7-1-2011

# A Framework for Integrating Human Factors into Work-System Design

W. Patrick Neumann
*Ryerson University*

Judy Village
*Ryerson University*, jvillage@ryerson.ca

This 2011 ODAM Conference paper has been extended and published as:
Neumann, W.P. and **Village, J.** (2012) Ergonomics action research II: a framework for integrating HF into work system design. Ergonomics, 55(10): 1140-1156. D.O.I.: 10.1080/00140139.2012.706714

# A Framework for Integrating Human Factors into Work-System Design

Patrick NEUMANN, Judy VILLAGE

*Human Factors Engineering Lab, Mechanical and Industrial Engineering Dept., Ryerson University, Toronto, Canada*

**Abstract.** This paper suggests a framework for helping companies integrate Human Factors (HF) considerations proactively into their development process. The interactive approach draws on activities aimed at successive stages in the development process: cognitive mapping of the strategic environment, process mapping of the design process, simulation of design alternatives, and development of metrics to support ongoing evaluation. Each initiative establishes a new dialogue in the company around how HF can be usefully integrated into design routines allowing stakeholders to adopt or adapt routines that include HF aspects as a regular part of the process of creating new work-systems.

**Keywords.** Production system design, developmental ergonomics, proactive ergonomics.

## 1. Introduction

Integrating human factors (HF; used synonymously here with 'ergonomics') considerations into the design of work systems (WS) is not a new concept. It has, however, not been the norm in most companies. This paper describes a pragmatic framework for integrating HF considerations into existing development processes that is currently being field trialed in the electronics sector.

### *1.1 HF and the Development Process*

For this paper, we define 'development process' as the organisation of activities for the design and delivery of new products or services - as illustrated in Figure 1. Traditionally, HF is marginalised from the development process and is frequently positioned in HR as a 'safety function.' As a result ergonomists are isolated in a 'side-car' and limited to expensive retrofitting of existing workstations when problems emerge, rather than affecting change earlier in design stages. In this paper we suggest a framework for considering this challenge, and approaches which can help ergonomists integrate HF considerations throughout the development process. We emphasize here that the focus of this framework is on the development process - not on the specific design solution of the work system itself. The aim of such a process based initiative would be to help organisations establish new routines to consider HF issues.

The development process, as simplified in Figure 1, may be considered as having several 'levels', each of which contributes to the extent to which front-line employees are exposed to hazards in the operation of the work system (Levels 4& 5, Figure 1). In the context of this model, strategic decision makers in Level 1, usually senior managers, have two major roles. Firstly, they are generally responsible for the organisational design and coordination of the development process - who is to do what and how in the process of development. The second important role for strategic decision makers is at the outset of the development process, in which critical decisions (Level 1) are made to develop a particular product concept in order to meet customer needs. Once a strategic choice is made to target a particular market sector, like young car buyers for example, the product-design process is initiated. The product-design team, in level 2 of the development process, will make all determinations around the product form with consequent decisions on, for example, part masses and connection forces required in construction. This defines the assembly task which the production system must accomplish. At level 3, the engineering team will design the production system itself determining flow strategies, outsourcing and logistics systems, the division of labour between operators, and the specific workstations and tools to be used by the operators in the eventual production system (Level 4). In practice there may be more or less interaction between layers during development.

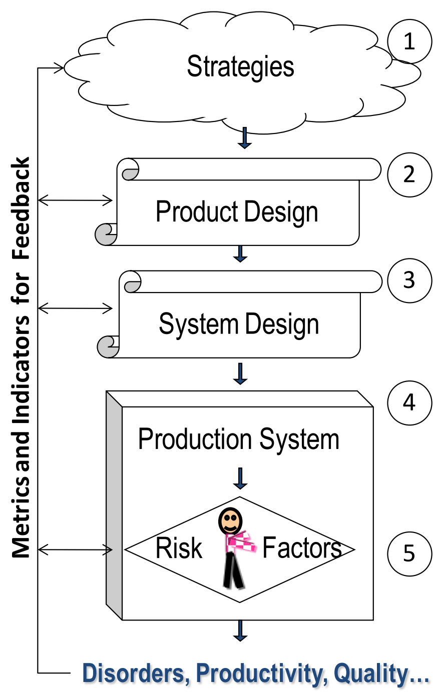



*Figure 1: Simplified model of the work-system development process.(adapted from Neumann et al., 2009).*

