Human Factors: Spanning the Gap between OM & HRM

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ABSTRACT AND KEYWORDS	
Abstract	Purpose: This paper examines the claim that the application of human factors (HF) knowledge can improve both human well-being and operations system performance. Methodology: A systematic review was conducted using a general and two specialist databases to identify empirical studies addressing both human effects and operations system effects in examining manufacturing operations system design aspects. Findings: We found 45 empirical studies addressing both the human effects and system effects of operations system (re)design. Of those studies providing clear directional effects, 95% showed a convergence between human effects and system effects (+,+ or -,-), 5% showed a divergence of human and system effects (+,- or -,+). System effects included quality, productivity, implementation performance of new technologies, and also more 'intangible' effects in terms of improved communication and co-operation. Human effects included employee health, attitudes, physical workload, and 'quality of working life'. Research limitations/implications: Future research should attend to both human and system outcomes in trying to determine optimal configurations for operations systems as this appears to be a complex relationship with potential long-term impact on operational performance. Practical implications: The application of HF in operations system design can support improvement in both employee well-being and system performance in a number of manufacturing domains. Originality/value: This paper outlines and documents a research and practice gap between the fields of HF and OM research that has not been previously discussed in the management literature. This gap may be inhibiting the design of operations systems with superior long term performance.
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Literature Review

Human Factors: Spanning the Gap between OM & HRM

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Literature Review

Human Factors: Spanning the Gap between OM & HRM

Abstract

Purpose: This paper examines the claim that the application of human factors (HF) knowledge can improve both human well-being and operations system performance.

Methodology: A systematic review was conducted using a general and two specialist databases to identify empirical studies addressing both human effects and operations system effects in examining manufacturing operations system design aspects.

Findings: We found 45 empirical studies addressing both the human effects and system effects of operations system (re)design. Of those studies providing clear directional effects, 95% showed a convergence between human effects and system effects (+,+ or -,-), 5% showed a divergence of human and system effects (+,- or -,+). System effects included quality, productivity, implementation performance of new technologies, and also more 'intangible' effects in terms of improved communication and co-operation. Human effects included employee health, attitudes, physical workload, and 'quality of working life'.

Research limitations/implications: Future research should attend to both human and system outcomes in trying to determine optimal configurations for operations systems as this appears to be a complex relationship with potential long-term impact on operational performance.

Practical implications: The application of HF in operations system design can support improvement in both employee well-being and system performance in a number of manufacturing domains.

Originality/value: This paper outlines and documents a research and practice gap between the fields of HF and OM research that has not been previously discussed in the management literature. This gap may be inhibiting the design of operations systems with superior long term performance.

Keywords

human factors, sustainable competitiveness, productivity, health, operations design, production planning

1 Introduction

Many companies rely on humans. In recent years there has been an increasing interest in human issues in operations management (Boudreau et al., 2003; Cook et al., 2002; Juran and Schruben, 2004; Wirojanagud et al., 2007; Yee et al., 2008). Humans are part of operations systems, both as decision-making managers and system operators. Operations Management (OM) practitioners recognise the importance of humans implicitly and OM textbooks contain sections on human factors (e.g. Heizer and Render, 2007; Wild, 1995), but the topic is infrequently covered in OM research journals. Where humans are included, severe simplifications of human characteristics and behaviour are made such as "people have predictable behaviour" or "people are constant without tiredness" (Boudreau et al., 2003). One discipline that could give realistic human input to operations management is the discipline of Human Factors (HF). We accept the definition of Human Factors as : *"the scientific discipline concerned with the understanding of interactions among humans and other elements of a system … in order to optimize human well-being and overall system performance."* (IEA Council, 2000). This definition of human factors spans both the physical, cognitive, and psychosocial interface between the operator and the operations system and is operationally defined as synonymous with the term 'ergonomics' (c.f. IEA Council, 2000) which is sometimes seen as a narrower issue by those outside the discipline. HF differs from Human Resource Management (HRM) in that HRM focuses more on selecting and developing people in order to fit them to the system, whereas HF focuses on adapting the system design in order to fit it to the people ("human factors engineering"). In the next section we will examine the separation of HF from OM in science and society that underlies the need for this study.

1.1 The Separation of HF and OM

The possible contribution of HF to OM may be hampered by the fact that the HF literature is separated from the OM literature. HF publications mainly appear in journals focusing on human well-being (e.g. psychological, medical and ergonomics journals) and rarely in business and management journals. A review of articles in 97 business and management journals, including popular journals like Harvard Business Review and Fortune, during a 10-year period, revealed that in 90 journals (93%) no HF paper at all was published, with a total of 10 articles in 10 years appearing in 7 (7%) different journals (Dul, 2003). A survey in Ireland found that over 36% of companies claim no knowledge of human factors whatsoever (James et al., 1994) and amongst managers in developing nations this figure rises to 88%. This knowledge gap may be limiting firms' ability to profit from application of HF principles in their operations system (OS) designs.

A second reason for the gap between HF and OM may be the misperception of HF as strictly a Health and Safety (H&S) tool to be positioned as part of HRM (Hägg, 2003). Jenkins and Rickards (2001) describe the problem thus: *"[HF]… 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… to improve labour efficiency and reduce the cost of production"* (Jenkins and Rickards, 2001, p 234). As a result, few companies have integrated HF thinking with the firm's strategy or operations improvement processes (Dul and Neumann 2009). By isolating HF as an H&S issue, separate from core OM decisions, it is in an organisational 'side-car' with limited influence and reduced ability to contribute to core system goals and performance (Frick, 1994; Jensen, 2001). The total (direct and indirect) costs of work-related ill health (WIH), however, are immense and have been calculated to exceed costs for coronary heart disease, and are roughly on par with the total costs of all cancers combined (Leigh et al., 1997). The World Health Organisation reports the costs of work-related ill health at 4-5% of the total global domestic product (WHO, 1999). The extent to which firms must carry the direct and indirect costs of WIH will vary with legislative context. The total costs of poor HF in OS design, of which injury costs are only a small sub-set, are rarely calculated by companies and are rarely studied from an OM perspective. HF science may be able to contribute here.

A third possible contributor to the HF-OM gap is the gradual shift of management research away from its original ideas of serving firms and society (including human well-being) to a more exclusive focus on firm profitability and a growing disinterest in issues with any ethical implications (Walsh et al., 2003). While this might be counter-indicated by the current interest in corporate social responsibility (CSR), CSR is frequently discussed in terms of profit in the OM literature (e.g.Salzmann et al., 2005; Weber, 2008). Interest in CSR notwithstanding, Walsh et al. (2003) have suggested that ethics and social agenda issues have lost credibility within the management and research community. We argue that, if H&S, and again by association HF, is seen as only an ethical issue and not a issue for firm profitability then it will again be isolated in the minds of management researchers and this could limit HF's ability to contribute to firm performance.

