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Literature review: Barriers to the application of Ergonomics/Human Factors in engineering design

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Literature review: Barriers to the application of Ergonomics/Human Factors in engineering design

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The purpose of this literature review was to identify barriers to the use of Ergonomics/Human Factors (E/HF) information and principles in engineering design.

Financial considerations, particularly the business strategy of a firm, can lead to managers being unwilling to spend money on using E/HF information, especially if they judge that there will be little financial benefit.

Organisational constraints such as a fixed timetable for bringing a product to market can prevent the use of E/HF in its design.

In most design projects, tasks are dispersed across a range of specialists and organisational units. Design compromises must be negotiated between individuals and teams with different goals, and E/HF considerations may be seen as less important than some other factors.

Personal factors are important to the use of E/HF, particularly commitment from individual senior managers who perceive its value.

Lack of **specific E/HF knowledge** among many designers and design engineers means they may fail to identify when E/HF could benefit the products they design. Also, they may not be aware of how to access specialist advice.

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EXECUTIVE SUMMARY

Objectives

To carry out a literature review to identify factors that act as barriers to the use of Ergonomics/Human Factors (E/HF) information and principles in engineering design.

Main Findings

A number of factors act as barriers to the use of E/HF in design processes. These can be summarised as financial, organisational, personal and knowledge-based.

Financial considerations and pressures within a firm, particularly its business strategy, can lead to it being unwilling to spend money on using E/HF information, especially if managers judge that there will be marginal or no financial benefit.

Organisational constraints such as a requirement to bring a product to market in a fixed time scale can prevent the use of E/HF in its design.

The need in most design projects to disperse tasks across a range of specialists and organisational units creates a situation in which compromises must be negotiated between individuals and teams with different goals, and E/HF considerations may be seen as less important than some others.

Personal factors are important to the use of E/HF, particularly commitment from individual senior managers who perceive its value to the business.

Lack of **specific E/HF knowledge** among many designers and design engineers means they may be unable to identify when E/HF could benefit the products they design. They may also be unaware of how to access specialist advice if it is not immediately available to them.

1. INTRODUCTION

This literature review was commissioned by HSE as part of an inter-linked series of research projects aimed at understanding the human factors issues associated with the operation and use of Mobile Elevating Work Platforms (MEWPs) in the UK. The findings of the previous projects (Leah *et al.,* 2013; Daws *et al.,* 2014; Jones and Bates, 2013) indicated that MEWP design may not have always taken account of some human factors and ergonomics design principles. HSE recognised that this is a much wider problem potentially relevant to the design and manufacture of most plant and machinery that has a person-control system interface. HSE recognised that it was important to gain an understanding of the practical challenges that engineering designers and manufacturers face when integrating human factors and ergonomics principles in the design of plant and machinery.

The purpose of this work was therefore to review published literature to identify the barriers which can prevent the effective integration of Ergonomics / Human Factors information and principles in engineering design in general. It was anticipated that the research findings could be used to assist equipment manufacturers to improve the design of equipment and to reduce the risks of accidents to its users.

2. METHODS

A series of searches was carried out on the *Ergonomics Abstracts On-Line* (EAOL) database in an attempt to identify relevant scientific literature that addressed the issue of why equipment designers fail to take account of Ergonomics / Human Factors (E/HF) considerations and design principles when bringing products to market. In other words, the desire was to identify the barriers that result in designers not using ergonomics.

The Ergonomics Abstracts On-Line database is a specialised bibliographic database that includes citations and abstracts of scientific publications that relate to the field of Ergonomics. It contains material from 1966 to the present day. It includes articles from peer-reviewed scientific journals such as *Applied Ergonomics*, and from national and international scientific conferences such as the *International Ergonomics Association* (IEA) triennial congresses.

The basic search strategy used the following combinations of keywords:

- Ergonomics AND barriers
- Human factors AND barriers
- Human Factors Integration
- MANPRINT

The final two sets of keywords were used because, over a number of years, there has been an emphasis in military procurement on "Human Factors Integration" (HFI). This followed an earlier military programme known as "MANPRINT". Both of these programmes were designed to improve the consideration of Human Factors in the design and procurement of complex military systems and hardware, ranging from the small scale such as communication equipment, to large scale fighting platforms such as warships.

The searches returned over 500 different references. These were exported from the EAOL database and imported into a Reference Manager database to facilitate searching and citation of the references. The abstracts were read and references that appeared to be relevant were identified. This resulted in over 80 references being identified at this stage for further consideration.

The budget for the project had been calculated on the basis that up to 30 references would be reviewed in detail. It was therefore necessary to prioritise the identified references in order to select the most valuable items for detailed review. Journal articles were treated as of greater worth than papers from conference proceedings. More recent articles were prioritised over older articles. Ease of retrieval was also a consideration. It was considered that as the number of references retrieved increased, the amount of new information or insights gained would decrease due to overlap between papers.

