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Who is Responsible for Human Factors in Engineering Design? The Case of Volvo Powertrain

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For a more in-depth look on this subject, please see:

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Neumann, W.P. and Winkel, J., 2005. Organisational design and the (dis)integration of human factors in production system development. In: B. Chase (Editor), Human aspects of advanced manufacturing: agility and hybrid automation, San Diego, USA. http://digitalcommons.ryerson.ca/ie/13/

Neumann, W.P., 2004. Production Ergonomics: Identifying and managing risk in the design of high performance work systems, Lund Technical University, Lund, 159 p. ISBN 91-628-6287-1. http://digitalcommons.ryerson.ca/ie/5/

Neumann, W.P., Wells, R.P., Norman, R.W., Jeans, B., Dubblestyne, D., Harvey, H., Peter, O. (1999) Roles and Relationships for Making Ergonomics Change: Results of a 2-Day Focus Session with Industry Personnel. Proceedings of the 31st Annual Conference of the Association of Canadian Ergonomists, Hull, Canada

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Who is Responsible for Human Factors in Engineering Design?

The Case of Volvo Powertrain

Neumann, W.P., Winkel, J.

Abstract

A case study in Volvo Powertrain is conducted to examine the distribution of responsibility for human factors in the companies' engineering design process. Design decisions with human factors impact, and hence system performance implications, are identified in the design of both the product and the production system in a chain of decisions, spread across multiple stakeholder groups. Thus the organisational structure of the engineering design process appears to influence the ability to handle human factors appropriately at each stage of design. Responsibility (although perhaps not accountability) appears to be distributed throughout the engineering design process. Thus human factors aspects require careful coordination throughout engineering design.

1. Introduction

Poor Human Factors (HF) in industrial systems can lead to lost productivity, quality deficits, and even injure system operators. The costs for work-related ill health (WIH) alone are globally estimated at about 4% of GDP [2] or, in Ontario's case, $19 billion in 2004. While many researchers have called for the integration of HF considerations into the routines of engineering design [5-7], it is not clear what this might mean in practice – the source of HF hazards is not understood. Where does responsibility for human factors lie in the design process? This paper presents results from a case study in Volvo Powertrain, Sweden, in which we examine the effect engineering design decisions have on operators and the distribution of decision responsibility within the design organization.

In this paper we emphasise *design* at three distinct levels:

1. Product Design,
2. Process (Production System) Design, and
3. Development Organisation Design

Figure 1 illustrates the linkages between product and production system design and eventual ergonomic risk factors in the operational production system. The production system has therefore joint outputs of health (or ill health) from the system operators perspective and productivity and quality aspects from the product's perspective. Human factors, by the International Ergonomics Association's own definition, supports dual objectives of human well being and system performance [8]. This is consistent with the aim of designing sustainable work systems in which human resources are used optimally rather than consumed in order to obtain lasting competitiveness [9]. The design of sustainable work systems requires attention to

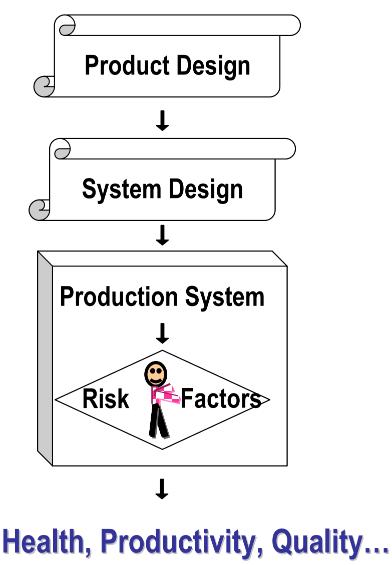

Figure 1: Simplified model of relations between design and ergonomic risk for in the production system. Risk Factors may lead to operator ill health and reduced performance. [Adapted from 3, 4]