These three elements; the separation of HF from business and management literatures, the misperception of HF as strictly a H&S tool to be positioned in HRM, and the loss of credibility of social objectives in management research, may have contributed to a 'dominant logic' in which HF has little to offer in helping organisations reach their strategic goals. Prahalad (2004) has described how 'dominant logic' creates barriers, or 'blinders', that can prevent managers from recognising innovative potential and results in missed opportunities for the firm. This, we argue, is what has happened to HF. There remains, therefore, a need to examine scientific research in this area if the full potential of the operations system is to be realised. This paper presents a framework and a systematic literature review examining the claim that application of HF knowledge in OS design can improve results in terms of both operator well-being and overall system performance.

1.2 A framework for studying effects of operations system design

Our framework is presented in Figure 1. The focal unit is any operations system (OS). The OS is operationally defined as the 'bundle of measures' that have been implemented in the realisation of the operations system including both technological and organisational characteristics (Brassler and Schneider, 2001). This includes the operators and the technical equipment, its configuration, and the approach by which work is organised into jobs and tasks for operators to perform – a view generally consistent with sociotechnical view of work systems (Eijnatten et al., 1993). The technical and organisational design features of the OS are the independent concepts; and the human effects and system effects the dependent concepts. System effects include the traditional production indicators quality and productivity, as well as new technology implementation performance (process innovation) and 'intangible' effects like communication culture or industrial relations. Human effects are defined as the physical and psychological consequences that the operations system has for system operators. This includes effects on health (e.g. pain or injury), worker attitudes (e.g. boredom or satisfaction), physical work load, and general effects on safety (e.g. from accident risk) or the quality of working life (e.g. improved communications and cooperation). To illustrate: the height of a box on a shelf and the process by which an operator is assigned to that station are characteristics of the operations system, the physical workload for the operator to reach the box and any related discomfort are human effects (Figure 1, link A), and the act of manipulating the box contributes to the system effect of productivity (Link B). Since humans are part of the OS, any effects on humans will immediately influence their work performance, for better or worse.

Firm profitability is seen as distal to the more proximal effects discussed here.

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Insert Figure 1 about here

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The implications of this framework are that any change in the technical or organizational characteristics of the operations system has both human effects (link A) and system effects (link B) with four possible outcomes (Table 1).

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Insert Table 1 about here

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Hence, central to our model is that the *set of design choices made during system (re)design lead simultaneously to both human and system effects*. Design options should not, therefore, be considered for these two kinds of effects separately. From this we develop the claim that application of HF can secure improved outcomes in terms of both system effects and human effects. Typically, these two types of effects are studied separately by researchers in separate fields. For example, workplace health researchers have studied link A (Figure 1; human effects). OM researchers have traditionally studied link B (Figure 1; system effects). In this paper we conduct a systematic literature review to examine the available empirical evidence for the claimed dual effects: 'human' and 'system', of OS designs – the 'A and B' linkage in Figure 1. Such evidence would provide the rationale for the application of HF science in OS design. In this review we focus on operations systems with manual work (excluding white collar work) in manufacturing. We propose that according to HF claims, changes in the operations system will result in joint human effects and system effects – either both improving or both worsening together. This can be contrasted against the view that human and system effects are oppositional – gains in one aspect must come at the expense of the other. Empirical evidence supporting this proposition will be indicated by studies which explore the human and system effects of OS design changes, and show joint win-win or joint lose-lose effects (per Table 1). Studies showing lose-win or win-lose effects would counter the proposition.

2 Methods

A systematic literature search was conducted with the assistance of research assistants and a professional librarian. The aim of this search was to identify peer-reviewed papers that presented empirical evidence on both the human and the system effects of operations system design changes in manufacturing – both 'A' and 'B' linkages in Figure 1. We excluded studies that focus on the relationship between human effects and system effects without linking these to operations system design characteristics (e.g. studies on the effects of physical workload on productivity, or studies relating motivation to performance), as we were interested in the dual effects of operations system design. Since the concepts 'human effects' and 'system effects' could not be defined with a few simple terms, a librarian chose an iterative approach in which a number of search terms relating to human effects were crossed (AND searched) with a number of different terms implying system effects. Initially chosen terms were supplemented with alternatives obtained from database thesaurus and index terms, as well as terms found in titles and abstracts from relevant references (See Table 2 for a summary of final terms used).

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These terms were applied in varying combinations to provide an overlapping web of search criteria using Boolean operators, wild-cards, truncation, phrase searching and 'find similar' functions whenever relevant (c.f. Harter, 1986). This search approach was applied to three databases: Web of Science, an all purpose scientific database, and a specialty databases for each core topic area - Ergonomics Abstracts, and Business Source Elite. Articles included were limited to English language and published in ISI journals (journals indexed by Thomson Scientific's Institute of Scientific Information). Year of publication was not limited; searching was conducted in 2005. Further searching was performed in 2009. Results from this process were then examined to eliminate papers not actually providing empirical evidence addressing both human and system effects in the manufacturing sector (service sector was excluded in this search). Papers dealing with the financial benefits of health interventions were excluded as being 'only' health-focussed despite the reckoning of those benefits in financial terms - a distal outcome from the focus of the framework of Figure 1 (e.g. Halpern and Dawson, 1997; Hantula et al., 2001; Seeley and Marklin, 2003). Similarly papers correlating human and system effects without attention to the design of the operations system were excluded, although key papers of this type, along with relevant conceptual papers, were included in the discussion of the results presented.

Core results of each selected article were summarized in a table, and the articles were further analysed by sorting them into a 2x2 matrix in order to classify the selected papers into groups based on explicit statements confirming (win-win or lose-lose) and disconfirming (win-lose or lose-win) the HF proposition per Table 1 (above). A summary was also made of the types of journals, based on journal title in the categories of: 'Human Factors', 'Safety', 'Management' (including HR and Industrial relations), or 'Engineering'.

3 RESULTS

The original searching process yielded 603 non-duplicate articles of which 36 were eventually deemed relevant based on having both outcomes resulting from a given OS design. The secondary round of searching, conducted in 2009, yielded 9 additional studies for a total of 45 relevant non-duplicate studies. These papers and their key findings are summarised in alphabetical order in Table 5. The papers identified in this search covered a wide range of study designs including case studies of 'participatory' interventions, cases of system re-design, surveys in industrial sectors, longitudinal studies of industrial development, and tests of particular technical (e.g. equipment) solutions.   The human effects considered varied widely in both construct and evaluation approach and are summarised in Table 3, showing an emphasis on physical workload (62% of studies) and health (40% of studies).

