DTC

Contents

Purpose	67
Why this booklet is needed	67
What this booklet contains	67
Introduction.....	67
Arguments for HFI	67
Process overview	68
HFI cost and risk factors.....	69
HFI costs during the Lifecycle	70
Measuring successful HFI.....	70
Varying depth depending on project stage.....	71
A. Establish objectives.....	72
A.1 Establish variables and constraints	72
A.2 Derive analysis needs.....	72
B. Identify and quantify project risks	73
B.1 Identify and assess risk areas.....	73
B.2 Identify cost impact	74
C. Specify HFI influence.....	75
C.1 Specify the role that HFI takes in the project.....	75
C.2 Specify target design areas	76
D. Quantify required HFI effort	77
D.1 Review project variables.....	77
D.2 Specify HFI activity costs or cost proportions.....	77
E. Specify options	80
E.1 Define suitable HFI expenditure variables	80
E.2 Define suitable ways to assess success.....	81
E.3 Relate spending variables and success	81
E.4 Assess confidence factor	83
E.5 Specify HFI process options	83
F. Choose preferred option.....	84
F.1 Compare options.....	84
F.2 Nominate preferred option and present case	84
Appendix A: RISK POTENTIAL CHECKLIST.....	84
Appendix B: COST ASSESSMENT METRICS	87
References	89
Acronyms	89

PURPOSE

WHY THIS BOOKLET IS NEEDED

Human Factors Integration (HFI) is critical to ensure that system performance is safe, effective, and efficient. However, it is often considered an expensive process and the cost benefits are frequently perceived as intangible. The potential losses due to not applying HFI are rarely assessed early enough for adequate consideration in budget allocations. The financial value of HFI through cost savings is poorly understood. HFI professionals often find it difficult to express HFI cost benefits and produce early budget plans when uncertainty is still high. Thus, project budget plans frequently allow insufficient resources for HFI.

A sound cost-benefit analysis will help HF practitioners to express HFI efforts and benefits in business terms. Cost-benefit analysis for HFI technical and management activities is can be as a difficult task. This is especially so for larger HFI projects, and during early project stages. It is not always easy to argue that there are situations where it is necessary to spend money in order to save money.

WHAT THIS BOOKLET CONTAINS

This booklet offers guidance on cost-benefit analysis to support the cost-justification of HFI, in order to define and demonstrate its benefits in financial terms. The approach taken identifies how HFI can affect overall project costs, in relation to the efforts that need to be spent to achieve cost reductions.

The guidance material provided here is intended to be applied by any stakeholder in need of planning suitable HFI efforts for a project or programme, having recognised that the human element is likely to be linked to overall system performance. It is primarily aimed at HFI practitioners, but may also be used by stakeholders with no or little HFI expertise.

It provides a detailed task breakdown, as well as heuristics (e.g. 'rules of thumb') for cost estimation and assessment. Additional resources (methods, data) are referenced for further elaboration and examples are provided. The heuristics draw

on initial experience values, in the absence of reliable data. The figures provided throughout have not been validated and need to be applied with care.

Since the provision of actual cost figures is often problematic for HFI, this guidance material takes the approach of showing cost relationships to present benefits. This is based on project risk assessments and cost estimation techniques, drawing on an understanding of the paths through which HFI can create value.

INTRODUCTION

ARGUMENTS FOR HFI

The material presented in this booklet follows on from the arguments made in the accompanying Case Study Booklet (HFI DTC, 2006), which provides a high-level case for HFI using a set of arguments to demonstrate how HFI creates value. The arguments presented there are supported by example case studies – including successes due to the application of HFI, as well as failures due to a lack of HFI. The generic arguments for HFI include:

1. HFI can reduce major cost areas. Costs may be incurred due to both operational and development risks.
2. HFI is increasingly required due to developments in technology.
3. HFI plays a critical role in identifying and mitigating operational risks. It has an essential support function throughout the product lifecycle.
4. HFI can draw on resources that enable an efficient development process.
5. HFI requires early, complete and close project involvement to ensure greater success.

Having established the need for HFI, this HFI Cost-Benefit Analysis booklet provides:

- A methodological aid for how to make the cost case for HFI for a specific project or programme, based on a risk analysis.

- Help for how to estimate costs both for potential problems and for HFI mitigation activities.

The overall aim of the cost-benefit analysis is to achieve a proactive approach based on a sound analysis of needs at the early project stages, to avoid reactive situations with late damage control. It also provides methods that help ensure that the right activities are conducted in the right areas, with the right amount of effort.

PROCESS OVERVIEW

The cost-benefit assessment methodology consists of the steps shown in Figure 17. All of the steps are required –but with varying depth and focus depending on circumstances. The process is initiated following the recognition that there may be a need for HFI involvement in the project. The process then establishes the extent and focus of HFI activities needed to mitigate potential risks. It may be necessary to iterate between the steps, and revisit some of them later, since they closely relate. Initially, the analysis may need to draw on some assumptions. Later, more detailed analyses need to be conducted to substantiate the plans.

The steps answer the following questions:

For this project,

- What are the aims, constraints, and priorities of the analysis, What will be the outputs, and for whom? (Step A)
- What can go wrong without HFI, and what are the potential cost effects of the risks? (Step B)
- Which HFI activities are needed to mitigate the risks to an acceptable level, and how should HFI get involved? (Step C)
- What are the costs for the required HFI activities? (Step D)
- What if full and optimal implementation of HFI activities needs to be traded off against other cost priorities? (Step E)
- Which is the most suitable HFI implementation option based on a trade-off analysis, and how to present it best to decision makers? (Step F)

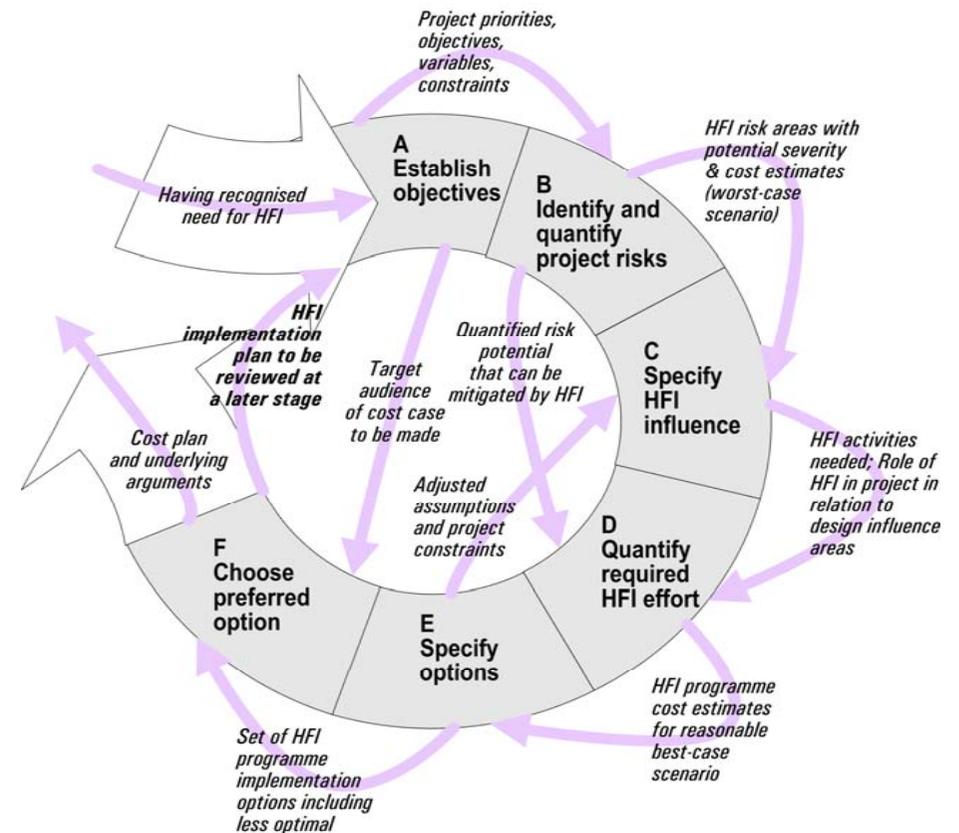


Figure 17: HFI Cost-Benefit Analysis process steps.

This process shall be initiated at the start of a project when the need to consider people-related issues is identified.

Step (A), *Establish objectives*, captures the purpose and strategy for the argument to be made, and how it is to be presented. It is essential to be clear about the focus of the analysis, about specific project circumstances, and about applicable values and priorities.

Step (B), *Identify and quantify project risks*, looks at where problems could occur without sufficient HFI, and which cost impact they may have. This is specifying areas of concern for the worst-case scenario of no HFI implementation. The underlying question is: ‘how badly could it go wrong?’

Step (C), *Specify HFI influence*, looks at what HFI can do to prevent such costs. The roles that HFI may take vary with the type of project. To help specify the most suitable set of HFI activities, a generic set of HFI functions is discussed. The necessary HFI effort to be spent may be estimated as a percentage of the overall project budget. This depends on the role HFI takes in relation to design.

Step (D), *Quantify required HFI effort*, provides aids for estimating the actual cost of the HFI activities needed. This specifies a (reasonable) best-case scenario for risk mitigation where HFI budget constraints are minimal. Depending on the stage of the project, and the associated level of uncertainty, three different methods are suggested for how to assess the necessary HFI spending.

Step (E), *Specify options*, discusses the variables and relationships that help determining HFI budget requirements to be proposed after considering external constraints. It discusses how insufficient HFI may impede risk reduction, and how successful HFI can be estimated through the reduction of design flaws. Predictions may need to be adjusted depending on confidence values. A set of less optimal options may need to be prepared besides the best-case scenario requiring the highest budget.

Step (F), *Choose preferred option*, compares and presents the options based on practical constraints and needs. Priorities and assumptions may need to be reviewed. This step involves a trade-off analysis. A final presentation and documentation of options and evidence is critical in influencing decision-makers as intended.

HFI COST AND RISK FACTORS

Figure 18 shows an overview of the elements that are part of the HFI cost calculation. The left side of the graphic deals with the *risk estimation*, the right

side deals with the *risk mitigation* through Human Factors (HF) activities. Cost can be specified for hypothetical risks, and assumptions can be made about the likelihood of them occurring. The risk mitigation side includes two aspects. One is the *cost of HF activities*; the second is the *risk reduction* through HF activities (depending on the extent to which necessary HFI activities are being implemented – i.e. ‘how well’). Some of the factors (shown in a grey shade) may be expressed as a percentage (experience-based or assumed estimates) that can modify risk or cost estimates.

