Ergonomics action research II: a framework for integrating HF into work system design

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This paper presents a conceptual framework that can support efforts to integrate human factors (HF) into the work system design process, where improved and cost-effective application of HF is possible. The framework advocates strategies of broad stakeholder participation, linking of performance and health goals, and process focussed change tools that can help practitioners engage in improvements to embed HF into a firm's work system design process. Recommended tools include business process mapping of the design process, implementing design criteria, using cognitive mapping to connect to managers' strategic goals, tactical use of training and adopting virtual HF (VHF) tools to support the integration effort. Consistent with organisational change research, the framework provides guidance but does not suggest a strict set of steps. This allows more adaptability for the practitioner who must navigate within a particular organisational context to secure support for embedding HF into the design process for improved operator wellbeing and system performance.

Practitioner Summary: There has been little scientific literature about how a practitioner might integrate HF into a company's work system design process. This paper proposes a framework for this effort by presenting a coherent conceptual framework, process tools, design tools and procedural advice that can be adapted for a target organisation.

Keywords: organisational development; work system design; ergonomics intervention; proactive ergonomics; participatory macroergonomics; meta-ergonomics

1. Introduction

The aim of this paper is to outline a conceptual framework and practical basis for an approach to integrating human factors (HF) considerations into the process of designing work systems. The initial context for this discussion will be manufacturing industries. The current proposition is to take a 'design' perspective towards identifying specific design process improvement initiatives – a re-designing of the design system to eliminate health hazards at source.

1.1. The challenge of applying human factors

Despite decades of ergonomics research on the causes of musculoskeletal disorders (MSDs) (e.g. de Beeck and Hermans 2000, Hoogendoorn et al. 2000, National Research Council 2001, Buckle and Devereaux 2002), MSDs remain the single most expensive category of work-related ill health (WIH) problems (Leigh et al. 1997, Wells 2009), continuing to pose difficulties for afflicted individuals (Pransky et al. 2000), their employers (Oxenburgh et al. 2004) and society in general (Leigh et al. 1997, WHO 1999, Leigh 2011). Recent experiences with ‘participatory ergonomics’ (PE) interventions in industrialised nations have shown rather limited success (Rivilis et al. 2008, Cole et al. 2009). The problem of mixed results from studies of the application of HF principles in workplaces has been noted in several reviews (Volinn 1999, Karsh et al. 2001, Neumann et al. 2010). Cole et al. (2009) in reviewing mixed results from a series of PE interventions discussed two possible contributors as being: 'program deficits' (flaws in the execution of an intervention) and ‘theory deficits’ (flaws in the intervention concept). One theory deficit identified included the inability of PE teams to make substantial changes to the design of already implemented, capital-intensive production systems.

1.2. WIH problems come from the development processes

In order to discuss the proposed integration approach, the authors draw on a model of work systems development, shown in Figure 1 for the example case of manufacturing. This model illustrates how WIH problems are the
consequence of a chain of decisions made at each development level, including corporate strategies, choice of new services or products, product/process design, the design of the work system itself and related work organisation choices, and finally the ‘realised’ implementation of these designs in which employees work. In this production example, the work system (or operations system) includes all aspects of the manufacturing process including division of labour, material supply and logistics systems, in-plant conveyance system and buffering capacities, processes and procedures for assembly, equipment, management policies and layout of the physical system (Neumann et al. 2006, Heizer and Render 2007, Carayon 2009). If this development process is flawed, then poor working conditions may result, contributing to MSD risk for employees. Problems in production can have their roots in product design as shown, for example, by Sundin et al. (2004) where awkward bending and reaches in assembly may be created by the design of the frame of a bus chassis (Sundin et al. 2004). Further issues may emerge in production system design due, for example, to materials supply, such as the choice of large crates that increase spinal loading for operators (Neumann and Medbo 2010). Similarly, the psychosocial conditions for operators may be affected by the layout of the system, permitting (or not) interactions between workers and the division of labour into highly (or not) repetitive work (Kihlberg et al. 2005). Outcomes of concern may include skill, competency and WIH for operators and performance and quality results for the system (Neumann and Dul 2010). These outcomes will, in turn, determine if a company’s strategic goals (at the top of the model in Figure 1) are met (Dul and Neumann 2009). Viewed dynamically, there is an ongoing interaction between the design of the work system, the physical and psychological working conditions for operators and the subsequent system performance. This model has been illustratively validated in case studies demonstrating how the cascading chain of decisions in work system design can lead to WIH in employees in the electronics (Neumann et al. 2002) and automotive sectors (Neumann and Winkel 2006, Neumann et al. 2006, Palmerud et al. 2012). For further analysis of the linkage between strategic level choices regarding a rationalisation approach and distal WIH outcomes, see the systematic review of Westgaard and Winkel (2011) and the example case of Jonker et al. (2011). This model of work systems development poses the ‘frame’ of the conceptual framework of this paper. The intent is to help practitioners find ways to integrate HF into each stage of development so that proactive ergonomics is part of the regular routines for the organisation. This would effectively move the organisation from a reactive situation shown on the left hand situation in Figure 1 to a more integrated development process as illustrated on the right hand side.