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Insert Table 3 about here

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The observed system effects were mainly productivity (89% of studies) and quality (31% of studies). The distribution of articles by discipline is illustrated in Figure 2. HF Journals made up over half the study sample, while OM journals carried less than 10% of the identified studies with joint effects.

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In the 2x2 classification analysis, presented in Table 4, 4 papers were eliminated as inappropriate for inclusion as their results could not be reduced to simple win-lose terms. The study of Adler and colleagues' (Adler et al., 1997) that describe the trials and tribulations of a new model launch at an auto company manufacturer could not be so simply categorised. Similarly, three studies from a case-series (Neumann et al., 2002, Neumann et al. 2006, Kazmierzcak et al. 2007), applied a holistic approach to understand the human and system effects of a series of production system design choices, while the authors claim the need for such nuanced analysis it makes such studies inappropriate for the meta analysis conducted here. A further three papers, with observed null-effect in one dimension, were also excluded from this analysis because these cannot be classified in a win-lose table: Bao et al., 1996, Rhijn et al. 2005, and Dababneh et al. 2001. The remaining 38 papers were classified according to the 2x2 classification matrix in Table 4 which shows that 95% of the sample is consistent with a joint win-win or lose-lose relationships between human and system effects. Hence, there is empirical evidence for the hypothesis that changes in the operations system will result in joint human effects and system effects, with most papers showing win-win outcomes. Two of the 'lose-lose' papers demonstrated linkages between postural and workload deficits for operators and quality deficits (Eklund, 1995; Lin et al., 2001) and the third showed that companies with more health problems have more productivity problems (Shikdar and Sawaqed, 2003). The papers with a 'null effect', that were excluded here, could be considered as counter to the 'oppositional' hypothesis - that human and system effects conflict. Finally, two papers (about 5%) had win-lose type findings countering the HF claim; these will be discussed in more detail.

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DISCUSSION

From a pool of hundreds of thousands of scientific articles in both business and human factors databases, only 45 empirical studies were identified, using the current search approach, that studied both the human and system effects of the design of operations systems in manufacturing. Over two thirds of these studies are published in HF or Safety journals while fewer than 10% are from OM or Management Science Journals and 15% are from Engineering journals. Given the thousands of articles published annually in each domain, we see this as an indication of lack of either researcher interest in, or capability to explore OS design choices' effects in both human and system dimensions. This can be seen as a confirmation of the research gap between these disciplines which may contribute to the underperformance of OS design efforts in manufacturing. This lack of studies of joint effects is also consistent with a dominant logic perceiving HF as a health matter with limited potential to contribute to OS performance. In contrast to our 45 papers, a review of system effects of manufacturing strategy found 260 relevant articles (Dangayach and Deshmukh, 2001) – without a single study that included human factors. Furthermore, many studies (e.g. laboratory studies) exist on the relationship between ‘human effects’ (such as posture) and ‘system effects’ (such as productivity), however without incorporating the operations system that could cause these effects (e.g., cellular production). While a few of the selected studies reported perverse relationships between human and system effects, the vast majority (95%) of the studies identified in our review report joint human and system effects resulting from the design of the operations system. These studies covered a broad range of both technical and organisational aspects of OS design that would be considered in both ‘managerial’ and ‘engineering’ domains. Most studies analysed the OS at company level, whereas few studies dealt with a broader level (sector) or a narrower level (workstation, equipment) with consistent results.

The two counterexamples warrant closer examination: Lutz et al. (2000) in developing mirror devices to improve vision and reduce awkward postures during assembly tasks (screw running) found improved postures, but degraded performance for workers who were inexperienced in using the mirror device – while the authors note performance-learning effects they did not extend testing to see if screw running performance with the mirrored-screw driving devices eventually reached that of a normal screwdriver or beyond. Moreau (2003) summarising Peugeot’s approach to ergonomics noted that “denser” task cycles (presumed to provide a productivity benefit) lead to increased musculoskeletal disorders in operators – a result consistent with physiological pathomechanisms for myalgia (Hagberg et al., 1995; National Research Council, 2001). A number of studies included more complex analysis, either of industrial development over time (Adler et al., 1997), or of the interactions of a bundle of implemented OS design measures (Neumann et al., 2006). While these studies illuminate important issues for OS design, they are not amenable to the simple win-win type analysis conducted here. These studies help confirm the relation between OS design and joint human and system outcomes without contradicting the general findings of this meta-analysis. Overall, we interpret the studies identified in this review as suggesting that there is a good potential to have both joint positive human and positive system effects by attending to HF in the design of the operations system – but counter-examples suggest that this performance gain is not guaranteed.

The system benefits observed in the reviewed literature are generally consistent with the 'Resource-Based View' (RBV) of the firm which suggests that firm competitiveness is a product of exploiting resources that are valuable and difficult to replicate (Barney, 1991; Barney and Wright, 1998). The social (human) sub-system in an OS poses a 'resource' that is much more difficult to replicate than the technological subsystems of the OS (Pfeffer, 1994). HF science may be able to help managers realise the competitive advantage of the resources their employees represent. We suggest that HF is not an objective like health and safety and is instead a *means* which can support many company objectives (Dul and Neumann, 2009). Capitalising on this *means*, however will require managers to have a better understanding of how HF can help in the creation of OS's that are sustainably competitive.

Our study has a number of limitations. Methodologically, every 'systematic' review will have weaknesses and blind spots – there may be relevant literature that is missed, despite extensive efforts by the authors, research assistants and a librarian to identify relevant articles. This was aggravated by the breadth of the concepts under study and related research fields which needed to be considered. We have limited our search to publications in ISI journals, whereas relevant articles may have been published elsewhere as well. However it is unlikely that this has biased our results substantially given the weight of the trend that we found. Publication bias, caused by the difficulty in publishing studies with negative results, may also skew the results of a literature review (Dickersin and Min, 1993; Torgerson, 2006). In this case we suggest that publication bias may hide difficulties in applying HF but does not negate the apparent success some firms have had in improving performance by using HF. The classification of the publications was not always easy. Both 'human effects ' and 'system effects' can be (and were) operationalized in many different ways, and some studies (e.g. Kazmierczak et al., 2007; Neumann et al., 2006) examined multiple design elements and their impact on different human effects (psychosocial and physical) and system effects (productivity, quality). The distinction between human and system effects can also become confused: Employee turnover, for example, noted to be reduced by HF applications (Abrahamsson, 2000; Oxenburgh and Marlow, 2005; Parenmark et al., 1993), could be interpreted as a positive effect in either the human or system domain. These problems notwithstanding we were able to identify general trends, and below we discuss the possible system effects of using HF principles in the design of operations systems: quality, productivity, new technology implementation performance, and intangible effects. Given the range of systems and the paucity of studies, it is not possible at this point to comment on the specific HF design features that should be applied to be useful to practitioners – more research is still needed.