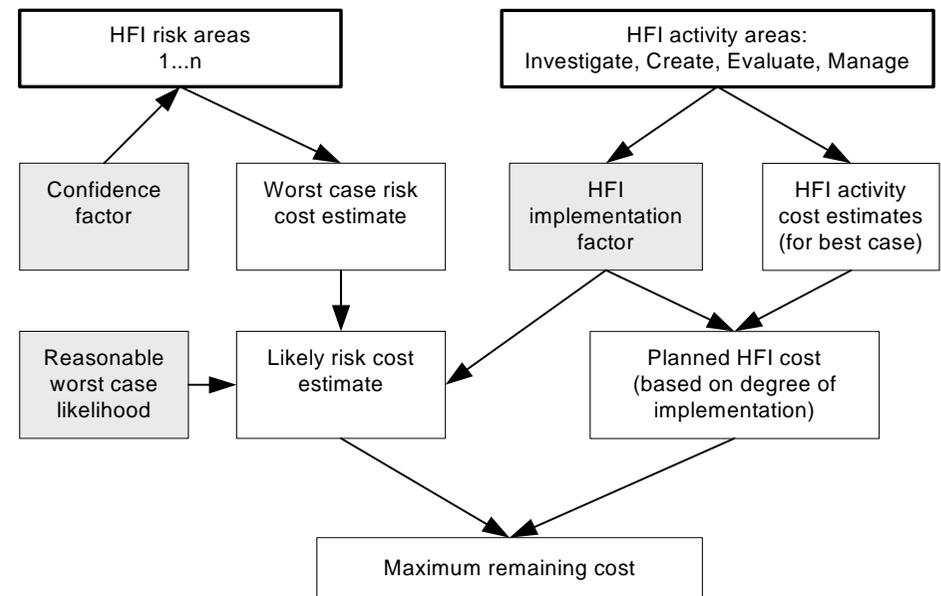


Figure 18: Components of HFI cost-benefit calculations.

HFI COSTS DURING THE LIFECYCLE

When determining HFI needs and cost impact, it is essential to consider the entire system lifecycle (e.g. CADMID⁷). It is important to differentiate between ‘actual spending’ at each lifecycle phase and ‘locked-in’ costs (see Figure 19). Locked-in costs describe investment commitments made through design decisions. At early project phases, design decisions have a high impact. At later stages, cost reduction efforts have a limited potential. Around 70% of the total budget for development has usually already been allocated before the detailed design stage.

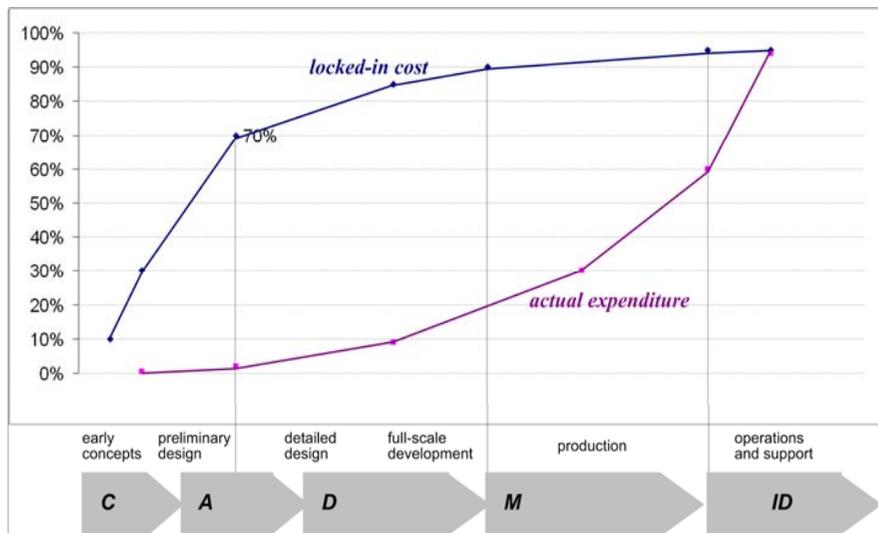


Figure 19: Locked-cost during the lifecycle.

This has several implications. First, the need for HFI costs varies with each stage. Second, HFI activities conducted at an earlier stage may affect cost savings at a

later stage. Third, a significant proportion of the HFI budget needs to be spent during the early project stages. Fourth, influencing HFI design decisions is central.

MEASURING SUCCESSFUL HFI

Successful HFI helps prevent operational problems and reduces development risks. HFI has a well-defined process and draw on a variety of methods, tools, standards and data to support its technical activities to achieve this. HFI activities can only reduce project risks by influencing design decisions across the DLOD. Figure 20 shows a generic HFI value chain, which illustrates the relationships between (1) HFI activities, (2) Design features, and (3) Problem Prevention.

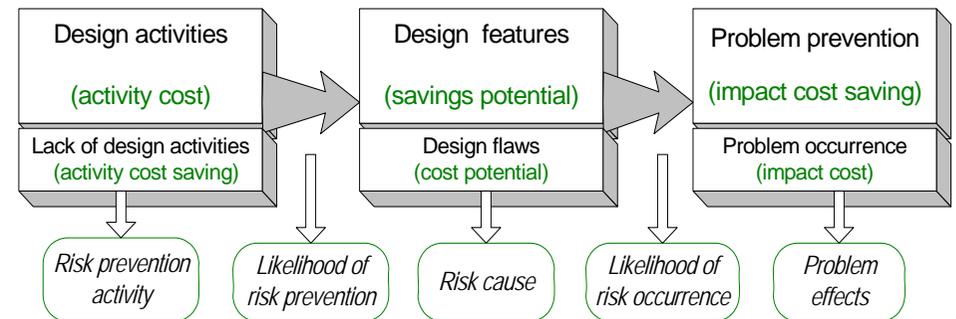


Figure 20: The HFI value chain.

It can be difficult to determine retrospectively the extent to which HFI has contributed to the success or failure of past projects. Whilst the ‘non-occurrence’ of costly problems after preventative HFI activities can be used as a final measure for success, it does not provide an understanding as to how they have been avoided, i.e. how HFI may have influenced the results. Moreover, there is usually a delay between the process stage at which HFI has been applied, and the occurrence of associated cost effects. This makes it difficult to express direct relationships clearly.

⁷ CADMID stands for Concept, Assessment, Demonstration, Manufacture, In-Service, Disposal.

It is useful to draw on the concept of ‘design flaws’ that can be prevented or mitigated through HFI. A design flaw can be understood here as a property of the design (i.e. the designed socio-technical system) that is likely to cause an operational problem. The concept of design flaws links HFI risks with the absence of HFI activities. The presence of design flaws can be linked to omitted or excluded HFI effort. Deficiencies may occur due to a lack of design decisions, delayed decisions, or ‘wrong’ decisions. It can be assumed that a certain number of potential non functional design flaws are always emergent as part of any design process without HFI intervention (which may vary by design domain).

VARYING DEPTH DEPENDING ON PROJECT STAGE

The analysis approach required differs depending on the project stage – due to varying levels of uncertainty for cost predictions. Three levels of detail are distinguished here:

1. *Initial justification of HFI*: Making the business case for investing in HFI at the inception of a programme of work, for justifying fundamental HFI activities. This specifies initial overall resource requirements when there is a high level of uncertainty. This is largely drawing on generic insights about HFI benefits.
2. *Justification of HFI effort for specific risk areas*: Further specifying risk and value factors and initial allocation of HF effort to HFI plans. This concerns early project stages when uncertainty is still high but gradually being reduced.
3. *Detailed planning and option selection*, based on informed assessments of contributory factors. This is specifying efforts for detailed HFI requirements, for an ongoing mapping of resources to needs. This applies throughout the project at increasing levels of detail⁸.

⁸ In terms of the CADMID lifecycle, ‘Initial justification of HFI’ may apply at the very beginning of the Concept Phase. ‘Justification of HFI effort for specific risk areas’ applies from the Concept Phase to early stages of the Assessment Phase. ‘Detailed planning and option selection’ may need to be addressed during all remaining phases.

When moving from one stage to another in the course of the project, the results of the top-level approach can feed into the next stage, including ongoing reviews and updates (e.g. calculations, plans).

Guidance is provided for all levels [only particular project types and examples can be covered at the lower levels]. Depending on the project stage and levels of detail available, approaches may vary as shown in Table 4. It provides a top-level summary of the information described in subsequent chapters. It also shows that some process steps (B1, B2, C2, D2) specify different methods for different levels of detail.

Table 4: Approach variations for different project stages.

	Project Conception	Project Specification	Project Detailing
(A) Establish objectives A1. Establish variables and constraints. A2. Derive analysis needs.	Establish variables, constraints, and values for the project and analyses to be conducted (e.g. safety, cost efficiency, system performance, re-use of processes and knowledge) to determine depth and focus of the analysis, as well as business case presentation and documentation requirements.		
(B) Identify and quantify project risks B1. Identify and assess risk areas. B2. Identify cost impact.	Assess the applicability of risk factors to the project, to assess the magnitude of HF-related risks. Specify likely cost types.	Further assess the magnitude of risk through identifying particular risk areas. Provide impact ratings, and quantify cost effects (e.g. through likelihood of occurrence, number of users affected).	Identify particular risks and problems to be mitigated. Assess potential impact and cost proportions for selected risks.
(C) Specify HFI influence C1. Specify the role that HFI takes in the project. C2. Specify target design areas.	Based on an understanding of the main functions provided by HFI, specify the desired role of HFI, and target design activities.	Identify influence areas for HF activities to inform design decisions, in relation to risk areas (i.e. what effort is needed where). Specify activities across the lifecycle.	Identify target design activities in relation to particular risks.

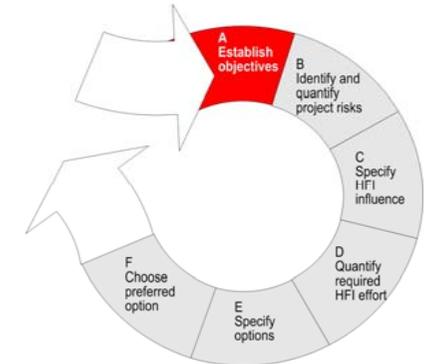
	Project Conception	Project Specification	Project Detailing
(D) Quantify required HFI effort D1. Review project variables. D2. Specify HFI activity costs or cost proportions.	Estimate HFI spending as a proportion of the overall project budget, based on the assessment of risk influence factors. Assess proportional distributions across project stages, and between HFI functions.	Estimate total HFI spending based on an approach that specifies and cumulates the number of HFI studies needed, and the volume of design effort required. Actual cost figures may be specified based on heuristics.	Specify costs for specific studies, by breaking down the effort needed into time, resources and user access.
(E) Specify options E1. Define suitable HFI expenditure variables. E2. Define suitable ways to assess success. E3. Relate spending variables and success. E4. Assess confidence factor. E5. Specify HFI process options.	Specify alternative options and variables for HFI spending in addition to the best-case and worst-case scenarios already specified. Based on defining suitable variables and measures of success, relate potentially inadequate HFI spending to shortcomings in risk reduction. Specify a set of alternative options, and alternative cost predictions.		
(F) Choose preferred option F1. Compare options. F2. Nominate preferred option and present case.	Clarify decision criteria for risk acceptance. Review assumptions, constraints, and trade-off priorities to present the most reasonable option.		

A. ESTABLISH OBJECTIVES

At the outset of cost-benefit analysis, the purposes and constraints need to be established to determine the intended focus, breadth and depth of the analysis, and to specify documentation needs.