1.3. **There is a need to integrate HF into design**

Design science (e.g. Hubka and Eder 1996) informs us that the most cost-effective controls are those applied early in the development process, while the design is malleable, ‘exposure latitude’ (c.f. Mathiassen and Winkel 1997) is
highest, and costs of change are lowest (Buur and Andreasen 1989, Alexander 1998, Miles and Swift 1998). Neumann et al. (2010), reviewing the effectiveness of ‘work environment’ interventions (WEIs) concluded that there is a need for ‘multifactorial WEIs that: (a) are owned by and aimed at the whole organisation; and (b) include intervention in early design stages where potential impact is highest.’ (from abstract). Most ergonomics intervention research, however, appears to aim at retrofitting processes and making changes to existing work systems (Westgaard and Winkel 1997, Denis et al. 2008). Furthermore, interview studies of ergonomists’ practice reveal a focus on issues at the level of the workstation (Whysall et al. 2004), and not at the system level where issues relating to critical time patterns of work are made (Wells et al. 2007). Many researchers have called for the integration of human factors considerations into the work system design process (Graves 1992, Haslegrave and Holmes 1994, Kragt 1995, Imai et al. 2002, Jensen 2002, Neumann et al. 2002, de Looze et al. 2003, Gervais 2003), and this was a central theme of the ‘sociotechnical’ movement which provided principles (Cherns 1976) and many examples of work system redesign that improved both working conditions and system performance (Eijnatten et al. 1993, Griffith and Dougherty 2002, Ryan et al. 2011). Despite the work of the sociotechnical movement, this approach remains uncommon in practice. Similarly in the research domain, the observed gap between human focussed and engineering-managerial focussed research and development remains, arguably, the norm (Jensen 2002, Boudreau et al. 2003, Neumann and Dul 2010). Special efforts are, therefore, required if we are to understand how knowledge on human considerations are to be successfully integrated into work system design (Buckle 2010, Chung and Shorrock 2011) which has led to calls for new alternative investigation techniques such as ‘Action Research’ (AR) (Neumann et al. 2012).

Applying HF late in the development process, makes meaningful change difficult since budgets have already been allocated and most decisions are already locked in (Perrow 1983, Helander 1999, Burns and Vicente 2000, Skepper et al. 2000, Imbeau et al. 2001, Baines and Kay 2002, Imai et al. 2002, Jensen 2002, Neumann et al. 2002, Broberg 2007, Sinclair 2007). From an organisational perspective, there is a tradition of positioning ergonomists within the occupational health and safety (OHS) function in the organisation. This has been referred to by some as the ‘OHS side-car’ because of its effect of isolating ergonomics considerations from the main line of the organisation (per Figure 1 left side). This can result in a ‘too little, too late’ application of ergonomics (e.g. Frick 1994, Helander 1999, Jensen 2001, 2002, Hasle and Jensen 2006). Intervention at the final stage of existing systems will be slow and costly. We suggest that better results can be achieved if HF principles are applied throughout the design process. This implies a need for organisations to make changes in their development processes to apply HF proactively.

1.4. Intervention needed at the organisational level

Integrating HF into the development process will require engagement at the organisational level. This is similar to a ‘macroergonomics’ (MEs) approach that recognises the need to address organisational issues to solve ergonomics problems (Kleiner 1999, Hendrick and Kleiner 2001, Kleiner 2006, Imada and Carayon 2008). At the risk of posing a straw man argument, the authors suggest that the difference in the current proposed approach and the ME school is one of perspective. While both recognise a need for organisational level attention, the ME writings appear to be aimed at a particular designer with authority to steer the process of a particular system design following, for example, application of the macroergonomic analysis of structure (MAS) and macroergonomic analysis and design (MEAD) methods (Hendrick and Kleiner 2001, Kleiner 2006). In contrast, the current proposal aims at improving the entire development process (per Figure 1) – which ultimately leads to improvements in the final work system design. In this approach, multiple levels of the organisation develop a sustainable capability to exploit the benefits available from early application of HF principles – the aim is at organisational design capability by many, not just an individual-based design solution. The proposed approach is consistent with calls for multi-factorial, organisational level interventions (Neumann et al. 2010), which avoid the limits of simple ‘point changes’. Bateman and Rich (2003) have stated: ‘“Point Changes” without sufficient infrastructure to support improvements, at the business level, are unlikely to yield real and sustainable change.’, a position echoed by management scientists (Bamford and Forrester 2003). Achieving such changes in the context of ergonomics, however, requires the participation of a wide range of stakeholders in the organisation (Neumann et al. 1999, 2009, Ekman Philips 2002, Vink et al. 2008).