This model has been empirically validated through case study research (Neumann et al., 2002; Neumann et al., 2009). The implication of this model is that both the psychosocial and biomechanical hazards for employee disorders in the work system are the consequence of a series of decisions made throughout the development process. If hazards are to be avoided then ergonomics considerations need to be embedded throughout the development process. A further implication is that the system's output is not just employee disorders, but includes also the quality and productivity of the system - both critical aspects for the firm that are known to benefit from the application of ergonomics. These benefits of good design become a potential means to engage stakeholders in the development process who do not see themselves as having an OHS responsibility and may be otherwise unmotivated to consider HF. As a motivational tactic, we have proposed that companies who intend to integrate ergonomics into their development process aim for the double-win available by targeting an improvement of 20% in both human outcomes (e.g. injury reduction) and technical (e.g. increased quality, productivity). We call this the 'HF 20/20 Challenge'.

## 2. Integrating HF into Development

This paper describes a 'framework', rather than a series of discrete steps. The starting point and the sequence of initiatives will depend on the particular case in question. Pragmatically, the ergonomist, or change agent (CA), will begin based on their entry point into the organisation, for example through engineering or human resources. The CA then acts with (micro-) political savvy to navigate amongst relevant individuals, groups and processes within the organisation to gain support in furthering their objectives (c.f. Broberg et al., 2004). While CAs must start with any initiatives that get traction, they should continue with new initiatives to achieve improved integration on an ongoing basis. We will present sample initiatives at each of the levels from the model (Figure 1) but would also encourage readers to be creative in adapting the line of thinking laid out in this framework to meet the particular situation they are facing.

Three tactics for the CA, which span developmental levels, need to be mentioned:

METRICS - The use of 'metrics' or indicators is often seen as a powerful tool to manage business improvement processes such as quality. We have observed that few companies have leading indicators of injuries, either at the shop floor level or as upstream design level indicators that can support consideration of ergonomics early in the design process (Neumann et al., 2002). The design and implementation of HF metrics requires close consideration of the existing metrics system. Currently in the literature there is little specific advice on creating such indicators and this element warrants further research. This is conceptually illustrated in Figure 1.

TRAINING - Training and education (T&E) have been suggested to be an important aspect of any HF initiative. T&E can either be done in separately at the beginning of the change effort, but may more usefully be built in to other aspects of the initiative so that the new knowledge can be brought to use as the integration efforts proceed. The CA needs to consider the timing, content and participants that should be involved in training for the specific HF integration initiative at hand.

PARTICIPATION - Participation is generally seen as an important means of engaging and motivating employees (and managers) in new initiatives. By participating in choosing new routes of action, and understanding the reasons for the change, people will be more inclined to support the change and make sure the best solution is reached. The use of Workshops, with cross-functional teams addressing a focussed issue under consideration, is one strategy to help stakeholders understand the larger process and identify avenues for desirable change.

In the next three sections we will, in a bottom-up sequence, describe some of the tactics and methods available at the individual development levels (per Figure 1). This paper will not explicitly address improvements to existing systems where re-design and retrofitting processes are needed - although we note that a feedback loop from such a re-development process should target the original design team to avoid repeatedly implementing flawed designs.

### *2.3 Production System Design Level*

In order to understand where in the design process critical decisions with HF implications are being made, a conventional business process mapping approach can be applied to the design process. Interviews or focus groups can be used to understand the actual stages and individual steps in the design process. These steps of the production system design process can then be sketched graphically in the form of a 'map'. The 'map' can then be used to engage design team members in identifying specific improvement opportunities using, for example, a workshop.