Full articles were then retrieved, with copies being downloaded from *Science Direct* or similar services that HSE has subscriptions to, or copied from paper issues of journals held at HSL. Articles from the *Contemporary Ergonomics* series were copied from paper copies of these conference proceedings held at HSL. Other articles were requested via the Inter-Library Loan system. Articles acquired in this way arrived as PDFs from the British Library. In addition, 16 articles were identified as of interest that had been published in the *Proceedings of the International Symposium on Design Process & Human Factors Integration* that was held in Nice, France in March 2006. The full Proceedings were obtained on CD-ROM.

Reading the retrieved papers led to further papers that they cited being identified as relevant, but an age limit of 30 years was applied, as themes from very old papers are likely to be quoted in the more recent papers. Retrieval of these papers increased the total number of potentially relevant papers to 92. Partly as a result of obtaining a large number of conference papers from the Proceedings of the Nice symposium, the final number of papers reviewed came to 45. Full citations of the reviewed papers are given in the reference list at the end of the report.

Reading the retrieved papers showed that some were not actually relevant to the question being addressed. Where the paper was relevant, appropriate information was extracted to "evidence tables", presented later in this report. Where a paper was not relevant, this was also noted in the evidence tables. Separate evidence tables were created for journal articles and conference proceedings, with the articles being listed from the most recent to the earlier. For each type of publication, the retrieved papers were categorised by their relevance to "design" in a broad usage, and to ergonomics. A brief description of the nature of the work reported in the paper was added to the table. The country of origin was also listed.

For each type of publication, a further table was created that summarised two things in the relevant papers:

- The barriers identified that discourage the use of ergonomics in design;
- Factors that promote the use of ergonomics in design

3. RESULTS

The results of the extraction of relevant information from the retrieved articles are shown in Tables 1 to 4. Table 1 and Table 2 respectively list the peer-reviewed journal papers and conference papers used and indicate their relevance, the nature of each paper / study, and its country of origin. Table 3 and Table 4 summarise the relevant information found in each of the papers listed in Table 1 and Table 2 respectively. A number of papers are identified in Table 2 as not being relevant to the issue of barriers to the use of E/HF. These are omitted from Table 4. In these two tables, the findings are summarised as either 'Barriers' or 'Promoters' to illustrate the fact that the cited studies identified both negative and positive factors affecting the use of E/HF.

It is clear from these tables that the financial and commercial factors are the most important barriers to the application of E/HF in design processes. Particularly important is the finding that marketing strategies for major companies involve targeting their primary products to the middle of the market, leaving smaller companies to target any speciality application markets (Vanderheiden and Tobias, 2000). Also, organisations that use a "late to market" strategy spend less on research and development and specialist knowledge acquisition but focus instead on reducing product design and production costs. Therefore, they are less likely to use ergonomics capabilities (Slappendel, 1994). These constitute elemental reasons why a manufacturer may not be interested in using ergonomics in designing their products. Company structures and market strategies can be very persistent over time and often shift radically only when the organisation undergoes major change in ownership and/or leadership (Slappendel, 1994).

Organisational and inter-personal factors are also very relevant, but may not be so effective in overcoming barriers. Two positive promoters that were found to have permanent effects on companies' willingness to consider human issues were the need to fulfil regulations that require this, and high profitability of specific products (Vanderheiden and Tobias, 2000). Other factors, such as the desire to be seen as good citizens, endorsement by senior management, specific knowledge and the activities of individuals championing an E/HF approach could have positive influences, but changes in products, people or company initiatives can easily result in these positive effects disappearing (Vanderheiden and Tobias, 2000).

A specific organisational barrier that has been repeatedly identified in the literature is related to the lack of adequate planning and time to incorporate ergonomics considerations into the design.

Also important is the lack of understanding of the ergonomics issues among the engineers designing the product. This is often coupled with a lack of specific data applicable to their particular design problems. It is also often linked to a lack of influence of E/HF specialists, even when they were present.

The nature of the design process is also important. The actual approach taken will depend on the object being designed and the complexity of the problems that must be solved to create it. In almost all designs, compromises will be made between the required and designed features of the final product in order to satisfy competing demands from different design domains and commercial constraints. In many firms, new designs will be modifications of existing designs, which makes it very difficult to make fundamental changes to accommodate E/HF concerns.

For all but the simplest designs, and in all but the smallest companies, designing an object, putting it into production and successfully marketing it, involves negotiation between individuals. Often, different individuals work on different technical aspects of the detailed

design. Some of these individuals will usually not need to consider the role of the user so are likely to have limited awareness of E/HF issues.

The design and production process is not simple and at many stages is not a rational problem solving process. Therefore, irrational behaviour and conflicts of interest are major ingredients that will affect the conditions for integrating ergonomics into design (Broberg, 1997).