1.5. The challenge: engaging stakeholders

One tactic for engaging stakeholders in the effort to integrate HF into a company's development processes is the linking of the human and performance objectives in a tactic referred to as ‘goal hooking’ (Poggi 2005).
The argument is that it will be easier to engage others in attending to HF issues if they understand it can contribute to their own agenda and strategic objectives (Dul and Neumann 2009). Despite the IEA’s definition of ‘ergonomics’ (and synonymously HF) as serving both human and system objectives (IEA Council 2000), it has been suggested that ergonomics ‘is still often viewed by management as a means to prevent injuries, while providing no return on investment. This mentality serves to hide the potential for ergonomics … to improve labour efficiency and reduce the cost of production’ (Jenkins and Rickards 2001, p. 243).

A systematic review of ergonomics applications with both human and system effects found that, at the operational level, HF application is associated with improvements in quality, productivity, implementation performance of new technologies, and also more ‘intangible’ affects in terms of improved flexibility, communication and co-operation (Neumann and Dul 2010). This is consistent with studies demonstrating economic benefits from the application of HF (Oxenburgh and Marlow 2005, Goggins et al. 2008, Tompa et al. 2008), the ‘ME’ movement (Hendrick 1996, Kleiner 2006, Hendrick 2008), studies of large-scale change projects such as the massive Swedish National Working Life Fund Program (Gustavsen et al. 1996) and broad reviews examining the ‘convergence of working life and competitiveness’ (Huzzard 2003).

1.5.1. Baiting the Hook – the HF20-20 challenge
In order to engage stakeholders in applying HF in their stages of design we propose to ‘hook’ their performance goals to the HF agenda (Poggi 2005). To do this, we suggest to ‘bait the hook’ by explicitly posing the following challenge: The ‘HF 20-20’ challenge is to integrate HF into the regular production system design process with the aim of improving both human and system outcomes by 20%. The magnitude of this improvement is in-line with gains observed in other studies (Gustavsen et al. 1996, Van Rhijn et al. 2005, Vink et al. 2006, Goggins et al. 2008, Hendrick 2008) and poses a challenging yet realistic objective that is of interest to a broad range of stakeholders in the organisation. The framing of this challenge also subtly shifts HF from being a goal, to being a tool by which a number of goals might be achieved, a strategy suggested by Dul and Neumann (2009).

1.6. Customise new processes
While a number of ‘HF process’ models from large companies have been published (Hägg 2003), it is not clear how these models might be customised and implemented in a particular company. If we look in to the quality field for example, we find that the mere adoption of an ISO9000 process has little correlation with quality performance until the ideas behind these programs are ‘fit’ to the company (van der Wiele et al. 2000) over a period of time (Taylor and Wright 2003). This is consistent with the published reports on ‘model’ corporate ergonomics processes that appear to be the result of years of effort by the company (Kilduff 1998, Joseph 2003, Moreau 2003, Munck-Ulfsfält et al. 2003, Smyth 2003, Törnström et al. 2008). There is a need to anchor HF processes into the organisation so that underlying principles can be incorporated fully, rather than superficially with just the forms filled out as suggested by Taylor and Wright (2003) for quality processes. With this rationale, we pursue the development of HF capability inside the organisation that is meaningful for the individuals involved, is applied in daily practice and is integrated within organisational structures, or creates new structures if necessary (Gustavsen et al. 1996, Toulmin and Gustavsen 1996). Rather than dictate a particular process ‘blueprint’, we offer instead a framework for change and an array, or smorgasbord, of methodological options that can support the emerging processes. The company personnel, who must live with the results, will need to make the critical choices with regards to how the change process will proceed in ways that make sense to them. Thus, this model for an initiative to integrate HF into design draws on the disciplines of organisational learning (Senge 1990, Siemieniuch and Sinclair 2002, Hasle and Jensen 2006) and organisational change management (Urlings et al. 1990, Mitki et al. 1997, Pettigrew et al. 2001, Holden et al. 2008, Zink et al. 2008), both of which provide specific advice on how the proposed initiative model should be implemented. This paper will focus more on the ‘targets’ of action in the initiative than specific change and project management issues, such as ‘maintaining active top management support’ that must also be attended to if the initiative is to be realised (for this see Holden et al. 2008, Zink et al. 2008).

2. Pragmatic approach to integration initiatives
Shifting to the more pragmatic aspects of the HF integration approach, we propose potential initiatives aimed at each level of the development model (Figure 2). We avoid presenting a simple, deterministic N-Step process approach as these have been shown to work poorly due to variability in social contexts (Collins 1998). Instead, we
recommend a ‘design’ stance in which the practitioner begins pragmatically with elements that have company support, while working to gain support for other elements as they proceed. Thus, top-down, bottom-up or middle-out approaches are all possible depending on circumstances. The following conceptual approaches are presented in a top-down sequence and are intended to provide ideas and possibilities to inspire action without proposing to be a definitive guide or set of sequential steps. The authors welcome methodological diversity and creative approaches to addressing the needs of the particular organisation. In this sense, the current framework is intended to be ‘open’ to a diverse set of approaches based on the underlying systems needs that the frame helps identify. The aim is to eventually reach all elements of the development process in Figure 2 in order to secure meaningful attention to HF issues throughout for improved well-being and performance.