4.1 Human Factors and quality

In our analysis, 14 studies reported a connection between HF design of the OS and quality performance. It is studies in this domain that report a 'double lose' relation in which poor postures and poor quality are joint outcomes of OS design. For example, Lin et al. (2001) found that 50% of the quality variance in the production lines was accounted for by a combination of the lack of time required for the task and postural deficiencies. Researchers Yeow and Sen (Sen and Yeow, 2003; Yeow and Sen, 2003; Yeow and Sen, 2004; Yeow and Sen, 2006) have conducted a series of cases in the electronics sector, each demonstrating how even retrofitting HF engineering design changes such as improved lighting and product redesign, can yield quantifiable profits from improved productivity and quality.

Quality has become an important competitive domain (Ghobadian and Gallear, 2001) that has been seen to have important links to human factors (Carayon et al., 1999; Drury, 2000; Eklund, 1995). According to Drury, "*Quality is a function of technological and human factors, and is greatly influenced by ergonomics in its broadest sense. Errors in the process can… result in product unreliability, poor productivity or even injury to the workforce or product user*" (Drury, 2000; abstract). Axelsson (Axelsson, 2000) found that jobs with poor postural ergonomics were 10 times more likely to have quality deficits than jobs with good ergonomics. Other studies have also shown a co-variation of human and quality effects, without considering the operations system (Dillard and Schwager, 1997; GAO, 1997; González et al., 2003; Govindaraju et al., 2001; Hendrick, 2003; Klatte et al., 1997; Kleiner, 1999; Tari and Sabater, 2006). Part of the effects observed here may be interpreted in terms of human error making – which can be interpreted as a phenomena arising from the design of the system which fosters errors, as well as from the human operator's knowledge and ability to avoid or recover from errors (Reason, 1990).

The evidence and supporting theory both suggest that, when designing the operations system according to HF principles, it is possible to have joint positive human and positive quality effects. Research priorities in this domain include better operationalisation and quantification of the relationship between both product and workstations parameters that contribute to quality deficits. More intervention case studies in this domain would allow more nuanced meta-analyses which could help managers make wise choices early in OS design.

4.2 Human Factors and productivity

Of the 40 studies (almost 90% of our sample) reporting on joint outcomes, all but 2 reported joint positive human and positive productivity effects. In our dataset, Helander and Burri (1995) claim over $130 million in savings due to HF-related changes at IBM. Lee (2005) found that the productivity gains of integrating HF into a TQM process outweighed the health related gains by 24 to 1 (direct versus indirect costs). De Looze et al. (2003) report productivity increases of 15-20% realised through a process of design that deliberately combined human factors and traditional assembly engineering (De Looze et al., 2003). These studies, amongst many similar studies (Abrahamsson, 2000; Lee, 2005) and the case series by Yeow and Sen, demonstrate how attention to HF at both systemic and work-station levels can yield improved system productivity, not only improved human effects.

This finding is echoed by reports not included in our analysis - studies that have adopted a broad (not just health-based) approach to human factors application there seems to be greater financial benefits from the productivity and quality gains than from the savings due to reduced ill-health (Koningsveld, 2003; Loeppke et al., 2007). Oxenburgh et al., in presenting an economic model for evaluating simple workplace changes, demonstrated return on investments (ROI) of 1-2 months (Oxenburgh et al., 2004). Hendrick (2003), describes large scale design projects with ROIs of 18 months and returns in the 10:1 range. ROIs as high as 800% to 6000% have been reported from the application of HF principles in redesigning OSs (Jenkins and Rickards, 2001). In a review of human factors program implementation in 5 companies, the US General Accounting Office found that, while measurement problems exist, the programs led to increased productivity, decreased absenteeism and injuries, increased quality and increased moral (GAO, 1997). Stanton and Barber (2004) present four cases with payback periods ranging from 1 to 18 weeks and an average savings of $241,000 with simple layout changes. Similarly Gustavsen and colleagues (1996), examining 1 139 companies from the massive Swedish ‘Working Life Fund’ that funded thousands of workplace development projects found that companies that made more substantial organisational changes (to support good HF), also experienced more substantial productivity growth. Another aspect of the health-productivity interactions is the concept of ‘sickness presenteeism’ which refers to those productivity losses occurring *before* an operator goes on sickness absence. In the construction industry, for example, affected workers reported losing 2 hours productivity work per day on average before leaving work due to the injury (Meerding et al., 2005).

It appears that there is convincing evidence that when designing the operations system according to HF principles, it is likely to have joint positive human and system effects. Theorists have discussed this in terms of the ‘convergence’ of quality of work life and competitiveness (Huzzard, 2003), and Dul and Put (2010) suggest, based on a study amongst cost leader manufacturing firms, that the application of HF in OS design is a necessary but not sufficient condition for cost leadership, for firms that rely both on humans and technology. The presence of counter examples suggests this relationship might be complex and warrants further examination. Time aspects, crucial for both productivity and ergonomics (Wells et al., 2007), require further study as trade-offs may occur in short term productivity gains reaped by having operators work faster, which are eroded as costs related to injuries and absenteeism begin to cause extra costs and disturbances in production. Studies of the specific combinations of types of design/human effects/system effects are needed as well as investigations of the dynamics of these effects over time (e.g. longitudinal studies).

4.3 Human Factors and new technology implementation performance

We found only four studies (9%) in this category that suggest smoother implementations are available when the new system also has better human outcomes. The study of Udo and Ebiefung (1999) provided the clearest example of the linkage between HF and the success of new implementation of advanced manufacturing technologies. Victor et al. (Victor et al., 2000) also showed HF to be an important aspect in successful implementation of TQM management approaches.