Probably the key inter-personal factor is the commitment of the appropriate managers to the use of ergonomics in design. Depending on the organisational structure, this may be senior managers or more local managers.

The requirement to conform to complex safety and product regulations and their detailed provisions can often result in engineering constraints that make ergonomic solutions to design problems more difficult. These constraints may limit the range of options available to designers and may therefore exclude the use of preferred E/HF solutions. Also, designers may require significant background knowledge to be able to make use of E/HF standards.

Systematic attempts such as MANPRINT and HFI to integrate ergonomics considerations into the processes of design and procurement for military equipment have had some success. Their use is being extended into other large-scale organisations, particularly safety critical industries such as oil and gas (Cullen, 2007) and railways (Lucas and Dickinson, 2006). HFI in the military domain benefits from purchasing being dominated by a small number of large organisations that can act as "intelligent customers" and require that their specifications are met. In smaller specialist industries with larger numbers of customers, the customers may assume that the manufacturers will provide equipment that meets all necessary E/HF requirements. This may result in situations where these requirements are neglected due to lack of expertise of both the manufacturers and customers.

4. EVIDENCE TABLES

Table 1 Evidence tables: peer-reviewed journal articles

Citation	*Relevant to design?*	*Relevant to E/HF?*	*Nature of paper / study*	*Country of origin*	*Notes*
Martin *et al.* (2012)	Yes	Yes	Case studies from the medical devices field showing how ergonomics can lead to better and more competitive products	UK	
Chung and Shorrock (2011)	Indirect	Yes	Questionnaire study of application of research by practitioners	Australia	Good recent overview
Neumann *et al.* (2009)	Yes	Yes	Longitudinal action research case study seeking to help company develop its own ability to deal with ergonomics issues in their regular work	Canada, Sweden, Denmark	
Newman *et al.* (2008)	Yes – military system design	Yes	Summary of work on HFI; interviews and workshops on barriers to HFI	UK	
Entzel *et al.* (2007)	Limited – attempt to spread "best practice" in construction	Yes	Qualitative analysis of group discussions of interventions available in construction to reduce the risk of musculoskeletal disorders	USA	Peripheral relevance due to focus on construction industry
De la Garza and Fadier (2005)	Yes – equipment / plant	Yes	Cognitive analysis of safety integration methods at the design phase	France	Identifies differences between different types of designers and engineers
Anema *et al.* (2003)	No	Yes	Pilot study for an randomised controlled trial on the effectiveness of a multidisciplinary (including Participatory Ergonomics) disability management programme for low back pain on return-to-work	Netherlands	Secondary outcome measures included obstacles for implementation of the ergonomics intervention. Not particularly useful due to focus on Participatory Ergonomics and Return To Work interventions
Jensen (2002)	No	Yes	Literature review / discussion of issues affecting integration of ergonomics into planning of new production	Denmark	Low originality Recommends a focus on the organisational context

Citation	*Relevant to design?*	*Relevant to E/HF?*	*Nature of paper / study*	*Country of origin*	*Notes*
			processes		
Burns and Vicente (2000)	Yes	Yes	Participant-observation over four months in the design of a control room for a nuclear power plant	Canada	Concluded that ergonomic guidance needs to be richer than laboratory results or guidelines
Kirwan (2000)	Yes	Yes	Personal perspective	UK	
Broberg (1997)	Yes – product development process	Yes	Cross-sectional case study; interviews and questionnaire study	Denmark	Differences between design engineers and production engineers
Haslegrave and Holmes (1994)	Yes – vehicle ergonomics	Yes	Report of impact of Teaching Company Scheme at Leyland DAF	UK	
Slappendel (1994)	Yes – product design	Yes	Comparative case study of six manufacturing organisations, qualitative analysis	New Zealand	
Wilson and Norris (1993)	Yes	Yes	Case study of development of ChildData	UK	Source for barriers is Wilson (1984)
Mossink (1990)	Yes – process automation design	Yes	Case studies: Interviews, document analysis, participant observation	Netherlands	
Berns (1984)	Yes – product and systems design	Yes	Narrative	Sweden	
Meister (1982)	Yes	Yes	Narrative	USA	