Another aspect to support system design stage consideration of HF is the use of 'virtual' human factors tools - tools capable of providing useful HF information when there is no 'real' worker to observe. Digital Human Models (DHMs) pose a widely used example of a virtual tool that can explore the interaction between the operator and the proposed layout of a given workstation. Discrete event simulation (DES) can be used to explore the dynamic flow aspects of the proposed system. While less commonly used for HF, DES has potential to provide useful information on critical work-rest patterns for workers as well as psychosocial considerations like autonomy Predetermined motion time systems (PMTS) pose another opportunity as some of these tools have been adapted to allow simultaneous consideration of force, posture and repetition while balancing flow lines (e.g. Laring et al., 2005). As technology costs drop, 'virtual reality' and 'mixed reality' approaches begin to become more generally affordable design assist tools (c.f. Hallbeck et al., 2010). More research and development is required to bring 'virtual' HF tools into regular use.

### *2.2 Product Design Level*

There are several methods available to support the consideration of HF aspects in the product design phase. Principles for 'Design for Manufacturability' have been spelled out by Helander & Nagamichi (1992). When applied, these techniques have been shown to greatly reduce both the time required to assemble products as well as the physical demands of the assembly. 'Failure mode effects analysis' (FMEA) is another industry standard technique for identifying potential quality issues in product design. FMEA is a systematic approach to examining each product component (or sub-system) to determine the probability and consequence severity of a failure of that component. It can be applied at the product-design stage, as well as during design of the assembly process for the product. FMEA has been applied to HF considerations where operator error is concerned (for example, in providing medication in hospitals), but few examples have been found where it has been applied to physical risk factors and prevention of musculoskeletal injuries.

'Virtual' HF tools are also useful in this stage. DHMs can be used to anticipate postural issues for operators - particularly when products are large and reach-fit and vision issues a concern. Simpler 'product design' checklists might also prove useful.

*2.1 Strategic Level*

To help senior managers understand the strategic benefits afforded by HF, a technique called “cognitive mapping” is suggested (Eden, 2004). Through individual interviews managers explore their perceptions about how human factors can be integrated into design processes to achieve a company’s overall strategic goals. The interviews are visually “mapped” – an operational research approach that yields a graphic representation of a person’s perceptions about an issue. The map helps organize thoughts, draws links between issues, explores cause and effect relationships, and allows the manager to see their emerging ideas. Individual maps are then merged into a group map and further explored during a workshop where individual ideas are seen in the context of others. The resultant group map provides the basis for action items for integration of HF into the companies design processes in a way that aligns HF with their overall strategic goals.

## 3. Discussion

Taken individually, the methods and tactics outlined in this paper are not new. Indeed each method is associated with a specific stream of research in either the ergonomics or operations management literatures. The framework in this paper is an attempt to assemble these tools in a coherent way in order to provide guidance for the integration of HF aspects throughout a company's development process. Neither design, nor organisational change, operate in a strictly linear pattern amenable to the application of n-step change models. For this reason, the 'framework' here provides a mental model to support the consideration of possible routes of action in a given context at a specific time in order to tailor the effort to match the situation. It also provides some of the techniques and methods that could be applied to a given level of the development process. The framework itself may be considered a 'tool' to help CAs identify useful and achievable improvement action in their organisations - it should be adapted as needed.

Two important aspects are beyond the scope of this paper - implementation and scientific evaluation. Regarding implementation, organisational change is difficult, and there are many discussions in the scientific literature on strategies and tactics for change. Our experience is that there is considerable improvisation and adjustment required in such change efforts (Neumann et al., 2009). This framework itself takes a 'developmental' approach to improving the organisation's product development process - through a series of participative 'initiatives' aiming at organisational change. This contrasts to an attempt to implement a more complete 'master plan' as a single large effort. This developmental strategy allows a unique approach to be developed that is optimised for the context of the current company and the employees involved. To achieve this end, Broberg & Hermund's (2004) conceptualisation of the 'political reflective navigator' is useful: the CA must begin with their current situation, identify the most feasible next step, and use that step to open doors for new initiatives at other levels of the system. Secondly, in terms of scientific evaluation, it is the authors' opinion that the complexity and context specificity of applying the proposed framework make it premature for experimental evaluations. Instead longitudinal case studies, formative analysis, and multiple cases using 'action research' approaches are more likely to generate useful knowledge on the utility of the framework presented here. We also see the need to extend this framework to less routine work system development than is seen in manufacturing, such as in service or process industries, where development is more periodic or the concept of 'product' is qualitatively different from manufacturing.