Main steps:

1. Establish variables and constraints.
2. Derive analysis requirements.



A.1 ESTABLISH VARIABLES AND CONSTRAINTS

Variables and constraints include type of project, and central purposes and objectives (e.g. risk type, criteria for success, novelty, development vs. purchase, proactive vs. reactive approach, project size, project pace, stakeholder responsibilities). These factors can have a major influence on HFI spending requirements and budget decisions. Moreover, it needs to be clarified who is the target audience of the cost arguments to be made.

A.2 DERIVE ANALYSIS NEEDS

With an understanding of objectives, variables and constraints, the requirements for detail and content of the analysis can be derived. Depth and focus of the cost-benefit analysis needs to be determined. An initial understanding of the scope of the HFI work can be gained, by matching it to major project requirements. A list of central values to be achieved should be produced at this stage. Moreover, presentation and documentation requirements for the business case can be determined.

B. IDENTIFY AND QUANTIFY PROJECT RISKS

To estimate the effort required for HFI, the potential for HF-related risks needs to be assessed. Risks need to be identified in relation to the overall values that need to be achieved by the project. Based on this, opportunities for savings through HFI can be identified, as can potentially missed opportunities for not applying HFI. They may be expressed either as project risks avoided (e.g. lowered performance avoided) or value added (e.g. efficient training design).

This step essentially specifies the worst-case scenario – i.e. the effects of no HFI involvement.

Main steps:

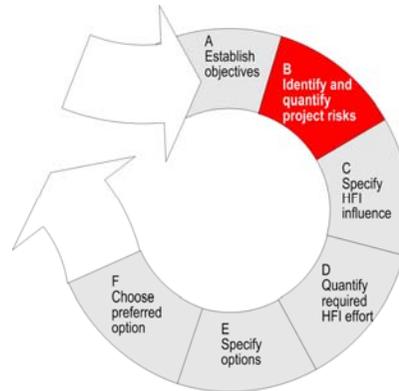
1. Identify and assess risk areas.
2. Identify cost impact.

B.1 IDENTIFY AND ASSESS RISK AREAS

PRE-PROJECT PLANNING

To be able to specify the need for HFI, the extent to which the project may lead to HFI-related risks needs to be assessed. A risk refers here to the likelihood of the occurrence of an undesired event or situation that leads to costs. The concept of risk is always predictive, with a probability and an impact level assigned to it. The impact level may be expressed through a severity rating or a cost figure.

The foundation for any risk assessment is to have established the values and priorities to be achieved, as described in step A. Examples include resource



spending during development, mission effectiveness and performance, productivity gain, safety, societal benefits and conforming with regulations. Such a list of values is the basis for assessing the extent to which they may, potentially, not be achieved.

The analysis approach changes with the project phase and the level of uncertainty. When making predictions at the earliest project stages, the exact risk areas, likelihood and severity are often unknown until more detailed investigations have been conducted. Thus, only an initial best guess can be made.

With an understanding only of the type of project and the main constraints and objectives, the scope of potential problems can be measured using a set of generic risk factors that HFI can have a particular effect on. The table in [Appendix A](#) shows a RISK POTENTIAL CHECKLIST that provides such risk influence factors (2nd and 3rd columns). The risk ratings can be translated directly into estimates for the percentage of the overall project budget needed for HFI activities (step D2).

The level of risk for each factor does not provide actual cost figures for potential losses, but it can be implied that a cost can be expected. Step B2 identifies the relationships to costs – both generically (when details are unknown) and more specifically.

ONGOING PROJECT SUPPORT

Later, at the stage of project specification, when specifying the first Human Factors Integration Plan (HFIP), more specific project risk areas need to be identified. An Early Human Factors Analysis (EHFA) can be taken as the basis for producing an HFIP.

One of the main outputs of an EHFA is an initial risk register where specific risk areas are identified and assessed. The risk areas should be specified for major project stages or elements. Taking into account also the risk influence factors from the checklist in [Appendix A](#), cost candidates can be established, drawing on assessments of the interplay between technology, operating conditions, users, and

tasks. Risk assessments are conducted through a combined impact rating (i.e. the extent to which the problem may decrease mission performance) and likelihood rating (i.e. novelty, and extent to which technology is proven and performance goals are understood). More detail on EHFA can be found, for example, in the Practical Guidance for IPTs (MoD, 2001).

During later phases of project detailing, the analysis focuses on specifying particular risks in relation to contextual factors, where original risk assessments from the HFIP are being reviewed.

B.2 IDENTIFY COST IMPACT

To further understand the risks and their associated impact, it is necessary to specify the types of cost that can be associated with problem occurrence. There is not always a one-to-one relationship between risks and costs. Risks may cause cost not only through adverse events and situations (e.g. performance reduction, failed task, accident damage), but also process-based cost such as the consequences of wrong investments and re-design needs. The potential benefits of HFI, to which a financial value can be assigned, also include wider-reaching benefits and savings outside the direct project scope (e.g. long-term effects of well-established HFI over many projects; established methods, processes and expertise).

When specifying savings, the effects throughout the CADMID lifecycle need to be considered – since HFI costs at one stage can create savings in a later stage. The overall argument for HFI can be presented as contrasting a typical best-case situation (Figure 21) with a worst-case situation (Figure 22).

For the stage of specifying initial HFI plans, the emphasis can be shifted more from identifying cost areas to specifying and quantifying them (likelihood and volume) for particular process stages.

The cost of risks may be estimated based on assuming a certain number of design flaws as a cause of risks. The concept of a design flaw can be understood here as a property of the designed system that is likely to cause an operational problem.

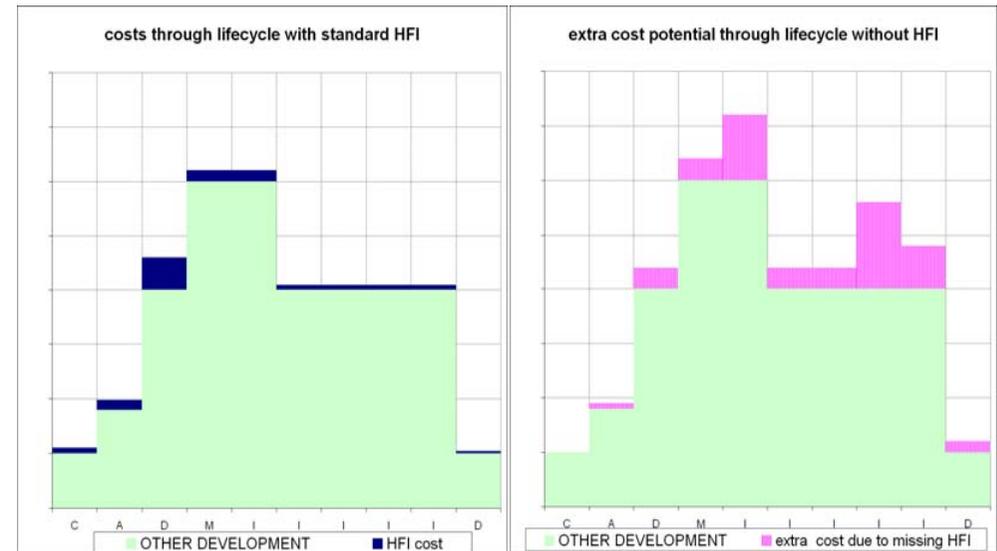


Figure 21: Example project situation where HFI is being applied.

Figure 22: Example project situation where required HFI is not applied.

Design flaws can be linked to cost effects through measures including:

- Total number of emergent design flaws (e.g. per design area, per project stage);
- Confidence/likelihood factor as a measure of probability of problem occurrence;
- Impact/damage/severity (e.g. minor to catastrophic) as a measure of potential cost magnitude;
- Impact severity proportions (e.g. 40 minor flaws, 10 major flaws) to specify actual figures, after assigning figures to impact categories.

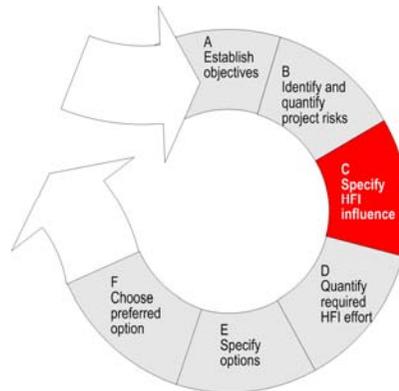
C. SPECIFY HFI INFLUENCE

To specify how HFI can reduce project risks, the paths through which HFI can influence design decisions need to be clarified. Understanding the functions that the HFI process contributes to the design process is crucial to comprehending how HFI creates value.

To assess the scope of HFI needed, it is necessary to demonstrate how design decisions can influence different domains and to target these areas to be supported through HFI..

Main steps:

1. Specify the role that HFI takes in the project.
2. Specify target design areas.



C.1 SPECIFY THE ROLE THAT HFI TAKES IN THE PROJECT

To be able to link HFI activities to benefits, the role HFI is to take in the project needs to be clarified. As part of this, the types of activities through which HFI can affect design decisions need to be understood.

For example, product development activities involve major cost investments. If unsuitable investments are discovered during tests and assessments after development efforts have been spent, re-design costs can be significant. Accurate requirements specifications that users have agreed to are crucial. Translating user needs into system specifications is a non-trivial task where HF expertise can be critical. Moreover, regular assessments of part solutions in an iterative design approach are essential for effective project risk management.

To be able to link HFI activities to the claimed benefits it needs to be established what functions HFI provides, and how they can affect the design choices, which

prevent problem costs. Design is understood here as a solution-generating activity that includes requirements specifications besides generating concepts, prototypes, and final product designs.

It is essential to establish that HFI takes effect through a set of standard functions. They include: (1) Investigate; (2) Create; (3) Evaluate; (4) Manage.

Table 2 provides more details on these HFI functions.

Table 5: The main HFI functions with explanations.

INVESTIGATE	Seeking understanding of constraints and resources	Researching: <ul style="list-style-type: none"> • Conditional factors such as human capabilities and limitations for selected situations; • Motivational factors due to organisational processes; • Effects of environmental constraints on human performance and health; • Users' current and envisaged tasks and procedures.
CREATE	Active generation of requirements and design solutions	Providing design guidelines, principles and means of compliance with regulations and standards to meet HF needs; Translating needs and constraints into envisaged functionality and solutions.
EVALUATE	Assessment and testing of ideas, concepts, solutions and prototypes	Understanding the effects of new designs (e.g. technology, equipment, interfaces) on, for example, human behaviour, cognition, capacities, skills, jobs content and structures, human interactions, social structures, information flows, distribution of responsibilities.
MANAGE	Process management	Ensuring implementation of information; ensuring HF design involvement; ensuring HF mediation role; planning and timing; defining assessment criteria; defining roles and responsibilities; assigning tasks; assessing progress; project risk management etc.

All of these functions, or component activities, are needed to prevent or mitigate risks. They interact closely, as visualised in Figure 23. They apply to every stage

of the CADMID process. They are not to be equated directly with design process steps such as design phase or testing phase.