Table 2 Evidence tables: Conference papers

Citation	*Relevant to design?*	*Relevant to E/HF?*	*Nature of paper / study*	*Country of origin*	*Notes*
Brunier *et al.* (2012)	Yes	Yes	Report of two-week "cross-disciplinary problem-solving workshops" (CPWs) involving engineers, architects and ergonomists	France	English is poor, so hard to understand. Not relevant to issue of barriers to use of E/HF
Olsen (2012)	No	No	Semi-structured interviews with ten Occupational Health and Safety practitioners	New Zealand	Not relevant to issue of barriers to use of E/HF
Vogel (2012)	No	Yes	Semi-structured interviews of supervisors of meat cutters	Sweden	Not relevant to issue of barriers to use of E/HF
Ala-Laurinaho and Launis (2006)	Yes	Yes	Description of development of a company-specific "human consideration handbook and toolbox"	Finland	Same project as Launis and Ala-Laurinaho (2006)
Chauvin *et al.* (2006)	Yes	Yes	Case studies of attempts to provide ergonomics advice to ship builders	France	
Fontaine *et al.* (2006)	Yes	No	Description of a design methodology for specifying industrial buildings	France	Not relevant to issue of barriers to use of E/HF
Goodman *et al.* (2006)	Yes – inclusive design for older and disabled users	Yes	Survey of awareness of inclusive design among 87 UK companies in design, manufacturing and retail	UK	
Huelke *et al.* (2006)	Yes	Yes	Describes a checklist for the testing and certification of ergonomic machinery design	Germany	
Lamonde and Richard (2006)	Yes	Yes	Case study of the influence of an ergonomist on occupational health and safety considerations in the design of an aluminium smelting plant	Canada	
Launis and Ala-Laurinaho (2006)	Yes	Yes	Description of the design process and tools used in a project to introduce human-focused design into a sawmill company	Finland	Same project as Ala-Laurinaho and Launis (2006). Not relevant to issue of barriers to use of E/HF
Nachreiner (2006)	Yes	Yes	Overview of ISO Human Factors standards and their	Germany	

Citation	*Relevant to design?*	*Relevant to E/HF?*	*Nature of paper / study*	*Country of origin*	*Notes*
			application		
Paques and Gauthier (2006)	Yes	No	Description of on-going projects on methods for assessing risks associated with hazardous industrial machinery	Canada	Not relevant to issue of barriers to use of E/HF
Paz Barroso (2006)	No	Yes	Assessment of occurrence of rule violations as a measure or safety culture / safety performance	Portugal	Not relevant to issue of barriers to use of E/HF
Titus (2006)	Yes	No	Discussion of the way machine safety has moved from being an afterthought to an integral part of a machine design	USA	Not relevant to issue of barriers to use of E/HF
Tytyk (2006)	Yes	Yes	General discussion of how E/HF can be integrated into the design process	Poland	Minimal discussion of barriers to use of E/HF
Vomberg and Lambert (2006)	No	Yes	Description of a search tool for accessing ergonomics standards	Germany	Not relevant to issue of barriers to use of E/HF
Von der Weth *et al.* (2006)	Yes	Yes	Summary of two studies about methods and tools for human oriented design	Germany	Not relevant to issue of barriers to use of E/HF
Weill-Fassina *et al.* (2006)	Yes	Yes	Description of a project to produce a guide to integrating E/HF in railway operation	France	Not relevant to issue of barriers to use of E/HF
Wichtl (2006)	Yes	Yes	Discussion of requirements for ergonomic design of office workplaces	Austria	Not relevant to issue of barriers to use of E/HF
Zink and Eberhard (2006)	Yes	Yes	Discussion of integration of E/HF into lifecycle oriented product management	Germany	
Carr (2005)	Yes – design of very large systems	Yes	Discussion of use of task analysis to identify areas of system activity where E/HF are of critical importance	UK	
Gregson and Gait (2004)	Yes	Yes	Discussion of features of ergonomics guidance that hinder their application	UK	
Storer and McDonagh (2002)	Yes	Yes	Small scale survey of perceptions of 'User-Centred Design' among product designers	UK	
Elder *et al.* (2001)	Yes – Engineering design in the	Yes	Description of HFI process being implemented in a petro-chemical firm	UK	

Citation	*Relevant to design?*	*Relevant to E/HF?*	*Nature of paper / study*	*Country of origin*	*Notes*
	petro-chemical industry				
Vanderheiden and Tobias (2000)	Yes	Yes	Interviews about "universal design" with middle managers in a range of companies providing consumer products and services	USA	This is a later report from the same study as Vanderheiden and Tobias (1998).
Vanderheiden and Tobias (1998)	Yes	Yes	Interviews about "universal design" with individuals in posts representing Human Factors (or other internal organisational descriptions) from 22 firms in a variety of sectors	USA	