2.1. Cognitive mapping of HF and management strategy

Theoretical work has established extensive connections between HF and business strategies (Dul and Neumann 2009). Similarly, research on organisational change strongly suggests that to be successful and accepted, initiatives must be seen as aligned with overall strategic objectives and goals (Zink et al. 2008). Few studies provide tools or techniques for obtaining and sustaining senior management commitment to HF change. One potential method currently being developed for helping senior management understand the link between HF and their strategic goals is cognitive mapping (Village et al. 2012). Cognitive mapping is a tool used in operations research and business management to determine strategic goals, facilitate decision making and solve complex problems, such as software development overruns (Swan 1997). In this approach, individual interviews are conducted with senior management using an open-ended question, such as ‘How does integrating human factors into your design processes help achieve your companies’ strategic goals?’ Responses are written on a large paper as concept nodes, and nodes are linked by directional arrows (for example, ‘reduce worker fatigue’ may have a directional arrow that leads to another concept such as ‘reduced errors’). Strategic goals are placed at the top of the page, sub-goals in the middle and action items that lead to sub-goals at the bottom. A 1-h interview can yield 60–120 concepts in a single map, which would represent the equivalent of a 20 page interview (Daley 2004). The process of seeing the concepts helps individuals make links they, otherwise, may not have described in an interview. Individual maps can be merged into group maps which then reveal the management ‘thinking’ or ‘cognition’ (Eden 1988). Using a workshop approach can allow individuals to see their concepts linked to those of others, which leads to seeing and talking about HF issues in new
and different ways. This leads to learning about how HF can link to the managers’ strategies. The outcome of the mapping tool is threefold: (i) management gains an increased understanding of the alignment of HF with their strategies; (ii) the ergonomist or practitioner will gain an understanding of how to support their managers’ objectives; and (iii) group maps help management teams negotiate a consensus and commitment to a portfolio of actions (Village et al. 2012).

2.2. Process mapping

Since the developmental objective is to integrate HF into the design process (DP), then it would be useful to understand how the design process is organised in the target organisation. While HF researchers have mapped the design process onto systems-theoretical frameworks (Burns and Vicente 2000), these theory-based approaches can be difficult for company stakeholders to understand and act on. Similarly, examination of how HF logically connects to design processes (Jensen 2002), does not necessarily reflect the current state of the process in ways that are understood by design team members. Applying ‘business process mapping’ (Hunt and Hunt 1996) to the design process provides one means to make the design process explicit (Lim et al. 2009). In this process, information from different stakeholders is gathered and integrated into a ‘map’ to illustrate the various design stages and critical decisions throughout the design process. Such maps are typically created as graphical representations based on information gathered from interviews with key personnel in the process. While the optimal approach for design process mapping remains a research issue, it could include information such as critical decisions, formal and informal check points, feedback loops and information input, as well as zones of stakeholder involvement (Lim et al. 2009, Neumann et al. 2009). For ergonomists who are frequently excluded from the design process, this mapping approach can help them understand the people and processes involved during design, aiding in navigation of the organisation during their efforts at change (Broberg and Hermund 2004).

Similarly to the cognitive map, the resulting design process map constitutes a ‘boundary’ object that can help foster a focussed discussion, among the cross functional design team, of where critical HF decisions are being made and how HF might be better integrated in the process (Balogun et al. 2005, Broberg et al. 2011). This approach can help improve the teams’ thinking about HF aspects in two stages: first, from the discussions during the creation of the DP map and second, during the ‘application’ of the map in a workshop. At the workshop, the aim would be to identify specific initiatives in a participative context. This ensures that those involved in implementing new ideas are involved in formulating the initiative in ways that they can understand and act on. Those applying this technique should be prepared to follow-up on the ‘action items’ that can emerge from the workshop (Lim 2011).

2.3. Workshops

In this framework, workshops are used to foster decision making based on the knowledge gained in any one initiative. Depending on the local context, these could be framed as ‘workshops’, ‘planning meetings’, ‘management kaizen events’ or other similar events as are most suitable for the particular audience. Workshops serve as learning opportunities for both employees and managers and can stimulate a range of HF development efforts within the firm (Neumann et al. 2009). Workshops and dialogue conferences that allow parties to speak across conventional organisational boundaries are seen to be a powerful stimulus of organisational change (Ekman Philips 1990, 2002, Wilhelmsson 1998, Jensen 2002, Ekman Philips and Huzzard 2007). These events allow the sharing of new information and can provide learning opportunities about HF. They also provide a forum in which stakeholders can voice their views and together determine new avenues or goals for further development. This approach is consistent with ‘participatory’ ergonomics (Brown 1986, Noro and Imada 1991, Kogi 1995, Kuorinka and Patry 1995, Haines et al. 2002, Vink et al. 2006), but instead of the creation of specific ‘ergonomics committees’ involving workers in design processes, it involves the designers and management stakeholders directly (Zink et al. 2008). Since isolated ‘ergonomics committee’ structures have been observed to collapse in the face of normal organisational dynamics (Neumann et al. 2009), we suggest this approach may be more sustainable. The workshop event should be structured to generate specific actionable plans for improvement. Those who are to act on these decisions should be included in the event. Previous studies have found that delays in action can occur if senior managers do not participate in such events (Neumann et al. 2009, Lim 2011). Delays can also occur if the team is not prepared to act on the range of improvement items that can emerge from such events (Neumann et al. 2009) suggesting it is important to set the stage for implementing improvement ideas before the workshop event.
2.4. Design criteria that integrates HF considerations