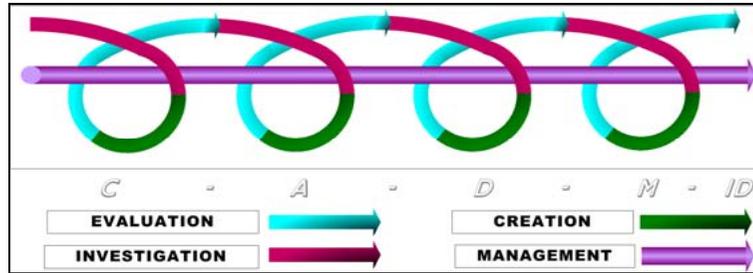


Figure 23: The functional elements of HFI.

The effects of HFI on risk reduction may be measured through:

- Design decisions influenced proactively (i.e. flaws prevented);
- Good design solutions generated (i.e. flaws prevented);
- Design decisions influenced reactively (i.e. flaws identified and rectified).

Based on the assumption that knowledge of operational and user constraints are required to provide effective designs (efficiently), HFI reduces risks through:

- Retrieving and communicating information;
- Applying information/findings to inform design decisions.

The total budget typically assigned to HF activities has been estimated to be between 2% and 10% during development phases for a medium to large multidisciplinary programme (Kopardekar & Hewitt 2002). This estimate depends partly on how the boundaries of the project are defined (e.g. the project output itself may be defined as an HF product such as a new HF method, where HF activities may contribute up to 100%). The estimate also depends on the role that is assigned to HF specialists. Figure 24 shows how projects may vary in terms of the role of HFI in direct creative involvement. It may be appropriate, however, to assign

higher proportions, depending on the design areas to be covered and the overall HFI strategy to be adopted.

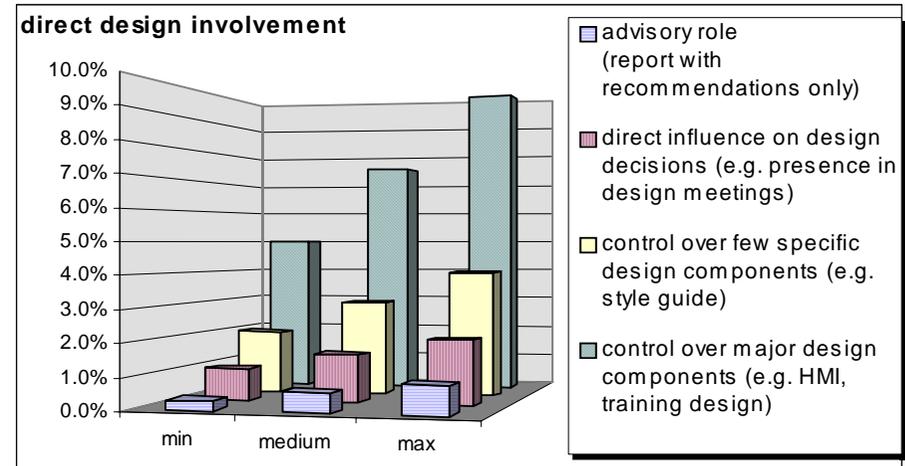


Figure 24: Variations in direct HFI design involvement – as a proportion of the total project budget (note the percentages are not validated).

C.2 SPECIFY TARGET DESIGN AREAS

To identify where HFI efforts need to be spent, it is necessary to specify and target design decision areas through which HFI can reduce project risks (e.g. user interface design, organisational specification, infrastructure design, training design).

Many design areas are not always considered as areas where HFI can make a crucial contribution. They are not explicit HFI areas, but HFI can contribute a certain percentage of the work directly (e.g. in some domains, 30 to 50% of requirements engineering may be carried out by HF specialists).

D. QUANTIFY REQUIRED HFI EFFORT

The HFI spending needed to prevent and mitigate risks can be assessed based on the severity of risk factors and resulting risk potential. Where no exact cost figures can be calculated, measures of magnitude can be used as a basis to estimate the appropriate effort of mitigation.

Initially, a best-case scenario for risk mitigation should be assumed. This implements a full HFI process with sufficient resources to have a significant impact on project risks. The cost effort may be assessed either as a total cost figure, or as a proportion in relation to other quantifiable activities that are specified elsewhere.

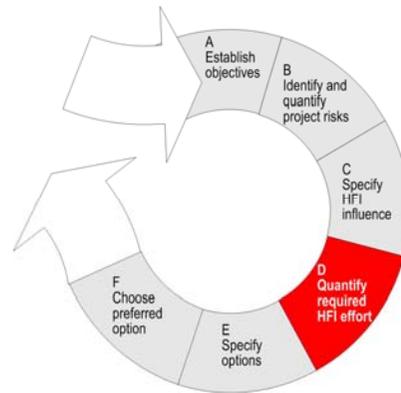
Main steps:

1. Review project variables.
2. Specify HFI activity costs or cost proportions.

D.1 REVIEW PROJECT VARIABLES

The same influence factors that were used in section B to assess project risks can also be used to assess the required HFI effort based on heuristics. The project risk ratings identified through the checklist in [Appendix A](#) can be translated into HFI budget needs. This assumes a typical, medium to large, multi-disciplinary system development project.

During the Project Specification and Detailing Phases, the risk influence factors can be updated and further specified. Likewise, the role of HFI with regard to its involvement in direct solution generation activities needs to be defined. Factors such as project size, complexity and uncertainty have a direct impact on time and



resource requirements. The level of fidelity required for simulators and prototypes has a high impact on cost requirements.

D.2 SPECIFY HFI ACTIVITY COSTS OR COST PROPORTIONS

Three different methods are suggested for how to assess the necessary HFI spending:

1. *Method 1* estimates HFI cost as a percentage of the overall project budget, assuming a typical range between 2 % and 10%. This is based on the high-level HFI risk assessment conducted under Step B. This approach is most suited to early project stages, when detailed project risk areas are not yet known.
2. *Method 2* further details the estimate from Method 1 and can be used to verify its high-level approximation when more project understanding becomes available. It is based on breaking the overall percentage down into budget components using broad categories for which proportional volumes can be estimated. This is based on experience values. The components draw on the HFI functions discussed under Step C (i.e. Investigate, Create, Evaluate, Manage) and a distinction of Productive Time, User Access, and Resources.
3. *Method 3* provides an alternative approach to Methods 1 and 2. It is more precise but requires extra information. It uses a parametric cost estimation approach that cumulates component costs. It provides heuristics for the types of studies to be conducted under the Investigate and Evaluate HFI functions. Using these, the cost components for the functions Create and Manage are then based on proportional relationships and a number of variables.

(1) CALCULATION AS A PERCENTAGE OF PROJECT BUDGET

At stages of high uncertainty, obtaining detailed cost figures is often not practicable. Instead, sufficient HFI spending may be estimated as a proportion in relation to other costs specified elsewhere. At this stage, HFI costs may be

calculated as a percentage of the overall project budget, based on the project risk assessment conducted earlier, and experience values.

Appendix B provides COST ASSESSMENT METRICS that translate risk influence factors into cost percentages, to calculate the proportion of the overall project budget that needs to be allocated to HFI activities.

(2) BREAKING DOWN THE BUDGET INTO COMPONENTS

Having identified the overall HFI effort needed in relation to project risk influence factors and cost impact ratings, the resources required can be broken down for a more detailed estimation.

Likewise, the size of the budget may be built up from the HFI functions as component activities (i.e. Investigate; Create, Evaluate, Manage). Figure 25 shows an example of that. Experience values can be used to assess proportional breakdowns of budget needs.

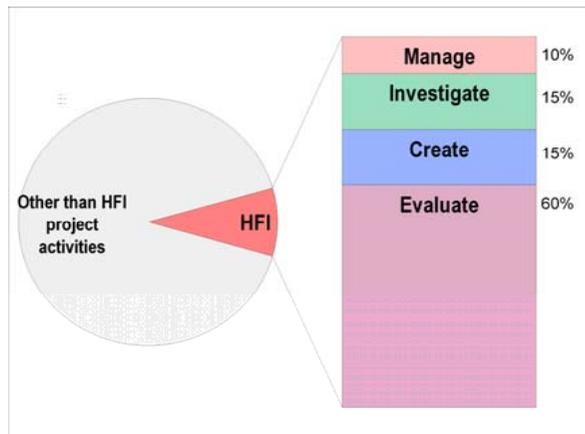


Figure 25: Breaking down the HFI budget (note the percentages are examples only, they not validated and not necessarily to be used as generic proportions).

Similarly, The HFI process, or each of its HFI function components, may be broken down by the main elements that cause HFI costs:

- Productive time;
- Resources;
- User Access.

Productive time refers here to labour time, i.e. time spent by HF practitioners. Resources may include producing simulations, mock-ups, and prototypes. They may also be understood here as access costs such as hire fees, travelling, or assistance. User Access includes user fees, travel costs to access users, time of users not spent on their usual activities etc. Cost element proportions may vary for different HFI tasks.

Proportions may vary with HF risk areas identified, and the domain (e.g. design for aviation vs. design of handheld devices). They may also vary depending on the overall approach to implementing HFI (e.g. through employing permanent HFI staff, employing HFI contractors, employing engineers trained in using HFI methods and resources, or combinations of these). Experience values from previous projects within a domain should be recorded to aid estimation.

These cost components may be broken down further, or in other ways. The component activities can either be used to further specify an overall budget figure proportionally, or to derive an overall figure from its components by estimating them separately based on experience values and then cumulating them.

(3) COST CALCULATION BY STUDY TYPE

An alternative approach to identifying HFI cost as proportions of the overall project budget is a parametric cost estimation approach that defines cost figures for constituents first, and then cumulates them.

The components are defined here again as the main HFI functions: Investigate, Create, Evaluate, and Manage. Heuristics are used to generate cost figures. The four elements then need to be added up, to come to a total HFI budget figure.

Investigate and Evaluate (elements 1 and 3)

For the elements *Investigate* and *Evaluate*, the cost can be assessed based on the number of studies needed. Figure 26 shows example cost distributions for the different categories defined.

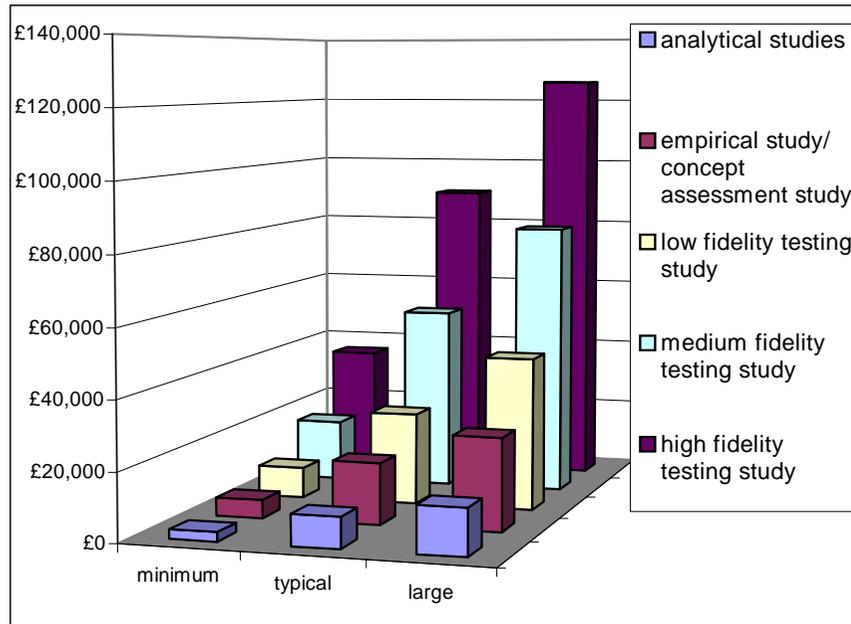


Figure 26: Example costs for different types of studies, based on cost assessment heuristics (note this is an example only, the cost figures are not validated and do not reflect generic figures).