Table 3 Barriers and promoters identified in journal papers

Citation	*Barriers or promoters identified*
Martin *et al.* (2012)	***Promoters*** • Demonstrated value of performing user research early in the development process.
Chung and Shorrock (2011)	***Barriers*** • Lack of relevance of research papers to practitioners' concerns. • Studies seen as 'relevant' tend to lack scientific merit. • The need to control laboratory studies reduces their applicability. • The "translation problem" – a lack of information on the implications of research for practice. • High volumes of research mask the useful information. Specific issues regarding research studies: • Difficulty of obtaining journal articles; • Low applicability of the studies; • Limited generalisability of the studies; • Lack of time for designers to read and apply research; • Lack of awareness by designers of the existence of research work; • Methodological inadequacy of the work. There is a gap between Human Factors Engineering (HFE) research (person centred) and HFE application (equipment centred) due to conceptual control by psychology. • Historic tension between HFE practitioners and engineers/managers.
Neumann *et al.* (2009)	***Barriers*** • Large investments of resource are difficult to reverse. • Consideration of ergonomics issues is often late or inappropriate. • Personnel changes – key leaders transferring to new roles or undergoing life changes. • Design time-lines may be too tight to include process improvements. • Creation of new 'ergonomics' structures did not manage to anchor ergonomics into daily practice – these groups wound down quickly when key members left. • There was a systemic barrier due to the company lacking a means to modify or develop its own design processes while meeting on-going daily demands. • Dispersed influence with no one person in control of ergonomics in production system design.
Newman *et al.* (2008)	***Barriers*** HFI is a well-established concept in military acquisition, but is not yet fully accepted in practice. Some methods and tools developed to address barriers to the application of the HFI process are: • Desktop Support Tool (DST); • Human Factors Impact Tracking Tool (HFITT); • COTS ("Commercial off-the shelf") Integration Tool; • Reusable Synthetic Environment (SE) for HFI.
Entzel *et al.* (2007)	***Barriers*** Interventions requiring large capital investments are beyond the reach of smaller companies. Industry stakeholders are resistant to interventions that they consider likely to cause:

Citation	*Barriers or promoters identified*
	• Decreased worker productivity; • Reduced job quality; • Frequent/costly maintenance; • New hazards; • Dramatic change to a job; Some technologies and work practices are impractical on many worksites due to: • Design issues; • Supply problems; • Jobsite conditions; • Management practices; • Designers/specifiers lacking awareness of E/HF issues and possible solutions.
De la Garza and Fadier (2005)	***Barriers*** • Designers lack the tools to help them consider E/HF in design; • Design integration of ergonomics is not included in initial representations because these issues do not feature as initial objectives in specifications; • Safety is not viewed as a real design objective; • Designers possess a mental representation that is neither complete nor relevant to user needs or to industrial equipment uses.
Anema *et al.* (2003)	***Barriers*** • Difficult to make work adjustments; • Physical disabilities of the worker; • Physical workload; • Employer's financial situation.
Jensen (2002)	***Barriers*** Citing Perrow (1983): The organisational context limits the E/HF specialists' influence and restricts their perspective due to: • Top management not emphasizing ergonomics in goals and perspectives; • The reward structure excluding performance in ergonomics; • Designers not being presented with the consequences of their decisions; • A contrasting logic for design and operation on what characterizes good design. In this context, E/HF specialists: • Are a small group; • Have insufficient formal influence; • Have no control of strategic resources; • Lack early information about opportunities and threats due to weak networks; • Have a professional approach that is unfamiliar to designers.
Burns and Vicente (2000)	***Barriers*** • Contextual constraints – constraints that arise directly from the design problem and specification and the user population. • Constraints of parsing and distribution due to the need to divide projects into subtasks. These subtasks constrain and impact each other – a design decision made in one sub-problem can cascade through, creating constraints in other design problems that were not there when the project began. • Constraints from other domains – designers must also satisfy constraints from other design domains; each design domain has a unique view of the design

Citation	*Barriers or promoters identified*
	problem and will search for a solution that is consistent with this view.
Kirwan (2000)	***Barriers*** • Ergonomists overpromising and being vague as to actual changes to be implemented. • Most companies do not have a hunger to use ergonomics. • Many companies have had poor experiences in the past ("suffered indigestion") from encounters with E/HF. • "… the beginning practitioner … in many cases … will find that the engineers, designers, trainers, operators and managers, actually, one way or another, have engineered a pretty good system and that E/HF techniques may find it hard to find vulnerabilities." • "If the project is a new and ambitious one, and if it relies on human performance, then there will be a far greater tolerance for consideration of new approaches to dealing with such challenges, in contrast to a project which is simply the next of a series for which 'traditional' methods have previously been shown to suffice." • "the larger and longer the project, the more opportunity for implementing ergonomics functions".
Broberg (1997)	***Barriers*** • Customers do not demand ergonomic products • Lack of ergonomics knowledge • Lack of time • Ergonomics specification need to be included in the product requirements document • Product development is a very complex undertaking involving many actors. • Integrating ergonomics into design is more complex than deciding at which stages ergonomic criteria are to be presented to the designers. • The design process involves negotiation between individuals, so is not a simple and rational problem solving process. Irrational behaviour and conflicts of interest are major ingredients that will affect the conditions for integrating ergonomics. • Design engineers less willing than production engineers to participate in ergonomics training at work. ***Promoters*** • For both design and production engineers the dialogue with other people in the company is the most important tool in their work. • Engineers need more ergonomists in their internal communication networks instead of being provided with ergonomics guidelines in databases or written form. • Tools are less important than training in ergonomics and the establishment of new communication patterns. • Specification of ergonomics criteria in product requirement and process specification documents. • Clarification of who has responsibility for ergonomics and the establishment of procedures of how to solve ergonomics problems. • Taking the ideas and experience of operators and supervisors and returning them to design and production engineers.
Haslegrave and Holmes (1994)	***Barriers*** • The lack of basic ergonomics guidelines that can be applied directly to design