Criteria form the start point for any design project and establish the requirements which the final design must meet (Pahl and Beitz 1988). This applies to both the design of a product and of the operations system where front-line employees work. It can also be considered to start with Human Resource policies around employees and the plan for employee development in the organisation – what, for example, are the companies long-term plans for employee development? If HF considerations are not part of the initial design criteria then it is less likely that designers will attend specifically to HF in any formal way. Similarly, HF considerations are unlikely to spontaneously become part of the criteria by which designers evaluate their design options. While the ergonomics literature has not addressed this issue extensively, Helander and Nagamichi (1992; see also Helander 2006) incorporated HF principles into ‘Design for Manufacturability’ guidelines and they have been shown to greatly reduce both the time required to assemble products as well as the physical demands of the assembly. This dual win from attention to product design will help further the goals set by the ‘HF 20-20’ objective.

In general, designers find their work difficult enough without new constraints to fulfil. Wulf et al. (1999a, 1999b) conducted a qualitative study of the use of criteria in the design of off-shore oil platforms and found that the formulation of criteria in ways that are easily understood and applied was a critical feature in determining if designers would prioritise and apply HF criteria. Information overload was a problem for these designers (Wulf et al. 1999a, 1999b). Criteria that were phrased in quantitative ways, which could be unambiguously evaluated, were preferred to more qualitative and principle-based criteria. Case study research in the auto sector revealed that the presence of ‘corporate standards’ for HF was insufficient to have these necessarily applied in design processes (Neumann et al. 2006). Therefore, design criteria or standards need to have a routine for their application, be reinforced with technical support as needed, and have regular follow-up to ensure that the process and criteria have been appropriately met. One application may be to create a checklist based on the design criteria and use a routine process indicator (e.g. sign-off) to identify any design flaws before new work systems are made operational.

2.5. Failure mode effects analysis (FMEA)

‘Failure mode effects analysis’ (FMEA) is an industry standard technique for identifying potential quality issues in product design or assembly process design. Failure mode effects analysis (FMEA) is a systematic approach to examining each product or assembly component (or sub-system) to determine the severity, probability and detectability of a failure of that component. Once causes of failures are determined, actions for improving detection or reducing the severity or occurrence can be developed. Human factors FMEAs have been applied to system failures, such as the Space Shuttle Challenger disaster (Rong et al. 2008) and health care applications where operator error is concerned (for example, in providing medication in hospitals) (Fletcher 2002). However, few examples have been found where FMEAs have been applied to physical risk factors and prevention of musculoskeletal injuries (Barsky and Dutta 1997, Munck-Ulfsfäll 2004). Current work is underway to develop an approach to incorporating a HF-FMEA into quality FMEAs that achieve both improved product/process design, as well as optimal employee health in the stage of product and process design (per Figure 2) (Village et al. 2011).

2.6. Virtual HF tools in design

‘Virtual’ HF (VHF) tools can be useful throughout the design process – especially when there is no human or system to observe (Perez 2011). When the product is particularly large, such as buses or automobiles, then digital human models (Chaffin 2005) (DHMs) can be used to anticipate postural issues for operators or assembly line workers – particularly, when reach-fit and vision issues are a concern (Sundin 2001, Sundin et al. 2004). Digital human models (DHMs) with connections to computer aided design (CAD) permit virtual assessment of workstations before the station is built. Digital human models (DHMs) have been widely discussed in the ergonomics literature and will not be further reviewed here (Honglun et al. 2007, Chaffin 2008). There are, however, a number of other VHF tools which might be usefully applied in system design (Perez 2011). Human factors (HF) extensions to pre-determined time and motion systems (PMTS) such as methods time measurement (MTM) allow the consideration of workload aspects during the process of allocating tasks to workstations as occurs frequently for line balancing purposes (Laring et al. 2002, 2005). Discrete-event simulation (DES) is a time-based simulation approach which aims to track the dynamic changes in flow of materials within a system (Banks 2001). Discrete-event simulation (DES) allows convenient examination of the relative performance of alternative system configurations. While developed as a purely technical analysis tool, recent efforts have begun to integrate human aspects into DES (Baines et al. 2004, Kazmierczak et al. 2007, Neumann and Medbo 2009, Perez 2011, Dode 2012). This would allow the examination of
the effects of the system on the operators and vice versa. New simulation technologies, such as virtual reality testing, for example (de Looze et al. 2003), also carry potential to incorporate HF in the early stages of system planning. While some of these technologies have been available for many years, their uptake and application by industry appears to be relatively slow and often excludes HF considerations. Relevant research questions here surround how such technology could be implemented in ways that are useful for the design team to help them manage HF aspects in their design concepts.