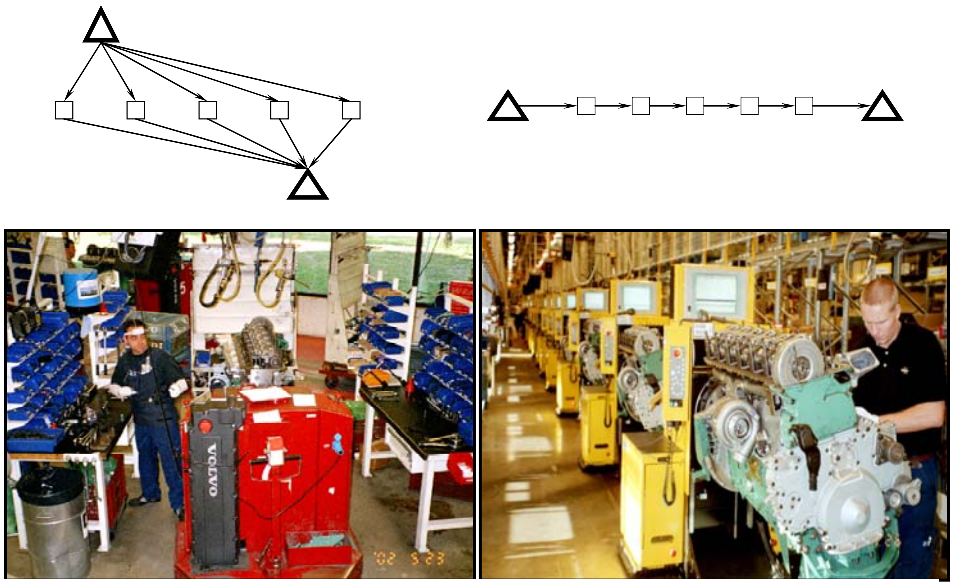

Figure 2: Schematic and picture for both long-cycle parallel flow assembly system (Left) and serial flow line assembly system (Right)

productivity, quality, and human factors in the design process.

By *development organisation* design we refer to the ways in which the developmental processes (including engineering design) within the firm have been organised. This can include both formal structures and procedures that define the responsibilities and communication channels throughout the industrialisation process [10]. The extent to which the company applies concurrent engineering, for example, forms a part of the design of the firms 'development organisation'[11].

In this paper we will use an example case of development at Volvo Powertrain in Sweden. Each of these aspects of design have the potential to influence human factors in the resulting work system and thus contribute to the elimination, or creation, of work related ill health in employees. This paper combines reports and analyses from previous work [1, 3, 12, 13] and re-frames the case in terms of engineering design; the context for the current academic discussion.

2. Methods

Serial line flow strategies were implemented after years of using a parallelised long-cycle assembly approach (see Figure 2). Key elements examined included the flow strategy, material supply sub-system, layout, conveyance system, and work organizational approach. The assessment included evaluation of known musculoskeletal WIH risk factors such as peak and accumulative physical loading, as well as psychosocial factors such as operator autonomy and psychological demands. The detailed analysis also included system performance indicators – details of methods are published elsewhere [13].

Following the comparison of old and new systems the research team entered into a collaboration with the company to improve their own ability to handle human factors in their development process. Operating in an 'action research' mode [14] we participated in and studied the organizations developmental efforts. The details of this methodological approach and of the organizational change process are also presented elsewhere [3].

3. Results

We found that choices made at each stage of the design process had an effect on the resulting HF conditions for system operators. In many cases these effects interacted. We present examples from this study that illustrate this general finding.

PRODUCT DESIGN

Product design defines the assembly tasks and can influence, for example, the forces required by the

Figure 3: Line operator installing turbo unit sub-assembly using lift assist device.

operator to complete the assembly task. In the case of engine assembly we observed considerable time and effort required to accommodate the mounting of turbo chargers onto the motor. Handling of the heavy turbo unit with it's associated sub-assembly was recognised as an ergonomic hazard. The desire to install lift assist devices in the assembly system was given as one of the advantages in the move from parallel long-cycle assembly to serial flow line assembly in production since the line could be served by a single assist device where the parallel flow system would require multiple devices to serve all stations. The lift assist is illustrated in Figure 3. The turbo unit, however, came in over 10 variants for different customers. Since these were delivered in large crates, there was insufficient space to place these crates along the line where the lift assist could reach them. As a result many variants still required manual handling in the new line system (Figure 4). The company spent considerable time and effort trying to accommodate this product component in manufacturing.

Figure 4: Heavy parts stored in large crates lead to high low back loading and elevated risk for operators.

PRODUCTION SYSTEM DESIGN

In this case study we observed a strategic change in production approach that included a shift to a serial flow organisation with shorter cycles, work organisation, material supply, and layout. The ergonomic and productivity effects of these changes in moving to conventional serialised line production are summarised in Table 1. The choice of linear flow, for example, led to reduced operators' psychological sense of control (a WIH risk factor), increased physical repetitiveness, and also compromised system performance due to systems losses of blocking and starving. Choices of material supply sub-system (logistics), combined with layout choices, affected operators' peak physical loading (figure 4) and increased the amount of time operators spend in indirect 'getting parts' work rather than completing actual assemblies. The adoption of team-work approaches, combined with a layout permitting operator interaction, improved operators' sense of co-worker support – an HF Benefit. The WIH risk posed by these system elements were generally 'locked in'

Table 1. Advantages and disadvantages experienced by Volvo Powertrain in moving from parallel dock to serial line production [adapted from,1] .

Change	PRODUCTIVITY		ERGONOMICS	
	+ Advantages	- Disadvantages	+ Advantages	- Disadvantages
From Parallel to serial flow	Easier to control and manage work.	Inflexible and vulnerable to disturbances.	System disturbances may offer physiological rest	System disturbances are not perceived as pauses.
Reduced Cycle time	Less training needed per station.	More system, handling, balance, and variant losses.	None.	Reduced physical variation and increased repetitiveness.
Work organisation	Operators work throughout the shift.	Extra operators needed handle disturbances.	No incentive to rush. Teamwork is encouraged.	Reduced work content. Reduced job control.
Material Supply	Conventional continuous supply which often implies reduced cost.	Many product variants can create space shortages and extra material handling.	Easier to introduce part specific lift assists.	More walking, more difficult getting parts from big crates.
Factory Layout	Complete assembly equipment not needed at each workstation	Less flexible, more space, buffers and workstations needed.	Some stations have lower workloads.	Some stations have higher workloads

by their own implementation – retrofitting to reduce risk would be too expensive and program budgets were depleted.