It is suggested that the benefits of IT seem to come less from the investment in technology itself than the ability of employees to use the systems in effective ways (Sigala, 2003) – a view consistent with the RBV of the firm (Barney, 1991). Failing to account for HF appropriately in new technology implementation can result in underperformance of the new system and the disappearance of anticipated financial gains, which has been referred to as 'phantom profits' (Neumann, 2004). In the early 1990s, many companies invested in new information technology (IT), but research was unable to show financial benefits of this broad investment. This so-called 'productivity paradox' suggests the need to attend to human aspects in implementation if the benefits of new technologies are to be realised in practice (Badham et al., 1995; Johansson et al., 1993; Stanton and Baber, 2003). A similar trend was observed in early adoption of robotic assembly approaches (Helander, 2006). In the manufacturing sector, international surveys have shown that companies have generally poor to moderate success in applying 'modern manufacturing processes' (Clegg et al., 2002). A four-year follow-up of the UK sample from this survey showed a consistent increase in implementation success over earlier levels (Wood et al., 2004). This suggests that the companies are learning to overcome weaknesses in the original design or implementation of these techniques to realise their benefits. Research on the process of implementing advanced manufacturing technology has found human factors to be critical to the technical, manufacturing and business success of the implementation (Efstathiades et al., 2002). Similarly, human and organisational factors have been seen as central to the implementation of cellular manufacturing (Park and Han, 2002), IT system implementation (Kerr et al., 2008), "Advanced Manufacturing' Technologies (Cordero et al., 2008), and (consistent with Victor et al. 2000) TQM implementation (Cheng and Chan, 1999; Detert et al., 2000). We argue that it is through attention to HF that companies can move beyond the 'fad' of a given technology to reach a 'fit' that produces positive results as seen in the quality area (Van der Wiele et al., 2000). Mital & Pennathur (2004), in their analysis of 'advanced manufacturing technologies' adoption came to the *"obvious but critical conclusion—technology and humans in modern manufacturing environments are interdependent" (p310)* and that humans play a critical role not just in operating, but in overcoming the limitations of a particular technology. One implication of this is that the value of a firms human resources will increases as collective learning learns to leverage new technologies (Yeung et al., 2007).

While the studies in our sample are consistent with the available theoretical literature emphasizing the importance of HF in technology implementation, clearly more research is needed to avoid the design of technologies that do not meet the needs of users and are therefore difficult to leverage successfully as they do not meet the needs of their users. Studies using available usability evaluation methodologies and tracking the success of various implementations may be particularly useful starting points for further research here.

4.4 Human Factors and intangible effects

We found 8 studies (18%) which mention 'intangible' benefits with application of HF in OS design. Intangible benefits that were noted in our dataset include: improved communications (Tjosvold, 1998), improved employee morale (Hull and Azumi, 1988) and improved industrial relations (Lanoie, 1996). It is difficult to separate some intangible effects due to conceptual overlap between system and human effect domains. For example, improved communication (as system effect) and employee 'attitude' (as a human effect) may be interrelated. Furthermore, Lanoie and Tavenas (1996) report difficulties valuing these 'soft' factors.

Also other intangible effects of HF application in OS design could be expected, such as effects on the reputation of a company (Dul and Neumann, 2009). Good or bad reputation regarding the work environment that can affect, for example, hiring and retention for the firm or goodwill of customers. The value of intangibles, elusive by definition, has been a noted problem for valuing HF efforts (GAO, 1997). Measurement problems notwithstanding, these trends are also consistent with the RBV of the firm and longitudinal panel studies of Tobin's Q and firm performance suggest that intangible factors may contribute to or inhibit future firm profitability (Villalonga, 2004).

Our analysis suggests that designing the operations system according to HF principles could have positive intangible performance effects. Research needs in this domain include improved methodological approaches to valuing intangible elements, as well as a broader understanding of what these various factors are and how they are influenced by OS design. Beyond a larger pool of case studies, longitudinal studies may also be required to understand the impact of these factors over time. Studies such as that by Villalonga (2004) provide a potentially useful model for investigation in this direction.

4.6 Implications for practice

The results of our analysis counter the notion that attention to human factors in the design of operations is an expense. Instead, it would appear that careful application of HF principles in the design of operations can improve productivity, quality, technology implementation, and have intangible benefits for operations while also securing well being and working conditions for employees. The results here show that HF is not just a health and safety tool. Unfortunately these potential system gains are not much presented or discussed in the management research literature (see Figure 2). Since few companies measure relevant human effects in their operations, such linkages would not normally emerge in their regular quality improvement processes. Without indicators, or without an engineering team well trained in HF, managers must make special efforts to require HF knowledge application in OS design. Managers should require attention to both technical and human aspects in the OS design process as the costs are lowest and availability of solutions are greatest in early phases of design (Alexander, 1998; Miles and Swift, 1998). Since most managers have no education or training in HF (Shikdar and Sawaqed, 2003) this remains a limiter for application – managers require training on how to manage HF in the creation and running of their operations. Managers must learn to see HF as a tool to help achieve excellence in their operations. In an article in Harvard Business Review, Barber and Strack (2005: p.84) emphasize the increased importance of human factors for operations managers: *"Success in people intensive business comes from hiring the right people and putting in place processes and an organization that makes them productive ….Line managers have a vital role …: how to create an organization and work environment that foster productive output. …People management need to be a core operational process and not solely a support function run by the human resource department"*

Another barrier identified by researchers is that the full benefits of HF may take a long time to reap fully (Hantula et al., 2001) – an element of delayed feedback that creates managerial difficulties (Senge, 1990). The organisational changes required to begin capturing the benefits of HF application have been observed to take many years and require ongoing managerial support (Falck, 2009; Neumann, 2004; Smith, 2003; Toulmin and Gustavsen, 1996). We suggest that managers be sceptical of new managerial fads or technologies that have been 'proven' without attention to HF or human effects – and demand evidence of how these approaches include HF. As Udo and Ebiefung (1999: p.300) suggest: "*If human factors are ignored in a firm during AMS [advanced manufacturing systems] implementation, there is a good chance that the workers will be discouraged and reluctant to apply themselves and as such, delays may occur in the production schedules."*

4.7 Implications for research

Replication

While the model presented may appear to be just common sense, such an understanding is not commonly reflected in the traditional system focused or human focused research fields and thus needs to be made explicit in OM (c.f. Boudreau et al., 2003). Due to the limited number and the diversity of studies that we found, we could only draw preliminary and general conclusions. Clearly there is a need for more studies to replicate the results in order to give more confidence to the claim that joint human and system effects can be realized with HF. Future studies could pay more attention to the operationalization of the dependent and independent variables with clear definitions of the concepts and possible standardization of the measures in order to make comparisons between studies possible. This seems particularly needed for the intangible system effects of the application of HF in OS design. Regarding human effect measures we note that most of the studies focussed on the physical workload aspects. Research is needed that include the psychosocial aspects of OS design as well, as these aspects have long been associated with risk of sickness-absence (Hoogendoorn et al., 2000; Karasek et al., 1998).

Specific operations systems

While this study has demonstrated a strong general linkage between HF and the dual outcomes for human and system, it remains a research issue to unravel these relations in a more specific and therefore useful way. Given the wide range of systems included here this will require many more cases, or more limited focus on OS types, to provide specific ‘design rules’ for engineers and managers responsible for a particular system. We have limited our analysis and conclusions to manufacturing systems. The trends observed in this study need to be re-examined for other sectors (in particular the service sector) to address the issues of differences and similarities of the effects of HF in OS design for sectors other than manufacturing.