## 4. Conclusions

Applying human factors in the development of new work-systems has the potential to help companies design superior systems at lower cost than more commonly applied reactive approaches. The framework for integrating HF into development outlined here aims at all levels of the developmental process and depends on participation throughout the organisation. A variety of tools have been discussed that can improve the production system process. This kind of development effort may be facilitated by establishing leading indicators of risk within the organisation that can help various stakeholders demonstrate the superiority of their new designs. It should also include feedback mechanisms that reward superior solutions and ensure that design flaws are not re-produced in subsequent generations. Achieving this change will be a non-linear, participative process in which the ergonomist must act a catalyst to foster organisational development across a range of organisational functions.

*Acknowledgements*

This work has been made possible by funding from the Natural Science and Engineering Research Council of Canada (NSERC) and by the Workplace Safety and Insurance Board of Ontario (WSIB).

## References

Broberg, O. & Hermund, I. (2004). The OHS consultant as a 'political reflective navigator' in technological change processes. International Journal of Industrial Ergonomics, 33(4), 315-326.

Eden, C. (2004). Analyzing cognitive maps to help structure issues or problems. European Journal of Operational Research, 159(3), 673-686.

Hallbeck, M., Bosch, T., Van Rhijn, G., Krause, F., de Looze, M. & Vink, P. (2010). A tool for early workstation design for small and medium enterprises evaluated in five cases. Human Factors and Ergonomics in Manufacturing & Service Industries, 20(4), 300-315.

Helander, M. & Nagamachi, M. (1992). Design for Manufacturability: A systems approach to concurrent engineering and ergonomics. Taylor & Francis.

Laring, J., Christmansson, M., Kadefors, R. & Örtengren, R. (2005). ErgoSAM: A preproduction risk identification tool. Human Factors and Ergonomics in Manufacturing, 15(3), 309-325.

Neumann, W.P., Kihlberg, S., Medbo, P., Mathiassen, S.E. & Winkel, J. (2002). A case study evaluating the ergonomic and productivity impacts of partial automation strategies in the electronics industry. International Journal of Production Research, 40(16), 4059-4075.

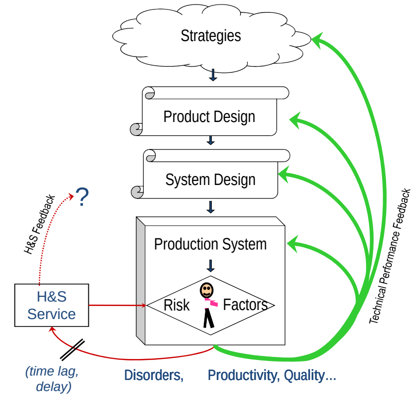
Neumann, W.P., Ekman, M. & Winkel, J. (2009). Integrating ergonomics into system development - The Volvo Powertrain Case. Applied Ergonomics, 40(3), 527-537.

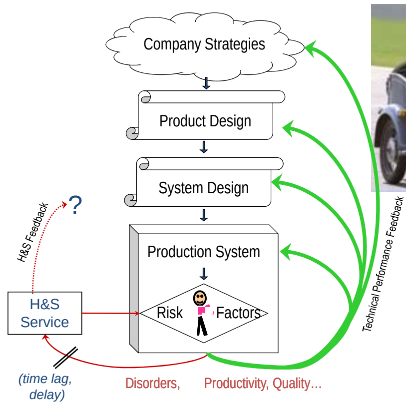
RYERSON UNIVERSITY HUMAN FACTORS ENGINEERING LAB