Citation	*Barriers or promoters identified*
	problems; • Complexity of regulations and their detailed provisions can often result in engineering constraints that make ergonomic solutions more difficult; • Ergonomists are often involved in modifying existing designs or solutions; • Lack of a common language between engineers and ergonomists. • Lack of engineering and product knowledge among ergonomists; • The need for an ergonomist to have an overview of the whole design throughout the design process; • Cost as a major factor influencing design decisions; • Failure of thorough documentation of ergonomics recommendations and their reasons; • Failure to communicate ideas enthusiastically and forcefully; • Failure to communicate in visual ways. ***Essentials for an atmosphere of collaboration between ergonomists and designers:*** • Reduction in the fear of engineering technicalities among non-engineers; • Education of engineers in ergonomics; • Good communication channels and permanent records of requests for advice and responses to them; • Involvement of ergonomists at the earliest possible stage of the design process; • Willingness by ergonomists to look for multiple solutions and accept sub-optimal solutions.
Slappendel (1994)	***Barriers*** • Reliance on of low-expertise design strategies such as copying / reverse engineering competitors' products; • Use of consultant industrial designers / ergonomists only at restricted stages of the design process preventing them applying an ergonomics approach early in the project or leading to ergonomic features being compromised or dropped altogether. • Organisations that use a "late to market" strategy spend less on R&D and specialist knowledge acquisition but focus on reducing product design and production costs. Therefore, they are less likely to use ergonomics capabilities. • Lack of economic demand can reduce use of ergonomics specialists. • Company structures and market strategies can be very persistent over time and often shift radically only when the organisation undergoes major change in ownership and/or leadership. ***Promoters - five positive elements identified:*** • Ergonomics capability; • Staffing routines – decisions were made to employ industrial designers, that also happened to have skills in product ergonomics; • Top management orientation – in some cases the emergence of an ergonomics capability followed directly from a major change in ownership; • Organisational configuration – ergonomics capabilities emerged at earlier dates in organisations with owner-managers instead of 'professional' managers; • External environment.
Wilson and Norris (1993)	***Barriers*** • Lack of perceived need for knowledge – need to overcome scepticism and ignorance; • Insufficient knowledge content – need to make hard to access data more easily

Citation	*Barriers or promoters identified*
	available; • Poor data quality – need to assure quality of data provided.
Mossink (1990)	***Barriers*** • Organisational, especially fixed project budgets; • Lack of knowledge of ergonomics; • Focus on objects, databases and information, not on tasks and processes; • Failure to use specified methodology; • Perceived lack of added value of use of ergonomics principles; • Lack of clarity of where ergonomics knowledge and skill need to be allocated. Designers often choose one solution to work out and are then reluctant to acquire new information and incorporate it in the design, especially when it does not fit the preferred solution. ***Promoters*** • Skill and expertise in ergonomics; • Positive attitude towards E/HF; • Commitment of top management.
Berns (1984)	***Barriers*** • "Unfortunately, the ergonomist's enthusiasm has not rubbed off on many outside the profession." • The majority of designers, engineers and management are still unconvinced of the benefits of using E/HF. ***Promoters*** • Interest and belief in ergonomics varies even within development teams; • Training / educating engineers, designers and marketing people in ergonomics. ***7 point summary for integrating ergonomics into product development*** (1) Ergonomics should, ideally, be included within the decision-making process. (2) It is never too early or too late to include ergonomics. (3) The ergonomist must be flexible in his working approach. (4) Simulations are often needed. (5) Continuous contact between the ergonomist and development team should be maintained. (6) Awareness of ergonomics should be high in all sections of the organisation. (7) There is a need for ergonomics specialists.
Meister (1982)	***Barriers - Organisational*** • Attitudes of designers and managers towards behavioural considerations and E/HF in particular. Most have a somewhat negative attitude. This makes it very difficult to secure adequate consideration of human engineering inputs. • Funding of E/HF efforts during system development. In many projects, the E/HF effort is underfunded, in part because of these engineering attitudes, especially when budgets are under pressure. • Excessive autonomy of project managers. This is especially so in government funded projects, resulting in project management attitudes similar to those of design engineers not being challenged. • Failure by customers to monitor the human engineering effort being put into projects. In situations where explicit requirements have been included in a specification, this can result in only lip service being paid to E/HF goals. • Absence of quantitative personnel performance requirements in system

Citation	*Barriers or promoters identified*
	specifications. System designers tend only to respond to quantitative specifications. ***Barriers - Technical*** • Inadequate techniques to answer behavioural questions arising in system development. Designers therefore tend to lack confidence in recommendations based on these techniques. • Inability to translate research concepts, methods and data into operationally usable techniques. • Difficulty in demonstrating the value of the human engineering effort in system development.