Alternatively, when more project details can be anticipated, study costs may be built up of estimates for Resources, Time (e.g. preparation, conducting, data analysis), and User Access. For example, a medium scale Focus Group study with 5 sessions and 8 participants per session may be estimated at around £15,000

including personnel, room and equipment hire, participant fees and refreshments, preparation and analysis.

Create (element 2)

The component *Create* can be assessed based on the role HFI takes in the generation of solutions. Figure 9 outlined the extent to which HFI input may vary regarding direct creative decision-making involvement. When assuming that the solution-generating element is around 15% of HFI activities, it can be calculated as a fixed proportion based on the cost of studies needed.

For a calculation independent of the effort already calculated for studies, the project size, and the associated total design effort for the project as a whole needs to be taken into account.

For this approach, again, the level of HFI participation in solution-generating design activities is a question of definition (e.g. HFI in minor advisory role, HFI taking part in HMI solution generation).

The volume of work required can be estimated based on the number and scope of system elements to be designed (e.g. by design areas, design components), taking into account factors such as:

- Complexity/volume of each component;
- Extent to which they are unknown;
- Extent to which they have already been prototyped;
- Extent to which resources can be drawn on (e.g. use cases developed).

Manage (element 4)

The component *Manage* can be assumed as an overhead figure of around 5 to 10% of the HFI budget, depending on factors such as:

- Project size;
- Number of collaboration partners;
- Presence of iterative design approach;

- Level of acceptance of HFI;
- Quality of organisational structure and information management resources.

USING THE METHODS TOGETHER

The different methods suggested here for estimating HFI effort should be used with one another. By triangulating the results, and by reviewing the earlier estimates in relation to later ones, more accurate estimates can be achieved. Moreover, trade-offs between HFI efforts in influencing design decisions may need to be considered (e.g. interface design option affecting required training effort).

Step D.2 has provided approaches for how to calculate an HFI budget as a whole, without specifying how it is to be distributed over the lifecycle. However, the best-case scenario is based on the assumption that sufficient effort is to be spent during the early project stages (i.e. concept and assessment, before detailed design). This does not necessarily result in disproportionately higher cost up-front. This is because earlier HFI activities are often less resource-intensive.

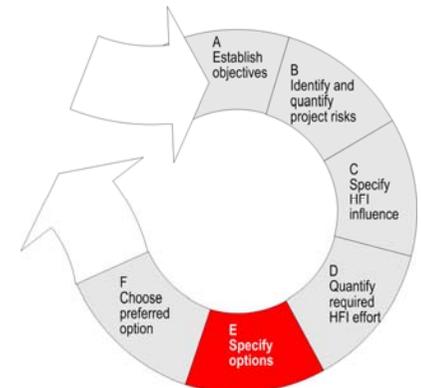
E. SPECIFY OPTIONS

Typically, project resources are constrained. To be able to justify the specified HFI effort in relation to other project cost constraints, the effects of alternative options to the suggested approach need to be demonstrated and assessed. Suitable approach variables need to be specified, and their effects calculated.

Measures of HFI success and effectiveness need to be specified. Confidence values and success factors may be attached.

Main steps:

1. Define suitable HFI expenditure variables.
2. Define suitable ways to assess success.
3. Relate spending variables and success.
4. Assess confidence factor.
5. Specify HFI process options.



E.1 DEFINE SUITABLE HFI EXPENDITURE VARIABLES

If resources are constrained, the best-case scenario for HFI expenditure specified earlier may need to be assessed regarding the suitability of other planning options. These may include spending resources at different project phases, spending resources on different aspects, and/or spending fewer resources. The following main variables may be considered:

- Timeliness of HFI implementation;
- Completeness of HFI functions;
- Sufficiency of resources.

Resource spending options should be specified based on an understanding of the variables that affect HFI success (Bruseberg, 2006). For example, an efficient HFI

process requires early involvement, to ensure spending on the right developments. Likewise, HFI needs to be applied and resourced as a complete process including the main functions:

- Investigate, Create, Evaluate;
- Manage HFI requires close involvement of HF practitioners to address emerging design issues.

A minimum level of resources for each function is needed to achieve its purpose.

The following types of HFI deficiencies may be considered:

- HFI functions are applied with limited resources (e.g. not enough depth, limited validity, information remaining uncertain);
- HFI functions are applied too late (missing involvement during Concept, Assessment, Demonstration, and/or Manufacturing phase);
- HFI functions are missing (e.g. analysis without implementation; design and assessment based on limited knowledge of use; limited design involvement);
- HFI functions are not applied to all design activities/domains;
- Missing/ineffective/inefficient process integration (e.g. activities carried out in isolation; Investigation function and Evaluation function not joined to design decision making; limited acceptance of HF contribution).

This is assuming a correct risk analysis and a suitable assignment of HFI activities to risk areas.

E.2 DEFINE SUITABLE WAYS TO ASSESS SUCCESS

In order to assess planning options, ways to assess HFI success need to be established. The primary influence of HFI activities is through design decision areas that affect how future systems will behave. ‘Design flaws’ (see Figure 20) are properties of the designed system that are likely to cause an operational problem. The number of design flaws to be expected depends on the risk level (due to risk factors) as identified earlier. Such a quantification approach can be

taken as the basis for mitigation targets. The larger the number of flaws, the higher the retrospective mitigation effort needed.

The impact magnitude of design flaws may be measured through potential cost effects, based on:

- Development process performance measures (e.g. delays, number of iterations, unexpected human resources needed);
- Operational performance measures (e.g. unexpected training and maintenance, unexpected failures, unachieved performance).

It needs to be noted, however, that concepts such as the number of design flaws, or the number of design decisions, are theoretical concepts that cannot easily be measured practically. The number of design flaws sometimes becomes apparent when an HF study categorises a number of design deficiencies that may cause problems when assessing design solutions during the later stages of a project. It may be measured through the number of design changes made retrospectively. However, measurable prospective influence on design decisions is less tangible. The occurrence of a certain number of design flaws needs to be assumed for any project, to be prevented and mitigated by HFI efforts.

E.3 RELATE SPENDING VARIABLES AND SUCCESS

To be able to assess the effects of planning options on risk reduction success, we can draw on heuristics that show the relationships between implementation variables and success measures. This may also be termed the ‘implementation factor’ – i.e. the extent to which HFI is to be employed (e.g. fully, reduced, none).

Figure 27 shows relationships between the times at which HFI is applied (with varying effort), and the risk cost potential – which may be measured through the percentage of design flaws remaining. This is based on experience values only. Relationships are shown for basic options including late implementation, incomplete implementation, and insufficiently resourced implementation, in comparison to an option of full HFI implementation and no HFI implementation

across the system lifecycle. The higher the remaining percentage of flaws is, the higher the potential of associated risks and costs at the same or later project stages.

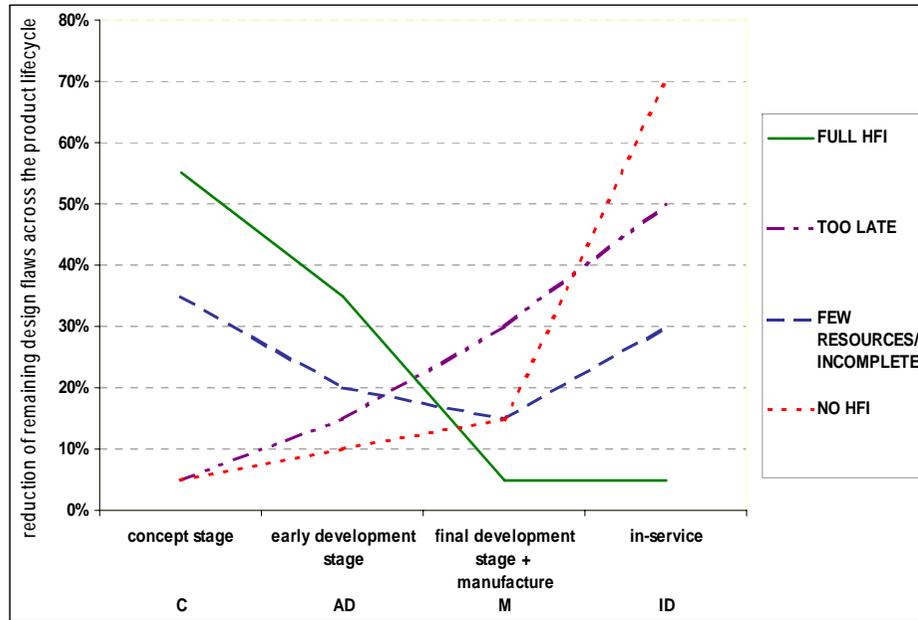


Figure 27: Relationships between HFI implementation options and reduction of remaining emergent design flaws across the product lifecycle
(note the proportions are estimates only and are not validated).

Such an assessment may be established for different tasking options. Specific cost effects may be attached separately. For example, the cost of not identifying a design flaw early is higher since it results in higher failed investment, due to the cost 'locked in' when commitments to investments have been made. Moreover, the cost effect of design flaws may differ with types of risks.

It is important to establish a minimum (and maximum) level of activity to achieve an acceptable level of risk reduction. Figure 28 further specifies the relationship

between the volume of resource spending on HFI and the effectiveness that can be expected. It shows that there are two cut-off points. Below a certain spending volume, the insight gained through HFI is likely to be incorrect, or invalid. This may be, for example, due to insufficient data, or not enough analysis effort to come to valid conclusions. From a certain spending volume onwards, no further useful information is likely to be gained, other than confirming already known facts. The challenge is to define the optimum at which most effect can be gained. The minimum effort may vary with project priorities. For example, in safety-critical domains, reducing the likelihood of human error may be regarded as paramount, requiring more scrutiny and higher effort. In other domains, less certainty for the risk reduction achieved may be more acceptable.