Complexity

Most studies simplified the complexity of real life operations systems by considering just direct OS design effects on one or two human effects and one or two system effects, usually in a cross-sectional setting. For deeper understanding it is necessary to add more complexity in the research design. For example, moderators, mediators and control variables could be added in the analysis, so as to address possible interaction effects between firm variables, human effects and system effects, and to control for other causes of human and system effects than OS design. One possible moderating variable at firm level could be firm status before intervention as firms with more room to improve might be more likely to reap the double benefit of HF. Furthermore, multi-level studies should be employed that could link HF application effects at different levels: operations equipment, workstation, company, or sector. Few of the studies identified in our review addressed the long term effects of applying HF. In our data set, the work of Adler (Adler et al., 1997) provided an example of a longitudinal study of OS development with HF attention. There is a need for longitudinal studies that can tap into the dynamics of the interplay of human and technical aspects in OS design over longer time frames – particularly if the effects of the more 'intangible' factors are to be better understood. Such studies could also address the 'chains' of causal relations (Cole and Wells, 2002; Westlander, 1995), and may shed light on more distant effects such as financial firm performance. Conway and Svenson (2001) suggests that firm level benefits do accrue noticeably over time with HF investment.

Emerging areas

There is a general call for incorporation of human insights into mathematical OM models, in particular in the emerging field of behavioral operations management (Bendoly 2006, Gino and Pisano, 2008; Larco et al. 2008). To address this call, for the topic discussed here, studies that aim to *quantify* the empirical relationships between OS design and human and system effects are needed in order to be able to integrate these relationships into mathematical OM models and to strengthen the relevance of such models for practical applications. This could help to overcome the observed gap between OM and HF in practice. Also, research could be started focusing on this gap in practice and on how to narrow it, providing useful guidance for operations managers who want to capitalise on HF in their operations.

Co-operation between HF and OM researchers

Successful research in this area depends on the co-operation between HF researchers and OM researchers, as the research topics that we suggest require expertise from both domains. HF and OM researchers need to work collaboratively, since the research issues span multiple expertise domains. Most of the studies in our review tended to do rigorous evaluation of one effect, with a less rigorous supplemental look at the other effects of interest. Improving study quality, by the collaboration of both OM and HF researchers might yield superior study quality with results that are credible in both domains. High levels of study quality through research collaboration can prevent inter-disciplinary HF-OM research from falling into the gap between research agendas of funding agencies that are often also divided between technical and health foci. While OM textbooks often explicitly include HF in its domain (e.g. Heizer and Render, 2007; Wild, 1995), we would encourage OM researchers to include HF knowledge in OM research. While researcher in the HF field are increasingly interested in correlating human and system effects, without examining how the OS contributes to these outcomes (Kahya, 2007; Layer et al., 2009), we would encourage HF researchers to use OM knowledge and to move beyond correlational analyses, to emphasize the linkages between the HF in OS design choices and their consequences in human and system terms. Integration of HF and OM knowledge will be most useful to those who design and manage operations.

5 CONCLUSIONS

45 empirical papers were identified as studying both human and system effects of manufacturing OS design. Of those with clear directional findings, 95% were consistent with the proposition that application of HF in operations systems can support improvements on both human and system outcomes. Studies providing counter-examples to the HF proposition suggest this relationship may be complex. System effects observed to be associated with improved HF included improved quality, increased productivity, and improved implementation of new technologies. Improvements to less tangible aspects such as morale or communications were also mentioned as effects of HF application. Human effects included those to health, attitudes, physical workload, safety, and more general quality of working life.

The theoretical framework proposed here can help managers and researchers understand the ongoing influence of HF in operations system performance. Future research into OS design alternatives should include HF aspects as well as both human and system effects. The paucity of data in this area implies an opportunity for research and development in the competitive advantages that appears to be available through the application of HF in the design and management of operations systems. Stronger research designs and evaluation methods, rooted in both HF and OM traditions, are needed to address this complex area. Then collaboration between HF researchers and OM researchers can help to span the gap between OM and HRM.

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FIGURES

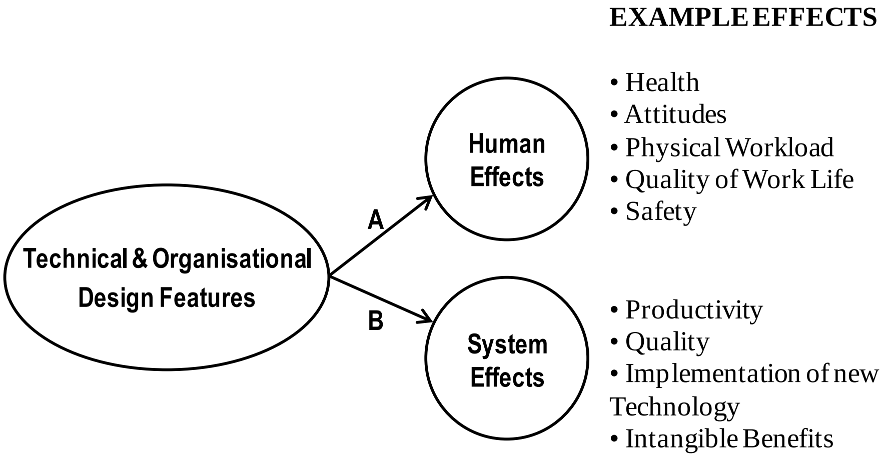

Figure 1: A simple framework illustrating how the technical and organisational features of the operations system have both human effects (e.g. physical workload) and system effects (e.g productivity).

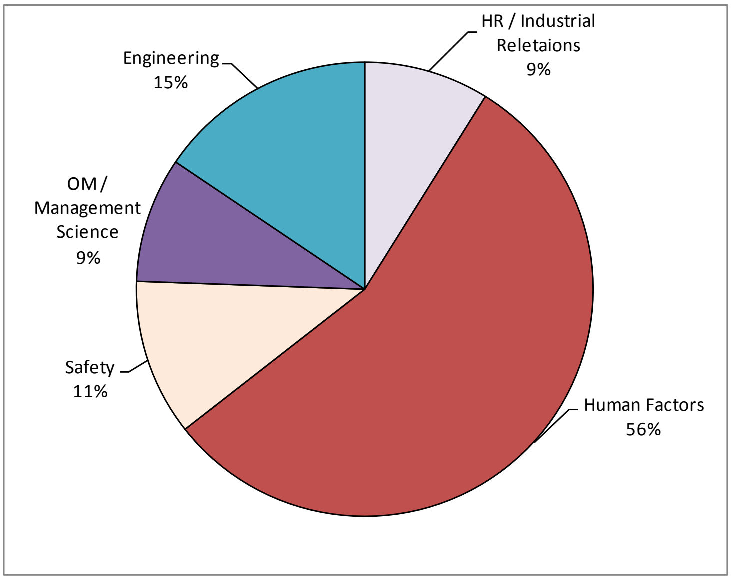

Figure 2: Relative distribution of articles by discipline

TABLES

Table 1: Matrix relating possible effects of operations system design choices on humans and the system.