Table 4 Barriers and promoters identified in conference papers

Citation	*Barriers or promoters identified*
Ala-Laurinaho and Launis (2006)	***Barriers*** • Technical experts and project managers involved in decision making on technical projects lack knowledge and understanding of E/HF. • The collaborative working that is needed to integrate E/HF into investments in an industry is very demanding. • Time resources for development tasks are marginal in many companies.
Chauvin *et al.* (2006)	***Barriers*** • The lack of a safety culture in the fishing industry. • Difficult to get the different 'actors' involved in the design project to work together. • The different groups could not react quickly enough to influence design changes made by the shipyard. • In the maritime sector, "safety" is seen primarily as the safety of the vessel. • There is no financial advantage to preventing occupational injuries. • The profitability of the enterprise (a fishing vessel) is not related to the quality of the working conditions of the crew. • The request for assistance came after the basic design of the new vessel had already been fixed so the scope for change was limited. • The shipyard did not work from formal plans or specifications so it was very difficult to influence them. • The ergonomics input was provided free so the recipients did not value it as highly as they would have valued advice they were paying for. • Design and construction of the vessels are usually delegated to the shipyard by the owner. • The members of the crew (the end users) are usually not consulted during the design phase.
Goodman *et al.* (2006)	***Barriers*** • Low levels of awareness of inclusive design • Lack of time and budget to support inclusive design; • Lack of knowledge and tools to practice inclusive design; • Perception that end users did not perceive a need for inclusive design;
Huelke *et al.* (2006)	***Barriers*** • The available information on ergonomics can be difficult to access. • It is difficult to establish a hierarchy of ergonomic measures due to the lack of reliable data on the causal relationships between ergonomics factors and accidents. • Many ergonomic factors can only be evaluated in the context of actual machine operation, taking account of work organisation and workstation conditions. • Making design changes to a machine as a result of ergonomics assessments is likely to be expensive. ***Promoters*** • There is a wide range of directives and standards on ergonomics. • Medium-term ergonomic revision of machine design can be implemented both efficiently and effectively. • Custom-built machines can be modified for each new order.
Lamonde and	***Barriers***

Citation	*Barriers or promoters identified*
Richard (2006)	• The project process expected the designers to carry out critical reviews and then decide whether to involve the ergonomists specialists, which led to them limiting their use of specialists. • If ergonomics specialists simplify their work to help non-specialists, the non-specialists fail to understand the complexity of the work of the specialists. ***Promoters*** • Use of accident data and ergonomic studies in similar plants to influence the general specifications for the plant. • Integration of ergonomics into project planning. • Use of a monitoring system to ensure that necessary changes were implemented. • Participation in operations pilot groups to influence the detailed engineering design.
Nachreiner (2006)	***Barriers*** • Design of work systems is often considered to be a mainly technical problem, with consideration of human operators relegated to the end of the design process. • Designers often lack education in E/HF and are therefore unfamiliar with ergonomics principles. • Human operators in systems can be viewed as a nuisance that would ideally be replaced by automation. • Existing provisions for ergonomics in ISO standards have not been adequately implemented in the design of work systems.
Zink and Eberhard (2006)	***Barriers*** • Ergonomics approaches are seen as solely cost causing and related to legal guidelines. • Ergonomically designed products are not seen as competitive in a market with excess production capacity. • Full lifecycle costs are often not considered. • Time pressures in product development cycles make it difficult to create ergonomic designs.
Carr (2005)	***Barriers*** • Lack of understanding of ergonomics; • Lack of concern about ergonomics; ***Promoters*** • 'Dissemination of basic information on the value of ergonomics and its role within the project can work wonders in "raising the consciousness" of the development team.'
Gregson and Gait (2004)	***Barriers*** • Generic guidance can be difficult to translate into practical design decisions; • It is necessary to know the status of any guidance used and whether compliance with it is essential (regulations or standards) or voluntary (textbooks, etc.). • Trade-offs have to be made between ergonomics compliance, running to program and basic economics. • It can be difficult to define the precise benefits of ergonomics compliance in economics terms, so compliance is reduced. • Some guidance documents are cumbersome to use. • Some guidance documents are poorly structured. • Some guidance can be overly restrictive.