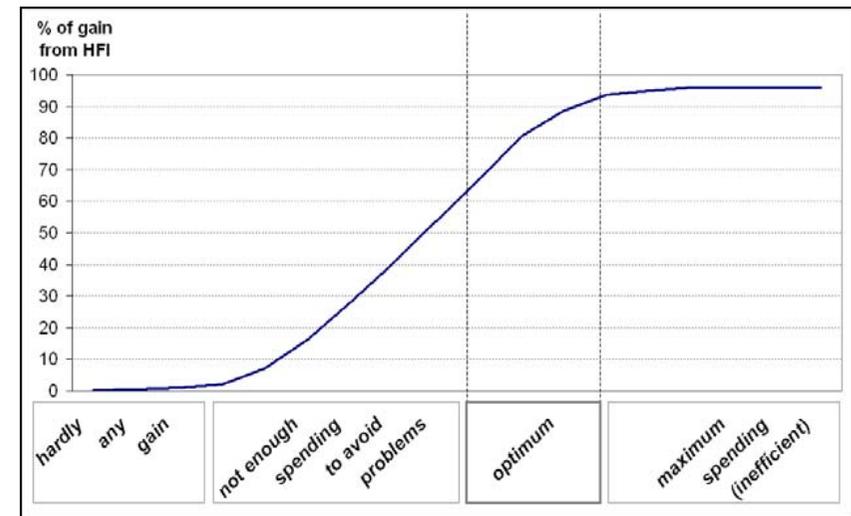


Figure 28: Relationship between spending volume and gain in value from HFI
(note the proportions are estimates only and are not validated).

E.4 ASSESS CONFIDENCE FACTOR

A factor that may be useful for consideration here is the Confidence Factor, expressing the extent to which the specified 'ideal' HFI process can achieve the savings specified. No project planning is perfect. Thus, it has to be acknowledged that the assessments of resources required may need to be revised during the course of the project, as the scope of risks and design challenges becomes clearer. Likewise, the confidence regarding the extent to which the right activities have been linked to the right problems needs to be assessed. This may include an assessment of the expected quality of the HFI process (e.g. effectiveness of communicating and implementing information into design).

E.5 SPECIFY HFI PROCESS OPTIONS

Having reviewed project-specific constraints, a suitable set of distinct options for HFI implementation should be specified to have a basis for comparison. Moreover, with the insight gained, the specification of both a best-case and a worst-case implementation scenario may be updated (i.e. complete and efficient HFI process vs. no HFI process). This may include, for example, a task list and budget estimate for a minimum spending option (e.g. reduced number of users, no observational studies, and minimum prototype fidelity) vs. a project outline for a fuller implementation option.

To specify distinct scenario options, it is necessary to:

- Determine the scope of potential budget constraints;
- Include potential trade-off options (e.g. in-service vs. development costs; performance/achievement/safety vs. improved processes and methods);
- Identify expected high-spending activities – to re-assess prime HFI activity areas (e.g. significance of information);
- Assess effectiveness factors (e.g. which HF activities have the highest benefits in which circumstances);

- Determine potential areas for HFI spending cuts using a model of HFI benefit mechanisms,.

Each option can be calculated based on the relationships summarised earlier in Figure 18, showing the cost-benefit calculation elements and their interaction.

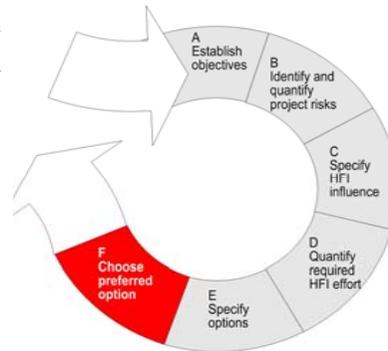
Cost assessments for alternative options should be produced. Using the same approaches as suggested in Sections B and C, the activity and risk costs for the specified alternative options may need to be reassessed.

F. CHOOSE PREFERRED OPTION

Having established options, variables, constraints, and priorities, the specified scenarios need to be compared. Assumptions need to be reviewed. Trade-off options for spending priorities need to be assessed. A commitment to a preferred option needs to be expressed with underlying reasoning, and presented in an appropriate format.

Main steps:

1. Compare options.
2. Nominate preferred option and present case.



F.1 COMPARE OPTIONS

The variations for costs and benefits across the product lifecycle for the specified options need to be compared in relation to priorities, constraints, and assumptions. This process includes tasks such as:

- Record any assumptions made.
- Review priority values and business goals.
- Establish constraints and cost boundaries, for example can the risk be accommodated or not (e.g. Could the cost of an accident close down the design organisation? Is public acceptance likely to be low, and is it of importance?).
- Assess trade-off options.

F.2 NOMINATE PREFERRED OPTION AND PRESENT CASE

The case for the preferred HFI implementation option should be presented. Suitable format options should be considered, including the use of diagrams, suitable structure, or the depth of detail required.

APPENDIX A: RISK POTENTIAL CHECKLIST

The list combines two types of factors:

- HFI-specific factors such as the level and focus of human involvement in the operation of new system/equipment, providing an initial prompt as to potential areas of concern (e.g. level of expected cognitive demand) – items 1 to 7;
- Generic cost factors (e.g. project uncertainty, novelty, and complexity) with an effect on the HFI effort needed for prevention and rectification – items 8 to 15.

The first step in quantifying the extent to which financial penalties can be expected is to identify the risk potential on a severity scale, based on the likelihood and impact of problem occurrence. The checklist in Table 6 provides a rating facility (the columns under ‘severity rating’) to estimate the potential impact of each factor (where ‘1’ is very low and ‘5’ is very high). It shows a completed example assessment. Impact ratings need to be based on experience values and expert judgements. To make the ratings more objective, Expert Rating Techniques may be used.

The assessments for each risk factor provide a qualitative overview as to where problem areas may lie. The ratings can also be used to derive a figure for an overall risk level. It may be expressed using the same rating scale as for each individual factor (1 to 5). There are 15 factors, so each contributes 6.67% to the overall risk. Since their contribution may vary, the risk influence factors in Table 6 have been given a predetermined weight (e.g. presence of health hazards: 5%). These may need to be adjusted depending on the type of project. They need to add up to 100%.

For the example rating given in Table 6, the overall risk level could therefore be determined as **3.6** on a scale of 1 to 5. This is derived by multiplying the rating for each (e.g. 5) with the weight (e.g. 0.05) and then accumulating them all ($0.25+0.05+0.50+0.05+0.25+0.75+0.15+0.30+0.25+0.25+0.50+0.05+0.25=3.6$).

Table 6: RISK POTENTIAL CHECKLIST (completed example).

	Risk influence factor	Explanation	Weight	Severity Rating					
				0 - None	1 - Very Low	2 - Low	3 - Medium	4 - High	5 - Very High
1	Estimated cognitive complexity of operation	The level of complexity for the interaction between people and technology, and the complexity of the operational environment, potentially leading to cognitive workload (e.g. decision-making tasks in dynamic environments; operation of complex equipment with many variables; time pressure; anxieties).	5%						X
2	Expected physical difficulty of operation	The severity and number of adverse operating constraints that may reduce operator performance and task achievement due to physical stressors and workload factors (e.g. extreme thermal discomfort, moving heavy loads, limited visibility).	5%		X				
3	Mission-critical operation	The extent to which the operation of the system affects the success of the mission, and the criticality of mission or task failures.	10%						X
4	Presence of health hazards	Presence of potentially harmful conditions due to the operating environment, technology interaction, or task demands (e.g. toxic substances, moving parts, prolonged operation under physically or psychologically strained conditions).	5%		X				
5	Expected operation under safety critical conditions	Risk of large-scale accidents due to human error (e.g. possibility of excessive cognitive workload, lack of situational awareness).	5%						X
6	Direct interaction scope	Extent to which people are directly affected by the equipment (e.g. number of users affected; occasional vs. continuous use) – not limited to operators, but including, for example, maintenance personnel, users directly benefiting from function of product/system, and people transporting and installing equipment.	15%						X
7	Expected change of manpower and skill levels	Likelihood of changes to personnel issues including manpower availability and requirements, and skill needs – potentially requiring manpower planning, recruitment, and/or training activities.	5%			X			
8	Extent of HF problems in predecessor systems	Extent of HF problems in existing systems, giving an indication of the amount of design change required to overcoming them and assessing improvements.	5%			X			

- Continued on next page -

	Risk influence factor	Explanation	Weight	Severity Rating					
				0 - None	1 - Very Low	2 - Low	3 - Medium	4 - High	5 - Very High
9	Scope of effects	The extent to which the new product/system affects related system design areas through the consequences of changes required. For example, new technology such as NEC information networks may require new organisational and information flow structures, re-training, re- recruiting, new maintenance schedules, new documentation. The lifetime of the product/system may come into the equation here.	5%				X		
10	HFI design scope in relation to project focus	If the purpose of the project is the design of a new user interface only (e.g. for an existing helicopter), then the HFI effort is proportionally much higher than, for example, the design of an entire new helicopter (where, for example, ensuring technical airworthiness will take on a much larger proportion than HFI activities).	10%				X		
11	Level of novelty	The extent to which the newly designed working system is novel (e.g. first-of-a kind) and produces sources of uncertainty (e.g. novel technology, new task and operating conditions, new organisational constraints). This affects design, implementation, and operation.	5%						X
12	Number of design constraints	The extent to which the design process needs to conform with external limitations that require optimisation of operational variables (e.g. need to comply with safety regulations, need to follow specific design standards).	5%						X
13	Project uncertainty	Amount of (not yet) available understanding of operational needs and system requirements (e.g. agreements on operational concepts, understanding of user constraints, definition of tasks and expected task performance, clarity of high-level human-equipment interface requirements, envisaged use of technologies). Technology Readiness Levels may be referred to here.	10%						X
14	Product purpose directly fulfils a Human Factors need	The purpose of the design is in itself fulfilling a user need, i.e. support to humans is the objective of the project (e.g. transporting them, housing them, providing them with information).	5%		X				
15	Absence of conducive design organisation conditions	The ease with which an effective HFI process can be integrated depends not only on the acceptance level of HFI, but also on the presence of conducive processes such as an iterative design process, efficient project management, effective communication, documentation, and information sharing processes.	5%						X

APPENDIX B: COST ASSESSMENT METRICS

Table 7 provides COST ASSESSMENT METRICS that translate risk influence factors into cost percentages for estimated HFI spending, to calculate the proportion of the overall project budget that needs to be allocated to HFI activities. The calculation is derived as follows:

- The HFI cost proportion is calculated by adding up the percentage elements for each risk influence factor.
- The higher the risk severity rating (chosen in step B) for each element, the higher the percentage element.
- For example, if each HFI factor is assessed at a very low intensity, they all add up to a total of 2% of total project cost. If all factors would be assessed at the highest severity, they add up to 12%.
- If some factors are assessed to have no impact, they contribute nothing to the total – so the total may be below 2%.
- Risk influence factors with a higher weight contribute more to the total, relative to each other. The weights must always add up to 100% of influence. For example, the first risk factor with a weight of 5% contributes at the lowest rating (2%) a total of 0.1% to the total budget (2% * 5% = 0.1%).
- Table 8 shows example ratings, for which the factors add up as follows:
0.6%+0.1%+1.2%+0.1%+0.6%+1.8%+0.225%+0.225%+0.35%+0.7%+0.6%
+0.6%+1.2%+0.1%+0.6% = **9%** of the total budget to be spent on HFI.