		Human effects	
		Negative	Positive
System effects	Negative	I (lose-lose)	II (lose-win)
	Positive	III (win-lose)	IV (win-win)

Table 2: Examples of search terms used in the systematic search of three scientific databases

Search terms to identify papers with possible Human Effects indicators.	**Search terms to identify papers with possible System Effects indicators**
Ergonomics	Business strategy
Health	Corporate strategy
Applied ergonomics	Management involvement
Engineering	Leadership
Occupational health	Top management
Occupational safety	TQM (and variations)
Quality of working life	Safety management
Human factors	Operations management
Occupational diseases	Industrial engineering
Industrial safety	Business
Work environment	Manufacturing
Safety	Manufacturing processes
Social goals	Industrial efficiency
Participation	Industrial productivity
Commitment	Labor productivity
Motivation	Production management
Introduction of ergonomics (EA)	Industrial management
Work design and organisation for health and safety (EA)	Business planning Strategic planning
Effects on the musculo-skeletal system (EA)	Cost Cost benefit (analysis)
Workload	Executives
Workload demands	Performance
Posture	Just-in-time systems
Job enrichment	Introduction and strategies for introduction of change (EA)
Marketing of ergonomics (EA)	

EA = terms particular to the Ergonomics Abstracts database.

Table 3: Types of human effects included in the identified pool studies (n=45, some studies included more than one type of factor listed here, resulting in greater than 100% total).

Human effects	# studies	% of studies
Health	18	40%
Attitudes	13	29%
Physical Workload	28	62%
QWL	5	11%
Safety	5	11%
Employee Performance	1	2%
System effects	**# Studies**	**% of Studies**
Productivity	40	89%
Quality	14	31%
Implementation	4	9%
Intangibles	8	18%

Table 4: Results of the 2x2 classification studies according to human and system effects (n=38).

		Human effects # papers (%)	
		Negative	Positive
System effects	Negative	3 (7.9%)	1 (2.6%)
	Positive	1 (2.6%)	33 (86.8%)

Table 5: Summary of research addressing both human and system effects in operations systems sorted alphabetically by first author. The nature of the study (e.g. 'case study of redesign') is stated along with the journal name, the human effect, the system effect. The Results include a direction of human and system effects, respectively as 'Win', 'Lose', 'Null' or 'Complex'.

Reference - *Study description*	**Journal**	**Human Effect**	**System Effect**	**Results**
(Abrahamsson, 2000) - Case study of re-design in a foundry for improved work environment	Applied Ergonomics	Health, Workload, Quality of Work Life	Productivity, Quality & Intangibles	HF investment yields ROI of 2.2 in direct benefits (WIN - WIN)
(Adler et al., 1997) - Longitudinal case study of introduction new car model in production	Industrial & Labor Relations Review	Health	Productivity	Good design can improve both employee health and profitability (COMPLEX)
(Bao et al., 1996) - Intervention study aiming to reduce physical workload	Applied Ergonomics	Workload	Productivity	Product redesign reduces assembly time to 52% without increased risk to operators. (NULL - WIN)
(Challis et al., 2002) (Challis et al., 2005) - Survey of 1289 firms in Australia and New Zealand.	International Journal of Production Research	Employee Performance	Productivity & Implementation	Employee performance and manufacturing performance correlate – particularly in advanced manufacturing technology environments. (WIN - WIN)
(Conway and Svenson, 2001) - Analysis of Bureau of labour statistics databases	Journal of Labour Research	Health	Productivity	Better HF related to faster productivity improvements (WIN - WIN)
(Dababneh et al., 2001) - Study of use of extra rest breaks	Ergonomics	Health	Productivity	Additional rest breaks reduced discomfort without reducing productivity (WIN - NULL)
(Dahlén and Bolmsjö, 1998) - Case study in a Swedish engineering firm	International Journal of Human Factors in Manufacturing	Workload	Productivity	Automation of repetitive monotonous work improves performance and yields better HF for employees (WIN - WIN)

Reference - *Study description*	**Journal**	**Human Effect**	**System Effect**	**Results**
(De Jong, 2002) - Intervention study of 'participatory ergonomics' in installation work	Applied Ergonomics	Workload	Productivity	HF improvements yield ROI of 1 year (WIN - WIN)
(De Looze et al., 2003) - Case study of assembly system re-design	Production Planning and Control	Workload	Productivity	Applying HF reduced risk and improved productivity 15-20% (WIN - WIN)
(Eklund, 1995) - Case study of quality deficits in assembly	Applied Ergonomics	Workload & Attitudes	Quallity & Intangibles	HF deficits related to quality deficits and reduced job satisfaction (LOSE - LOSE)
(Fenton-O'Creeyv, 1998) - Survey of 114 companies using employee involvement practices.	Journal of Organisational Behaivior	Attitudes	Productivity & Intangibles	Employee involvement improves both attitudes and performance. (WIN - WIN)
(Fisher et al., 1993) Simulation study of work-rest scheduling in repetitive manufacturing work	Human Factors	Workload	Productivity	It is possible to maximise performance within lower risk system profiles (WIN - WIN)
(Getty and Getty, 1999) - Case overview of process with specific ergonomics examples from Lockheed Martin	International Journal of Occupational Safety and Health	Health Status & Workload	Productivity & Implementation	Applying HF is a competitive advantage with ROIs as low as 6 weeks (WIN - WIN)
(Harms-Ringdahl, 1990) - Four case studies of safety interventions	Journal of Occupational Accidents	Health Status & Safety	Productivity	Safety interventions' main economic benefit is on the production side. (WIN - WIN)
(Helander and Burri, 1995) - Overview of four cases of ergonomics redesign at IBM	International Journal of Industrial Ergonomics	Health, Workload & Attitudes	Productivity & Quality	Extensive application of HF has saved over $130 in 17 years (WIN - WIN)