# A Framework for Integrating Human Factors into Work-System Design

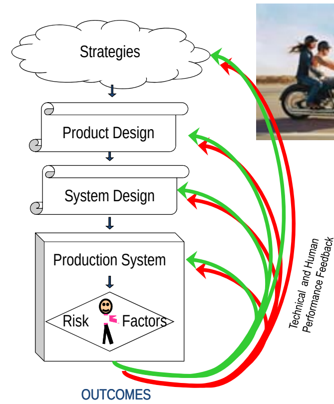
Patrick Neumann, Eur.Erg., Judy Village
Ryerson University, Toronto, Canada
Department of Mechanical and Industrial Engineering
Human Factors Engineering Lab

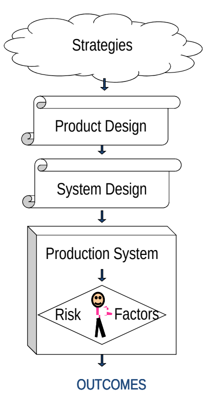
pneumann@ryerson.ca
www.ryerson.ca/hfe



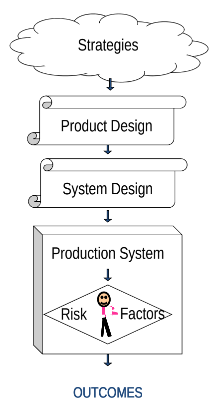

Ergonomics 'Side Car'




## ENGAGE via Goal Hooking

- Connect to Strategy
  - (Dul & Neumann, 2009)
- HF 20+20 Challenge
  - + 20% in both Human and System effects
  - HF as means not goal
- Action at ALL levels of Model

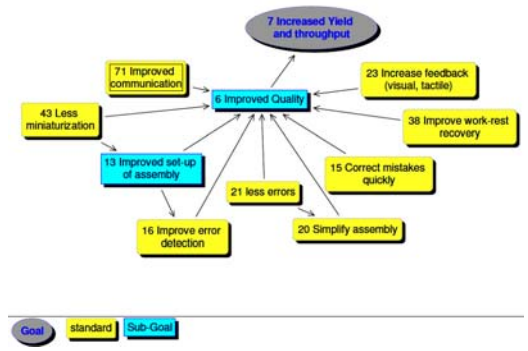



## CONNECT TO STRATEGY

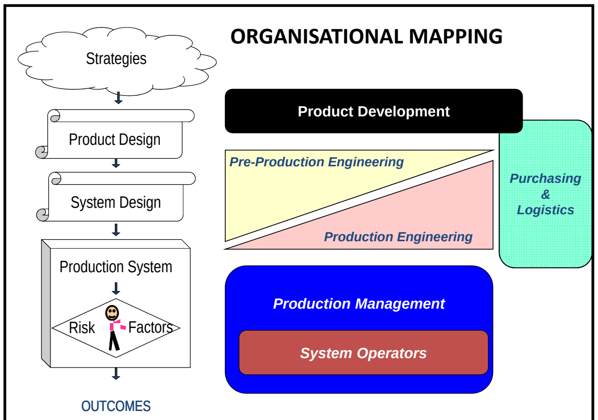
**1. Cognitive Mapping**
- **Interview Managers**
- **Map key concepts**
- **Identify HF links**
- **Build support for action**

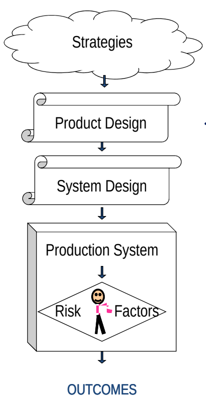
**2. Organisational Mapping**
- **Identify Groups**
- **Relate to theory model (left)**
- **Use plan steps - PRN**
- **(c.f. Broberg & Hermund, 2004**