2.7. Training and education
Training and education have been suggested as important aspects of any HF initiative (GAO 1997). Training and education can be done at the beginning of new initiatives, but may more usefully be built into multiple aspects of the initiative so that the new knowledge can be brought to use as the integration efforts proceed. There is a need to consider the timing, content and participants that should be involved in training for the specific HF integration initiative at hand. Training alone does not appear to provide much change for engineers (Broberg 2007) without supporting changes to routines that help bring the new knowledge into practice. It may, therefore, be desirable to tailor HF training to the new methods or process needs that are currently under development within the integration initiative. As new initiatives are launched, supplemental training could also be provided. For example, as a new HF-FMEA is developed and incorporated into a company, training for engineers specific to features of the HF-FMEA would be important for successful use of the new method.

2.8. Shop floor development work
While the emphasis in this framework is on integrating HF into development and design processes, the more conventional human factors retrofitting improvements should also continue to be pursued. Indeed, since mistakes or missed opportunities in design are likely to occur, some kind of retrofitting process is warranted. Efforts, here, might include kaizen-like or gemba-like efforts incorporating participatory ergonomics (PE), or a programmatic improvement approach using an ergonomics team, or a more expert-driven approach (Caccamise 1995; De Jong and Vink 2002, Sundin and Medbo 2003). For this, a wide range of tools are available to help quantify hazard levels and demonstrate improvements (David 2005, Dempsey et al. 2005, Neumann 2007, Takala et al. 2010). The choice of approach should be made based on the organisational context and the nature of risk factors at hand (e.g. office vs. heavy industry). This paper will not discuss the relative merits of these more conventional ergonomics improvement efforts. More germane to the current discussion on proactive ergonomics in the development process is the potential for lessons learned in shop floor improvements to be used as feedback to the rest of the development process. This might take the form of ‘lessons learned’ for product designers, revisions to design criteria, changes to processes and procedures or the adoption of new assessment techniques to prevent a reoccurrence of the identified design flaw. Employees might also be included in ‘workspace design’ workshops to explore scenarios and alternatives for the system using, for example, diagrams or models of the proposed system (Seim and Broberg 2010). The engagement of employees in development is also consistent with modern management techniques such as six sigma, which seek to systematically apply defined measures to provide feedback to help drive process improvement efforts (Cronemyr 2007).

3. Indicators and metrics
While many of the tools mentioned here provide metrics or indicators, a special discussion of this topic is warranted. The use of ‘metrics’ or indicators is often seen as a powerful tool to manage business improvement processes, such as quality. We have observed, however, that few companies have leading indicators of HF aspects as illustrated in Figure 3 (e.g. Neumann et al. 2002). Furthermore, if existing data, such as quality or injury data, are gathered in ways that cannot be re-connected to the various design stage decisions, then it is difficult to make the HF connection required for improvements. Cybernetic systems control theory (Smith 1999, Skyttner 2001), organisational change theory (Bateman and Rich 2003) and organisational learning theorists (Senge 1990) all emphasise the importance of feedback for reaching goals. As Figure 1 illustrates, feedback on HF tends to be limited for designers and strategic decision makers who: (i) are increasingly isolated from their system’s ‘HF’ consequences (Perrow, 1983) and (ii) may also lack knowledge and procedures for handling the HF implications of their work (Imbeau et al. 2001, Broberg 2007). It is little wonder, therefore, that these important stakeholders often doubt the utility of HF to improve system performance (Helander 1999, Baird et al. 2001). This poses a developmental need if companies are to
actually succeed in the ‘HF 20-20’ challenge – how do you know success if you have no measure? There is a need for leading indicators that predict outcomes, process indicators that confirm procedures are followed, and the more conventional shop floor health outcomes data (Figure 3).