Table 7: COST ASSESSMENT METRICS

		Weight of influence factors:		Budget elements depending on factor severity				
		100%		Very Low	Low	Medium	High	Very High
1	Estimated cognitive complexity of operation	5%	0.100%	0.225%	0.350%	0.475%	0.600%	
2	Expected physical difficulty of operation	5%	0.100%	0.225%	0.350%	0.475%	0.600%	
3	Mission critical operation	10%	0.200%	0.450%	0.700%	0.950%	1.200%	
4	Presence of health hazards	5%	0.100%	0.225%	0.350%	0.475%	0.600%	
5	Expected operation under safety critical conditions	5%	0.100%	0.225%	0.350%	0.475%	0.600%	
6	Direct interaction scope	15%	0.300%	0.675%	1.050%	1.425%	1.800%	
7	Expected change of manpower and skill levels	5%	0.100%	0.225%	0.350%	0.475%	0.600%	
8	Extent of HF problems in predecessor systems	5%	0.100%	0.225%	0.350%	0.475%	0.600%	
9	Scope of effects	5%	0.100%	0.225%	0.350%	0.475%	0.600%	
10	Project scope regarding design focus	10%	0.200%	0.450%	0.700%	0.950%	1.200%	
11	Level of novelty	5%	0.100%	0.225%	0.350%	0.475%	0.600%	
12	Number of design constraints	5%	0.100%	0.225%	0.350%	0.475%	0.600%	
13	Project uncertainty	10%	0.200%	0.450%	0.700%	0.950%	1.200%	
14	Product purpose directly fulfils Human Factors need	5%	0.100%	0.225%	0.350%	0.475%	0.600%	
15	Absence of conducive design organisation conditions	5%	0.100%	0.225%	0.350%	0.475%	0.600%	
<i>Maximum budget per severity:</i>			2.0%	4.5%	7.0%	9.5%	12.0%	

Table 8: Example for a HFI budget estimation based on risk factors.

Weight of influence factors:		Budget elements depending on factor severity					
		100%	Very Low	Low	Medium	High	Very High
1	Estimated cognitive complexity of operation	5%					✓ (0.600%)
2	Expected physical difficulty of operation	5%	✓ (0.100%)				
3	Mission critical operation	10%					✓ (1.200%)
4	Presence of health hazards	5%	✓ (0.100%)				
5	Expected operation under safety critical conditions	5%					✓ (0.600%)
6	Direct interaction scope	15%					✓ (1.800%)
7	Expected change of manpower and skill levels	5%		✓ (0.225%)			
8	Extent of HF problems in predecessor systems	5%		✓ (0.225%)			
9	Scope of effects	5%			✓ (0.350%)		
10	Project scope regarding design focus	10%			✓ (0.700%)		
11	Level of novelty	5%					✓ (0.600%)
12	Number of design constraints	5%					✓ (0.600%)
13	Project uncertainty	10%					✓ (1.200%)
14	Product purpose directly fulfils Human Factors need	5%	✓ (0.100%)				
15	Absence of conducive design organisation conditions	5%					✓ (0.600%)
<i>Maximum budget per severity:</i>			2.0%	4.5%	7.0%	9.5%	12.0%

The method suggested in **Table D1** has been derived modifying an approach suggested by an FAA study (Kopardekar & Hewitt 2002). The underlying metrics draw on experience values. They have been derived as follows:

- The maximum HFI proportion of project cost has been assumed as 12%. The contribution added by each factor is a breakdown (by weight) based on this total.
- The minimum has been assumed as 2% – based on a fairly even distribution across the five severity rating levels (i.e. 2%; 4.5%; 7%; 9.5%; 12.0%).
- 12% as maximum HFI budget may be a fairly high figure – however, it cannot be assumed that only totalling all risk factors leads to the highest amount – hence the typically assumed maximum of 10% was slightly increased.
- This is assuming a typical medium to large, multi-disciplinary, engineering-based project. The weightings, and the assumed budget maximum and minimum, may need to be adjusted as needed.

REFERENCES

- Bruseberg A (2006) Presenting the Value of Human Factors Integration – Guidance, Arguments and Evidence. Cognition, Technology and Work. In press.
- HFI DTC (2006) Cost Arguments and Evidence for Human Factors Integration. Issue 1. Produced by Systems Engineering & Assessment Ltd. on behalf of the Human Factors Integration Defence Technology Centre for the UK MoD.
- Kopardekar P & Hewitt G (2002) Human Factors Program Cost Estimation – Potential Approaches. A Concept Paper. March 23, 2002. Available from the FAA Human Factors website.
- MoD (2001) Human Factors Integration (HFI): Practical Guidance for IPTs. <http://www.aof.mod.uk/content/docs/hfiweb/data/current/HFI%20Guidance2.pdf>.

ACRONYMS

CADMID	Concept, Assessment, Demonstration, Manufacture, In-Service, Disposal
EHFA	Early Human Factors Analysis
HCI	Human-Computer Interaction
HF	Human Factors
HFI	Human Factors Integration
HFI DTC	Human Factors Integration Defence Technology Centre
HFIP	Human Factors Integration Plan
HMI	Human Machine Interface
MoD	Ministry of Defence

Appendix C Proposed Quick Sheet/Flyer

DEFINITION

The Human Factors Integration Cost-Benefit Analysis (HFI CBA) guidance provides methodological aids for how to make the cost case for HFI for a specific project or programme, based on a risk analysis. Its aim is to achieve a pro-active approach based on a sound analysis of needs at the early project stages, to avoid reactive situations with late damage control. It also provides methods that help ensure that the right activities are conducted in the right areas, with the right amount of effort. They help in specifying suitable HFI efforts in relation to problem potential, and in generating data to support the planning and justifying of HFI activities as part of projects or programmes. A full version of the guidance can be found in an HFI DTC report (HFI DTC 2008) including detailed techniques and resources. A reduced version is available as an overview guide in the report.

WHO IS THIS GUIDE FOR?

This guide is aimed at any stakeholder concerned with having to make judgements about how much project budget should be spent on HFI (and how), based on predicting the potential concrete cost benefits of such activities as opposed to none. These include but are not limited to: HFI Foci; IPT Leaders; Project Engineers.

WHEN DO I NEED TO CONDUCT HFI CBA?

The HFI CBA is first applied at the conception of projects or programmes and then revisited and refined as the project progresses and uncertainty decreases. The analysis approach required differs depending on the project stage – due to varying levels of uncertainty for cost predictions. Three levels of detail are distinguished here:

1. *Initial justification of HFI* (e.g. **early concept phase, and pre-concept**): Making the business case for investing in HFI at the inception of a programme of work, for justifying fundamental HFI activities when there is a high level of uncertainty. This is largely drawing on generic insights about HFI benefits.
2. *Justification of HFI effort for specific risk areas* (e.g. **during concept phase**): Further specifying risk and value factors and initial allocation of HF effort to HFI plans. This concerns early project stages when uncertainty is still high but gradually being reduced.
3. *Detailed planning and option selection* (e.g. **assessment and subsequent phases**), based on informed assessments of contributory factors. This is specifying efforts for detailed HFI requirements, for an ongoing mapping of resources to needs. This applies throughout the project at increasing levels of detail⁹.

WHY IS HFI CBA IMPORTANT TO ME?

It is increasingly accepted that HFI is critical to ensure that system performance is safe, effective, and efficient. However, HFI is often considered a costly process. The cost benefits of HFI are frequently perceived as intangible. The potential losses due to not applying HFI are rarely assessed early enough for adequate consideration in budget allocations. The financial value of HFI through cost savings is often poorly understood. An assumption can be made that every project that is affecting humans in some way will develop a certain number of HFI issues that need to be identified and mitigated. Without an HFI CBA this is guesswork.

HFI CBA provides help for how to estimate costs both for potential problems and for HFI mitigation activities. It supports the cost-justification of HFI, in order to define and demonstrate its benefits in financial terms. It identifies how HFI can affect overall project costs, in relation to the efforts that need to be spent to achieve cost reductions.

CONDUCTING HFI CBA

The cost-benefit assessment methodology consists of the steps shown Figure 1. All of these steps need to be conducted – with varying depth and focus depending on circumstances. The process is initiated following the recognition that there may be a need for HFI involvement in the project. The process then establishes the extent and focus of HFI activities needed to mitigate potential risks. It may be necessary to iterate between the steps, and revisit some of them later, since they closely relate. Initially, the analysis may need to draw on some assumptions. Later, more detailed analyses need to be conducted to substantiate the plans. The steps are answering the following questions:

⁹ In terms of the CADMID lifecycle, 'Initial justification of HFI' may apply at the very beginning of the Concept Phase. 'Justification of HFI effort for specific risk areas' applies from the Concept Phase to early stages of the Assessment Phase. 'Detailed planning and option selection' may need to be addressed during all remaining phases.

For this project,

1. What are the aims, constraints, and priorities of the analysis, what will be the outputs, and for whom? (Step A)
2. What can go wrong without HFI, and what are the potential cost effects of the risks? (Step B)
3. Which HFI activities are needed to reduce the risks as far as possible, and how should HFI get involved? (Step C)
4. What are the costs for the required HFI activities? (Step D)
5. What if a full and optimal implementation of HFI activities needs to be traded off against other cost priorities? (Step E)
6. Which is the most suitable HFI implementation option based on a trade-off analysis, and how to present it best to decision makers? (Step F)

Step (A) - *Establish objectives*, captures the purpose and strategy for the argument to be made, and how it is to be presented. It is essential to be clear about the focus of the analysis, about specific project circumstances, and about applicable values and priorities. A checklist is provided that guides through the different areas of concern.

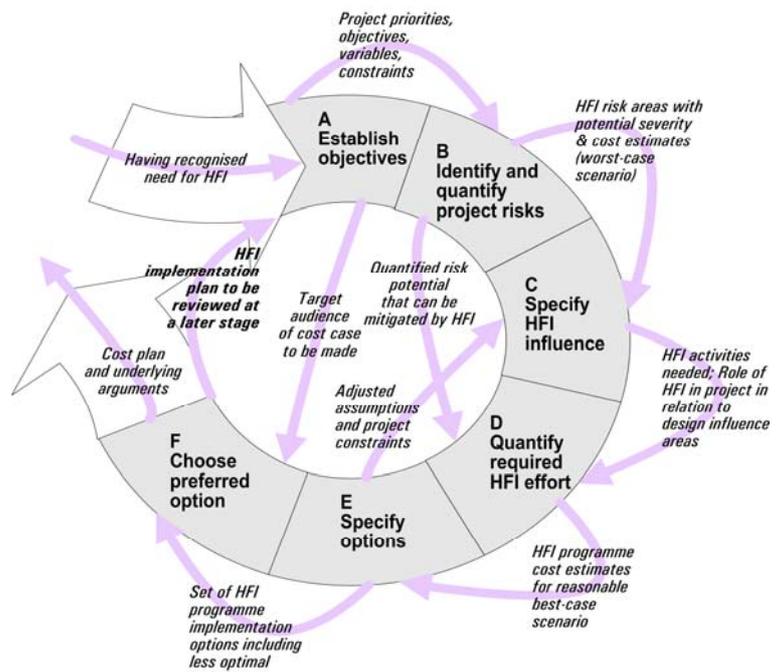


Figure 1. HFI Cost-Benefit Analysis process steps.