## Cognitive Mapping




## ORGANISATIONAL MAPPING




## PRODUCT DESIGN STAGE

**- Design For Manufacturability (c.f. Helander et al.)**

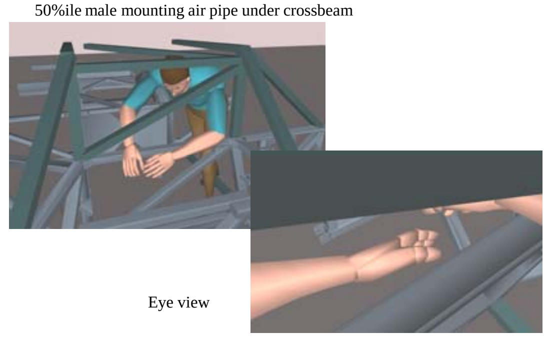
**- HF Design Criteria ('Standards')**

**- Virtual Ergonomics (e.g. DHMs)**

**-Failure Mode Effects Analysis (FMEA)**

## Examples of analysis situations - Buss

50%ile male mounting air pipe under crossbeam

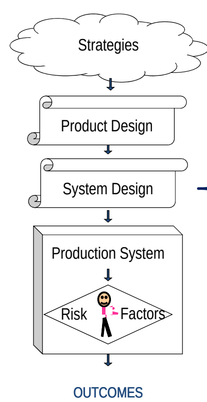


Eye view

Sundin 2000, IEA

## HF-FMEA

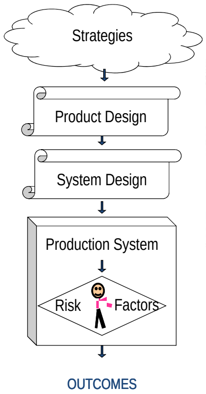
- Failure Modes Effects Analysis
- A standard risk assessment tool
- Examines Product Element by Element:
  - Type of Failure
  - Probability of Failure
  - Severity of Failure
  - Countermeasure
- Need approach to create HF-FMEA
  - (Village et al., ACE Conference )



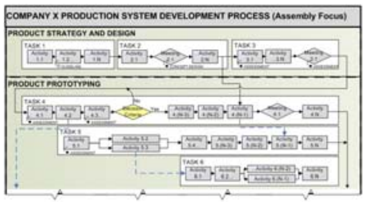

## DESIGN PROCESS IMPROVEMENT

**- Business Process Mapping (BPR)**

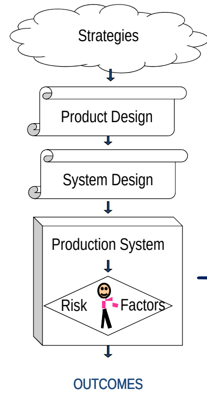
1. **Interviews and docs analysis**
2. **Map acts as boundary object**
3. **Identify Points of engagement**
4. **Improve HF capability at each points**




**DESIGN PROCESS MAP**




- **Watch out for detail level**
- **Adapt as needed**
- **Use anticipatively to**
- **Identify Opportunities**

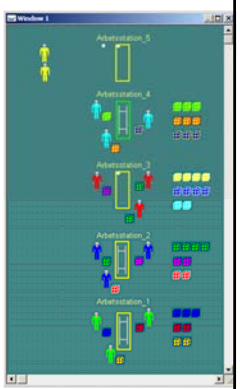



**IMPROVE SYSTEM DESIGN**

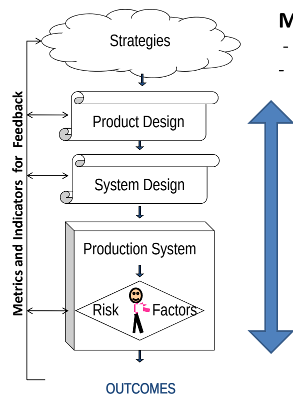
1. **HF in System Modelling (e.g. DES)**
2. **HF – Kaizen events (a.k.s. PE)**
3. **Apply typical retrofitting tactics**

## Flow Simulation

- Discrete Event Simulation
  - Model sof the SYSTEM
- Needs HF think
  - (e.g Neumann & Medbo ODAM 2009)
- Time pattern of work



**METRICS to Support Design**
- Feedback to decision makers
- Helps Anchor process




Leading Indicators

Lagging Indicators

## Discussion / Conclusions

- Framework addresses multiple levels
- aims to support participation
- Apply Workshops and multiple methods
- A framework not a plan – a tool for planning
- Needs Evaluation
- Case studies 1st
- Participatory Action Research

## Stop Talking about here

**Acknowledgements:** Support from Workplace Safety and Insurance Board (WSIB) of Ontario and the Natural Sciences and Engineering Research Council (NSERC) of Ontario