The utility of feedback is further inhibited by the use of trailing indicators such as sickness absence, which are unspecific and suffer from both lag and delay compared to productivity data or available leading indicators of risk (Cole et al. 2003), as illustrated in Figure 1. This delay and attenuation of feedback to designers tends to inhibit organisational learning (Senge 1990, Hatch 1997). Feedback is a central feature of the current approach which aims to establish leading risk indicators that can both support design teams’ innovation efforts and managers’ evaluation of system performance. While there have been large amounts of research on ergonomics evaluation tools and hazard quantification (Burdorf and Laan 1991, Wells et al. 1997, Mathiassen and Winkel 2000, Neumann 2007, Deeney and O’Sullivan 2009, Takala et al. 2010), less work has been done on how these tools should fit into a company’s design and management processes. Audit tools for OHS management systems, such as the CSA Z-1000, may be of assistance but these currently tend to focus on return to work and retrofitting processes more than to the scope of the development process as illustrated in Figure 3. In the absence of a clear model, there is little specific advice to give the practitioner at this stage excepting standard Six-sigma techniques like Define-Measure-Analyse-Improve-Control (DMAIC) or Define-Measure-Analyse-Design-Verify (DMADV) (Cronemyr 2007). Similarly, Deming’s continuous improvement approach using Shewhart’s cycle of Plan-Do-Study-Act (PDSA) may help provide a useful starting point (Deming 2000). It may be possible to use the output from tools, such as the FMEA and criteria documents, to link HF indicators alongside other design indicators in the existing metrics system. Connecting to existing systems, as illustrated in Figure 1 (right side), is likely more sustainable than creating exclusive ‘HF’ systems that are readily dropped with the first change of personnel (Neumann et al. 2009). Recent interview studies with professional ergonomists have found that some practitioners in larger firms are successfully applying ‘score-board’ and audit tool type indicators that help anchor attention to HF into organisational routines (Theberge and Neumann 2010, Wells et al. in press). Understanding how best to create and maintain indicator systems that integrate leading, lagging and process indicators (per Figure 3) to support sustained change in the development process is another research priority emerging from this framework.

4. Discussion and limitations

Several researchers have spelled out models of what a work system design process with integrated HF might look like (e.g. Jensen 2002). These studies, however, do not deal with the issue of how such a desirable state might be

Figure 3. Indicators should be used throughout the development process. Leading indicators of HF should be used to inform design decisions, while process indicators can be used to ensure the desired procedures are actually being followed.
reached. The framework presented here attempts to provide tools and a theoretical model that can be used to help move a company towards such an idealised state. Examinations of ergonomists’ practice find that they spend considerable energy engaged in ‘organisational work’ – trying to negotiate with workplace stakeholders to achieve meaningful improvements in the work system (Theberge and Neumann 2010). Manoeuvring within the organisation to achieve their objectives is what Broberg and Hermund (2004) have dubbed ‘political reflective navigation’. This process involves identifying key stakeholders and working with them in ways that further their objectives and are consistent with their current work routines – a process we advocate in this framework. We have not provided details here of approaches supporting ‘navigation’, such as qualitative stakeholder analysis (Neumann et al. 1999), mapping of organisational groups’ influence on the development model (Neumann et al. 2009), applying organisational development tools like ‘force-field analysis’ (Cummings 2008) or the application of other ‘context assessment’ tools that are beginning to emerge in the ergonomics research literature (Baril-Gingras et al. 2010). More research is needed in the area of stakeholder analysis for ergonomics applications.

We resist the temptation to provide a stepwise process as these have been shown to be ineffectual (Collins 1998). Instead, we urge practitioners, regardless of their organisational role, to begin to gather support for initiatives at each level in the model and to pursue those areas where opportunities emerge. In this sense, we draw on the systems-theoretic concept of equifinality – different routes can be used to reach the same ends. The intent, therefore, is not to provide a strict ‘blueprint’ of exactly how such an initiative must operate, but instead to provide an adaptable framework for achieving helpful change that builds on critical system elements of: (i) the organisations’ development process; (ii) the organisations’ evaluation (metrics) system and (iii) the organisations’ design process, as means of achieving better application of HF. As a further motivator to the various actors in the organisation, we also draw on the potential for improved performance and strategic advantage available from HF, in order to help move HF out of the OHS side-car and into mainstream design processes (Dul and Neumann 2009).

The extent to which this approach may apply to a company will likely vary with context. Companies that have very stable workplaces, for example, may not even have a design process or dedicated personnel, since work system design problems occur so infrequently. In such cases, a participatory system design approach such as that presented by Seim and Broberg (2010) may be more appropriate, possibly combined with some of the elements of the framework presented here. While the current framework was designed with manufacturing in mind, it may also apply to multi-site service or hospitality industry sectors, where new locations are being established as the company expands operations. This framework should be considered a starting point, or model, that could itself be adapted to suit the specific context of the given organisation. The authors admit that there are other ways in which HF integration might be achieved and welcome a broader discussion of these issues in the literature. An unexplored example might be the altering of manager and employee reward schemes within the organisation which could act as a further motivator for positive development. These are complex approaches and instead of a simplistic research question, such as: ‘does intervention X work?’, we suggest there is a need for a broader discussion of: ‘how can HF be better applied in work system design?’ Since it is unlikely that there will be a single ‘universal’ approach to integrating human factors into the development of new workplaces (Gustavsen 1996), it is likely that a range of hybrid approaches will be needed. Adapting, combining, inventing and testing new approaches to integration are required to further broaden the bandwidth on how to support HF initiatives in modern organisations. Furthermore, the transferability of these methods between organisations also warrants examination. Finally, the relative merits and drawbacks of these approaches in furthering the agenda to integrate HF into work system design processes remains a critical research issue.