Citation	*Barriers or promoters identified*
	• Guidance can be inappropriate in circumstances the author did not envisage.
Storer and McDonagh (2002)	***Barriers*** • Limited resources – companies do not perceive the value of User Centred Design as outweighing its costs; • Lack of shared language between users, designers and stakeholders.
Elder *et al.* (2001)	***Promoters*** Creation of a set of procedures explicitly linking HFI activities and techniques to the goals of the various stages of the engineering design process. Key elements are: • Human Factors Integration Plan; • Existence of 'Ergonomics Champions' for each project; • Use of an HFI Issues Register to manage the implementation of results from HFI studies.
Vanderheiden and Tobias (2000)	***Barriers*** • Universal Design is perceived as relating to people with disabilities. • Marketing strategies for major companies involve targeting their primary products to the middle of the market, leaving smaller companies to target any speciality application markets. ***Promoters*** Only two factors have permanent effects: • Regulation; • High profitability of specific lines; Over time, initially positive effects due to the following are lost as products, people and initiatives come and go: • Good citizenship initiatives; • Endorsement from high in the organisation; • Knowledge; • Championing an idea.
Vanderheiden and Tobias (1998)	***Barriers - fears*** • Fear of being sued by disability rights groups whose expectations have not been met; • Fear that Universal Design (UD) means that a product must be usable by everyone; • Concern over cost of implementing UD; • Concern that implementing UD will delay product launches. ***Barriers – inadequate training or resources*** • Lack of appropriate knowledge; • Lack of time to learn how to implement UD; ***Barriers – lack of interest*** • Perception that UD equals design for disability; • Perception that the cost of product changes will outweigh financial benefits. ***Barriers - structural*** • Product development is not controlled from the centre of the organisation so dissemination of UD is difficult; • Product development is centralised and the process cannot be modified; • The company is so large or diverse that adopting UD is too complex; • The company has too few resources to adopt UD.

Citation	*Barriers or promoters identified*
	Promoters – marketing and management
	• Belief that UD will increase the company's market;
	• Belief that UD can be cost-effective;
	• Belief that UD can benefit non-disabled /"ordinary" customers;
	• Knowledge that competitors are using UD;
	• Support for UD from senior management;
	• Internal champions for UD within middle to upper management;
	• Requests from large customers for products incorporating UD.
	Promoters – product designers and E/HF resources
	• Knowledge of how UD can be applied to actual products;
	• Regulations requiring improved usability and accessibility;
	• Appropriate internal resource to facilitate the practice of UD;
	• Product testing involving a diverse range of subjects;
	• Policies and procedures requiring the adoption of UD;
	• Inclusion of success with UD within personnel evaluations of designers.

5. DISCUSSION / CONCLUSIONS

The purpose of this review was to help identify the barriers that might lead to engineering designers failing to use the available resources from the Ergonomics / Human Factors discipline to help them produce devices that take into account the capabilities, needs and limitations of likely operators of their products.

A significant body of literature was found that addressed the question of barriers to the use of E/HF information by engineering designers / design engineers. These can be summarised as financial, organisational, personal and knowledge-based.

Financial considerations and pressures within a firm, particularly its business strategy, can lead to it being unwilling to spend money on using E/HF information, especially if managers judge that there will be marginal or no financial benefit.

Organisational constraints such as a requirement to bring a product to market in a fixed time scale can prevent the use of E/HF in its design.

The need in most design projects to disperse tasks across a range of specialists and organisational units creates a situation in which compromises must be negotiated between individuals and teams with different goals, and E/HF considerations may be seen as less important than some others.

Personal factors are important to the use of E/HF, particularly commitment from individual senior managers who perceive its value to the business.

Lack of **specific E/HF knowledge** among many designers and design engineers means they may be unable to identify when E/HF could benefit the products they design. They may also be unaware of how to access specialist advice if it is not immediately available to them.

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Literature review: Barriers to the application of Ergonomics/Human Factors in engineering design

The purpose of this literature review was to identify barriers to the use of Ergonomics/Human Factors (E/HF) information and principles in engineering design.

Financial considerations, particularly the business strategy of a firm, can lead to managers being unwilling to spend money on using E/HF information, especially if they judge that there will be little financial benefit.

Organisational constraints such as a fixed timetable for bringing a product to market can prevent the use of E/HF in its design.

In most design projects, tasks are dispersed across a range of specialists and organisational units. Design compromises must be negotiated between individuals and teams with different goals, and E/HF considerations may be seen as less important than some other factors.

Personal factors are important to the use of E/HF, particularly commitment from individual senior managers who perceive its value.

Lack of **specific E/HF knowledge** among many designers and design engineers means they may fail to identify when E/HF could benefit the products they design. Also, they may not be aware of how to access specialist advice.

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