Step (B) - *Identify and quantify project risks*, looks at where problems could occur without sufficient HFI, and which cost impact they may have. This is specifying areas of concern for the worst-case scenario of no HFI implementation. The underlying question is: 'how badly could it go wrong?' A checklist is provided to help quantify the risk potential for early project stages. Relationships to cost are aided by a checklist detailing the types of cost that may be incurred. Simple metrics are provided such as predictions based on the number of users affected.

Step (C) - *Specify HFI influence*, looks at what HFI can do to prevent such costs. The roles that HFI may take vary with the type of project. To help specify the most suitable set of HFI activities, a generic set of HFI functions is discussed. The necessary HFI effort to be spent may be estimated as a percentage of the overall project budget.

Step (D) - *Quantify required HFI effort*, provides aids for estimating the actual cost of the HFI activities needed. This specifies a (reasonable) best-case scenario for risk mitigation where HFI budget constraints are minimal. Depending on the stage of the project, and the associated level of uncertainty, three different methods are suggested for how to assess the necessary HFI spending.

Step (E) - *Specify options*, discusses the variables and relationships that help determining HFI budget requirements to be proposed after considering external constraints. A set of less optimal options may need to be prepared besides the best-case scenario requiring the highest budget. It brings together all the steps.

Step (F) - *Choose preferred option*, compares and presents the options based on practical constraints and needs. Priorities and assumptions may need to be reviewed. This step involves a trade-off analysis. A final presentation and documentation of options and evidence is critical in influencing decision-makers as intended.

When moving from one stage to another in the course of the project, the results of the top-level approach can feed into the next stage, including ongoing reviews and updates (e.g. calculations, plans). Since projects vary with size and budget, it needs to be noted that the level of depth and scrutiny allocated for the cost-benefit analysis may vary.

SOURCE DOCUMENTS

Bruseberg (2008) Cost-Benefit Analysis for Human Factors Integration: A Practical Guide. Unpublished HFI DTC report to UK MoD, Reference number: HFI DTC/WP 2.7.2.

OTHER QUICK GUIDES OF INTEREST

Human Views for MODAF
HFI Trade-off Analysis
The HFI Case

References

1. Bias RG & Mayhew DJ, eds. (1994) Cost-Justifying Usability. Harcourt Brace & Co., Boston.
2. Booher R & Minninger J (2003) Human Systems Integration in Army System Acquisition. In: Booher R: Handbook of Human Systems Integration. Wiley-Interscience.
3. Bralla JG (1996) Design for excellence, New York: McGraw-Hill.
4. Bruseberg A (2006) Presenting the Value of Human Factors Integration – Guidance, Arguments and Evidence. Cognition, Technology and Work. In press.
5. Bruseberg A & Linsell M (2006) Cost-Justifying HFI (WP 3.7.2): A comprehensive approach to provide evidence and guidance. Unpublished HFI DTC report to UK MoD, Reference number: HFI DTC/WP 3.7.2/1.
6. Chao LP & Ishii K (2004) Design Process Error-Proofing: Challenges And Methods In Quantifying Design Elements. Proc. of the 10th ISSAT International Conference on Reliability and Quality in Design, Las Vegas, Nevada, USA. <http://mml.stanford.edu/publications/2004/ISSATquantify-C04-24.pdf>.
7. Def Stan 00-25 (2004) Human Factors for Designers of Equipment.
8. DoD Medical Case Management Working Group (2004) White Paper, April 2004, http://www.ergoworkinggroup.org/ewgweb/SubPages/ProgramTools/Accomidations/FinalMCMWhitePaper8Apr04_for_Members.pdf.
9. Erwin SI (2002) Navy Aviation Mishaps Cost \$4.3 Billion Over Five Years. National Defence: NDIA's Business and Technology Magazine. October 2002. http://www.nationaldefensemagazine.org/issues/2002/Oct/Navy_Aviation_Mishaps.htm.
10. Eurocontrol (1999) Human Factors Module A Business Case for Human Factors Investment. Report No. HUM.ET1.ST13.4000-REP-02. [http://www.eurocontrol.int/humanfactors/gallery/content/public/docs/DELIVERABLES/HF17%20\(HUM.ET1.ST13.4000-REP-02\)%20Released.pdf](http://www.eurocontrol.int/humanfactors/gallery/content/public/docs/DELIVERABLES/HF17%20(HUM.ET1.ST13.4000-REP-02)%20Released.pdf).
11. Eurocontrol (2000) Human Factors Integration in Future ATM Systems - Identification of Tasks and Development Scenarios. [http://www.eurocontrol.int/humanfactors/gallery/content/public/docs/DELIVERABLES/HF23%20\(HRS-HSP-003-REP-03\)%20Released.pdf](http://www.eurocontrol.int/humanfactors/gallery/content/public/docs/DELIVERABLES/HF23%20(HRS-HSP-003-REP-03)%20Released.pdf).
12. FAA (1999) Operational Concept Validation Process. Report by the National Airspace System Advanced Concepts Branch of the FAA. www.nas-architecture.faa.gov/nas5/Reference/Documents/OCVP.PDF.
13. Fujita K & Nishikawa T (2001) Value-Adds Assessment Method For Product Deployment Across Life Stages Through Quality Function Deployment. Proc. of International Conference On Engineering Design Iced 01 Glasgow, August 21-23, 2001, pp 405-412. http://syd.mech.eng.osaka-u.ac.jp/papers/2001/08_ICED01.pdf.

14. Gawron VJ, Dennison TW & Biferno MA (1996) Mockups, Physical and Electronic Human Models, and Simulations. In: O'Brien, T. G, Charlatan, S. G. (Eds.) Handbook of Human Factors Testing and Evaluation. Lawrence Erlbaum Associates, Publishers, Mahwah, New Jersey.
15. Hewitt G (2003) Human Factors Assessments in Investment Analysis: Definition and Process Summary for Cost, Risk, and Benefit. January 28, 2003, Ver 1.0. Federal Aviation Administration, Human Factors Research and Engineering Division, AAR-100.
16. HFI DTC (2006) Cost Arguments and Evidence for Human Factors Integration. Issue 1. Produced by Systems Engineering & Assessment Ltd. on behalf of the Human Factors Integration Defence Technology Centre for the UK MoD.
17. House of Commons (1993) Session 1992-93, Defence Committee Third Report – The SA80 Rifle and Light Support Weapon. Report, together with the Proceedings of the Committee relating to the Report. Minutes of Evidence and Memoranda, 9 June 1993. The Stationery Office Books, ISBN 0100209831.
18. Hutchison G, Maddock-Davies K, Mock M & Newman P (2006) HFI DTC: Improving HFI in Design Trade-offs. Unpublished HFI DTC report to UK MoD Reference number: HFIDTC/WP 3.7.7/1.
19. ISO13407 (1999) Human-centred design processes for interactive systems.
20. Karat C (1990) Cost benefit analysis of usability engineering techniques. Proceedings of the Human Factors Society. Orlando. FL.
21. Kirwan B (2003) An overview of a nuclear reprocessing plant Human Factors programme, Applied Ergonomics, 34(5):441-452.
22. Kopardekar P & Hewitt G (2002) Human Factors Program Cost Estimation – Potential Approaches. A Concept Paper. March 23, 2002. Available from the FAA Human Factors website.
23. Landauer TK (1995) Usefulness and Usability. In Landauer TK: The trouble with computers. The MIT Press, Cambridge, MA, pp 141-168.
24. Leonard B & Maddock-Davies K (2008) Impact of Emerging Technology on Humans – Review of Current Human Factors Technology Insertion Guidance and Advice. HFIDTC/IETH/4, V.1, 01 April 2008.
25. Lintern G & Naikar N (2000) The Use of Work Domain Analysis for the Design of Training Systems. In: Proceedings of the XIVth Triennial Congress of the International Ergonomics Association and 44th Human Factors and Ergonomics Society Annual Meeting. (Volume 1, pp. 198-201). Santa Monica, CA: Human Factors and Ergonomics Society.
26. Milk K (2001) “Cost Analysis Data Collection And Research - Final Report”, Unpublished Report by HVF Consulting Services Ltd to MoD UK, Ref: FG/54/010 Issue 1.
27. MoD (2001) Human Factors Integration (HFI): Practical Guidance for IPTs. <http://www.aof.mod.uk/content/docs/hfiweb/data/current/HFI%20Guidance2.pdf>.
28. MoD (2006a) MAP-01-010 HFI Management Guide (formerly STGP 10), Issue 4, Nov 2006, Sea Systems Group, MoD. <http://www.aof.mod.uk/content/docs/hfi/map-01-010.pdf>.

29. MoD (2006b) MAP-01-011 HFI Management Guide (formerly STGP 11), Issue 4, Nov 2006, Sea Systems Group, MoD. <http://www.aof.mod.uk/content/docs/hfi/map-01-011.pdf>.
30. Naikar N & Saunders A (2002) Crossing the boundaries of safe operation: Training for error detection and error recovery. Proceedings of the 21st European Conference on Human Decision Making and Control, 8-15.
31. 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.
32. Nielsen J (1994) Guerrilla HCI: Using Discount Usability Engineering to Penetrate the Intimidation Barrier. ” http://www.useit.com/papers/guerrilla_hci.html.
33. Nielsen J (1998) Cost of User Testing a Website. Jakob Nielsen's Alertbox for May 3, 1998, <http://www.useit.com/alertbox/980503.html>.
34. Public Accounts Committee (2000) Minutes of Evidence, Wednesday 8 March 2000 <http://www.publications.parliament.uk/pa/cm199900/cmselect/cmpubacc/319/0030801.htm>.
35. Treasury Board of Canada Secretariat (1998) An Enhanced Framework for the Management of Information Technology Projects: Creating and Using a Business Case for Information Technology Projects. http://www.tbs-sct.gc.ca/emf-cag/business-rentabilisation/cubcitp-euarpti/cubcitp-euarpti00_e.asp.
36. Vicente K (1999) Cognitive Work Analysis. Toward safe, productive, and healthy computer-based work. Mahwah, NJ: Erlbaum.
37. Wiklund ME (2005) Return on Investment in Human Factors. Medical Device & Diagnostic Industry 27, no. 8 (2005): 48–55. <http://www.devicelink.com/mddi/archive/05/08/021.html>.

Acronyms

ATC	Air Traffic Control
CADMID	Concept, Assessment, Demonstration, Manufacture, In-Service, Disposal
CWA	Cognitive Work Analysis
DoD	Department of Defense
EHFA	Early Human Factors Analysis
FAA	Federal Aviation Administration
HCI	Human-Computer Interaction
HF	Human Factors
HFI	Human Factors Integration
HFI DTC	Human Factors Integration Defence Technology Centre
HFIP	Human Factors Integration Plan
HMI	Human Machine Interface
MoD	Ministry of Defence
NEC	Network Enabled Capability
QFD	Quality Function Deployment
ROI	Return on Investment
SA	Situational Awareness
SRD	System Requirements Document
TRL	Technology Readiness Level
UAV	Unmanned Air Vehicle
UI	User Interface
URD	User Requirements Document
WDA	Work Domain Analysis

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