### 4.1. Design processes

While we present the main stages of a development process as a linear series, the development process in organisations is not entirely linear-rational. Instead it can be bounded by corporate politics, time constraints and access to information, among other factors (Engström et al. 2004). Nevertheless, there is a consistent dominant flow of constraints that runs downwards (as illustrated in the figures) with each stage setting critical constraints and demands on the next stage of development. The tight time-lines of development can also inhibit process improvements and be a barrier to organisational change (Smith 2003, Neumann 2004, Neumann et al. 2009). We suggest to counter this problem by focussing on the company’s processes and focussing on future systems, rather than on the immediate scheduled demands to launch production. Design also contains elements of iterativeness as interactions between design elements under consideration are discovered (Pahl and Beitz 1988). Concurrency in the engineering design process, in which product and production are designed simultaneously (Stahl et al. 1997, Zha et al. 1999), pose potential for including HF as product-related assembly problems can be addressed at the
4.2. Research approach

This paper has outlined an ambitious approach to integrating HF into work system design. There are many unknowns and much research is required. The approach as formulated is not amenable to traditional experimental evaluation as it is intended for the development process to be heavily adapted to suit the local and time-point circumstances of the particular organisation. At this stage of development research, more qualitatively-oriented case studies seem warranted. An action research (AR) (Reason and Bradbury 2001) approach may be helpful for studying this kind of issue (Huxam and Vangen 2003, Neumann et al. 2012, Ottosson 2003, Rosencrance and Cook 2010). Action research, with its many variations (Raelin 2009), is a research form in which knowledge is gained while solving practical real-world problems in close collaboration with the problem ‘owners’; in this case, the organisation and its personnel. It has been considered part of a ‘Mode 2’ form of knowledge generation which complements more traditional theory testing experimental science with a more problem-based approach. The aim is to gain understanding of the solution building process in vivo with real stakeholders (Gibbons 1994). Working collaboratively with the stakeholders, it becomes possible to understand, from a close and embedded position, the factors influencing the success of the change effort. Data collection within the AR project can include techniques of applied ethnography (Sørensen et al. 1996, Zickar and Carter 2010). Specific aspects of the project might use more traditional quantification of, for example, risk factors for different design options, but these would be structured as sub-studies dealing with the more technical aspects of the proposed design. While there is considerable literature on AR, it has not been widely adopted in the ergonomics community (Neumann et al. 2012), possibly due to the training of ergonomists which is heavily based in the experimental paradigm (Pålshaugen 1996, Greenwood 2002, Ottosson 2003). There are, nevertheless, some excellent examples of how a ‘participant observer’ approach, such as AR, can provide useful insights into design processes (Burns and Vicente 2000). The AR approach is also amenable to the changing and dynamic context of many organisations. If an initiative is ineffective, a new route can be planned to bring it back on track or a new initiative tackled in another area. Embedding new techniques and processes within the organisation offers the possibility of sustainable HF efforts and organisational learning (Senge 1990, Patton 2011). For a more detailed justification of the use of AR in ergonomics research, see the position paper of Neumann et al. (2012).

5. Conclusionary comments

The authors have argued that the need to integrate HF into the early stages of the design of work systems requires a new approach. Such an approach must engage a broad range of stakeholders. One way to gain the support of these individuals is to focus on the multiple benefits of HF that can include reduced risks for health and quality deficits as well as other forms of improved system performance. The use of a ‘HF 20-20 challenge’ aimed at achieving a 20% improvement in both human and performance domains poses a specific target that can be used to engage company personnel. A second way to gain support is to help senior management align HF with their strategic goals. Cognitive mapping techniques may be a helpful tool for this. In the context of organisations, where workplaces are continually redeveloped, such as manufacturing or multi-site service operations, it is necessary to make changes to the processes by which systems are developed. For this reason, it is suggested to begin with a process evaluation which can be facilitated by the creation of a process ‘map’ which can support the discussion of how and where to integrate HF considerations into the workplace design process. Given a specific quantifiable improvement target of 20%, and the observation that few companies have established HF metrics that support design, it will likely be necessary to develop leading indicators of HF in order to support design decision making. Having established buy-in with a set target, aligned HF with strategic goals, identified where in the design process key decisions are being made, and set indicators that can demonstrate improvements, the stage is set for developing improved designs to the work system itself that can pose a new model for future systems. This approach goes further than current descriptions of PE which focus on improvements to the existing system. It also differs from descriptions of ‘macroergonomics’ in that it does not assume the power of a system designer. Instead, this approach, which might be called ‘participatory macroergonomics’, advocates efforts to activate the existing actor network in the company to include HF considerations in their regular work routines and processes. The authors consider this more of a framework for
improvement than a definitive step-wise plan. Many variations are possible and the authors welcome discussions of alternatives. The sequence of initiatives and level of interventions within the organisation might be changed to suit the preferences and context of the organisation. The framework presented here may be seen, therefore, as more of a conceptual starting point for integrating HF into workplace design, rather than a finished prescription. There is a need to understand what techniques and approaches work under which conditions in order to establish a flexible approach to helping organisations apply, and benefit from, the application of HF in their work systems. This poses a challenge to HF researchers and an innovation opportunity for HF practitioners.

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