Reference - *Study description*	Journal	Human Effect	System Effect	Results
(Hull and Azumi, 1988) - Survey of 2500 employees in 40 companies	Work and Occupations	Attitudes	Productivity & intangibles	HF and technical factors account for equal amounts of productivity gain. Morale improved. (WIN - WIN)
(Hunter et al., 2004) - Case study of cell production implementation	Forest Products Journal	Workload	Productivity & Quality	HF in cell design improved productivity and reduced injury risk. (WIN - WIN)
(Ingelgård and Norrgren, 2001) - Survey of 69 companies conducting change (unspecified) projects	International Journal of Industrial Ergonomics	Quality of Working Life	Productivity	HF learning strategy correlates to quality of working life and economic output (WIN - WIN)
(Kazmierczak et al., 2007) - Simulation model examining both performance and spinal loads	Human Factors and Ergonomics in Manufacturing	Workload	Productivity	Strategy change increases throughput – and both increases and decreases risks. (COMPLEX)
(Lahiri et al., 2005) - Cost models of ergonomic interventions	Journal of Safety Research	Health	Productivity	Ergonomic interventions yield financial benefits from both HE & SE (WIN - WIN)
(Lanoie, 1996) - Case of 'participatory ergonomics' in a warehouse	Safety Science	Health & Quality of Working Life	Productivity & Intangibles	HF changes were profitable, some benefits difficult to quantify. (WIN - WIN)
(Lee, 2005) - case study of low cost workplace improvements	Ergonomics	Health, Workload, Safety	Productivity	HF in job design reduced injuries, reduced costs, and increased productivity 10-30% (WIN - WIN)
(Lin et al., 2001) - Two-line case study in camera assembly	Human Factors and Ergonomics in Manufacturing	Workload	Quality	Poor HF and short times linked to 50% of quality variance. (LOSE - LOSE)
(Lutz et al., 2000) - Experimental evaluation of an assembly assist device	Ergonomics	Workload	Productivity	HF device improved posture but increased task time by 13-23% without full training (WIN - LOSE)
(Morag, 2007) - Case description of applying HF programmatically	Applied Ergonomics	Health, Workload	Productivity	Applying HF systematically helps control injuries while improving performance. (WIN - WIN)

Reference - *Study description*	**Journal**	**Human Effect**	**System Effect**	**Results**
(Moreau, 2003) - Case overview of ergonomics approach at Peugeot	Applied Ergonomics	Health & Workload	Productivity	Increases in work density (productivity) increased MSD symptoms despite efforts to apply HF. (LOSE - WIN)
(Motamedzade et al., 2003) - Case study of participatory ergonomics	International Journal of Occupational Safety and Ergonomics	Health, Workload, & Quality of Working Life	Productivity & Quality	Participatory application of HF improves efficiency (WIN - WIN_
(Neumann et al., 2002)	IJPR	Workload	Productivity	Automation implementation decreased monotonous work for some increased it for others (COMPLEX)
(Neumann et al., 2006) - Case comparison of two different manufacturing strategies	International Journal of Operations and Production Management	Health, Attitudes, Workload	Productivity	System design choices have direct and interactive effects on HF and system performance (COMPLEX)
(Oxenburgh and Marlow, 2005) - Case demonstration of the economic effects of HF bsed change	Journal of Safety Research	Health, Workload	Productivity & Quality	Intervention reduces injury, and improves quality and performance (WIN - WIN)
(Parenmark et al., 1993) - Case study of HF redesign	International Journal of Industrial Ergonomics	Health, Workload	Productivity & Quality	HF redesign improved health, productivity and performance, reduced workload and turnover (WIN - WIN)
(Park et al., 2001) - Survey of tier 1 suppliers to an automotive OEM	Journal of Operations Management	Attitudes, QWL	Productivity, Quality & Intangibles	High rated suppliers have better HF that emphasise employee satisfaction than do low rated suppliers. (WIN - WIN)
(Rhijn et al., 2005) - Case study of production system re-design	International Journal of Production Research	Workload	Productivity	HF in system design secured 44% improved productivity without increased MSD risk. (NULL - WIN)
(Sen and Yeow, 2003) - Intervention case study in electronics assembly	Applied Ergonomics	Attitudes & Safety	Quality & Productivity	Product redesign improved both OHS performance and improved quality related costs; benift:cost ratio 245.8x (WIN - WIN)
(Shikdar and Sawaqed, 2003) - Survey of 50 production managers	Computers in Industrial Engineering	Health, Attitudes, Workload & Safety	Productivity	HF problems in OS correlated to poor performance and absenteeism. (LOSE - LOSE)

Reference - *Study description*	**Journal**	**Human Effect**	**System Effect**	**Results**
(Shikdar and Das, 2003) - Experiment of different production standard setting and feedback approaches	Ergonomics	Attitudes	Productivity	Participation and feedback in production standard setting improves attitudes and performance. (WIN - WIN)
(Smith, 1999) - Descriptions of case description illustrated with examples	International Journal of Occupational Safety and Ergonomics	Safety	Productivity & Quality	Including HF in system design improves safety, performance and quality (WIN - WIN)
(Sundin et al., 2004) - Case study of participatory ergonomics in product design	International Journal of Industrial Ergonomics	Workload	Productivity	Design for Manufacture improves efficiency and HF in assembly (WIN - WIN)
(Tjosvold, 1998) - Interviews of 60 employees in 1 company	Human Relations	Attitudes	Productivity & Intangibles	Use of cooperative goals resulted in improved communication, performance, and employee commitment. (WIN - WIN)
(Udo and Ebiefung, 1999) - Survey of 92 companies on their advanced manufacturing implementation	Computers in Industrial Engineering	Attitudes	Implementation	Implementation of advanced manufacturing systems improves with application of HF principles (WIN - WIN)
(Vi, 2006) - Case study of automation	Ergonomics	Workload	Productivity	Automation can reduce back injury risk and increase productivity (WIN - WIN)
(Victor et al., 2000) - Survey with 213 employees in 10 plants from 1 company	Organisational Science	Attitudes	Implementation & Intangibles	Effective employee switching strategy associated with better TQM functioning , with less stress and greater job satisfaction (WIN - WIN)
(Yeow and Sen, 2004) - Case Study of workstation re-design	International Journal of Occupational Safety and Ergonomics	Health	Productivity & Quality	Applying HF in re-design improves quality and efficiency (WIN -WIN)
(Yeow and Sen, 2003) - Case study of workstation redesign	International Journal of Industrial Ergonomics	Workload, Safety	Productivity & Quality	Applying HF in re-design improves quality and efficiency (WIN - WIN)

Reference - *Study description*	**Journal**	**Human Effect**	**System Effect**	**Results**
(Yeow and Sen, 2006) - Case study of workstation redesign	International Journal of Industrial Ergonomics	Workload, Attitudes	Productivity & Quality	Applying HF in re-design improves quality and efficiency (WIN - WIN)

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