The use of large crates, chosen by logistics, for material supply of heavy parts, designed by product development, provides a good illustration of how decisions made early in design can affect HF in terms of both risk and performance. In terms of risk, the large crates lead to awkward postures and elevated loading for operators – particularly as they reach to the bottom and back of the container (Figure 4).

DEVELOPMENT ORGANISATION DESIGN

Product design was coordinated by a group in a different city from where production occurred and included stakeholders from the firm internationally. The production system design process was divided amongst several groups each with separate responsibilities namely, pre-production engineering, production engineering, purchasing and logistics, and production management. These groups are illustrated, in Figure 5 which also includes production operators who are exposed to any eventual risks in the designed system.

The pre-production engineering group was responsible for meeting production objectives set by senior managers operating at strategic levels. Pre-production engineering's tasks included designing the flow pattern of the system, fitting this flow into available space, designing the transport sub-system, and making a preliminary division of labour based on the assembly specifications provided by the product development group. In this case, the move to serial line assembly appeared to be influenced more by strategic manager's choices rather than from the pre-production engineering group directly. Production engineering, in turn performed the detailed design of workstations, material and component placement, and tool positioning for the system based on the system outline provided by the previous group. Purchasing and logistics worked in parallel with these groups sourcing components from suppliers and arranging for the timely arrival of components to the production manufacturing facility. Production engineering was generally required to accommodate the component containers and packing materials determined by the purchasing and engineering groups. Finally production management was responsible for work organisational aspects of the system including job rotation schedules (if any) and staffing levels required – for example the number of extra operators needed to assist along the line to help handle production disturbances.

Thus we saw the engineering design process distributed between different groups with different priorities and often working in different locations. The interaction and coordination between groups appeared to vary depending on the design issue and organisational factors such as physical proximity that simplified formal and informal communication. During the field work, it was our impression that concern for HF increased the closer the group was in space and 'design stage' to the production operators themselves.

The company used a formally established 'Global Development Process' to manage their development system. This 'stage-gate' management system established criteria that must be met before each consecutive 'gate' could be opened for further development [15]. HF elements were generally not part of this process. In the course of the project however, this system became was targeted target by the production manager as a means of embedding HF into the engineering design process. Making changes to the formal system however required the participation of a number of stakeholders including managers with international responsibilities who were based in different cities from the production facility. These change efforts appeared to require both time and energy to realise.

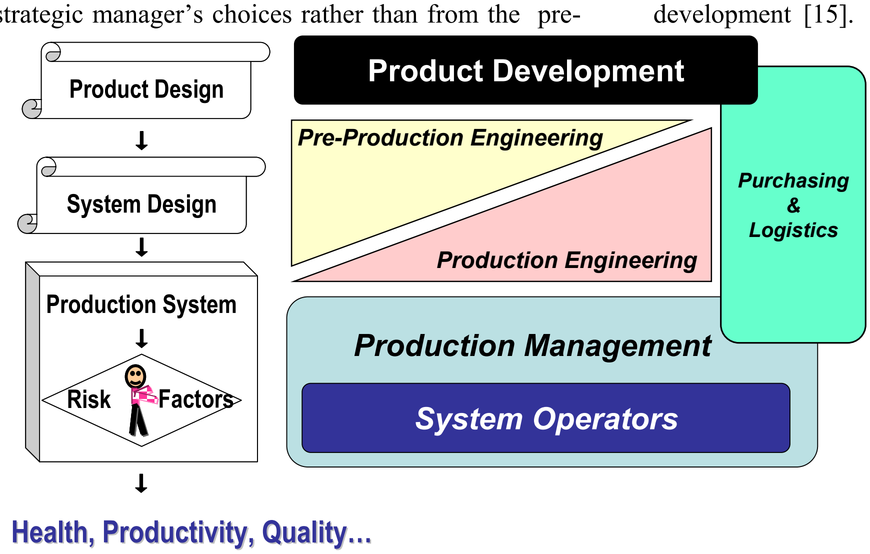

Figure 5: Organisational design as observed in the case of Volvo Powertrain (adapted from Neumann 2004)

4. Discussion

This case has illustrated how health risks for production operators can be influenced by engineering design. This can include the design of the product as well as the design of the production system itself. Furthermore these design processes are themselves subject to influences based on the design of the organisation's own development process – the make up of the groups and their roles and responsibilities in the development of both the product and the production system.

While this paper has focussed on the health risk aspects of poor HF, we point out that HF, as defined by the international ergonomics association contains dual objectives of operator well being and system performance. While attention to HF can save money by avoiding costs related to ill health there are many performance benefits beyond this including quality improvements [16, 17] and productivity improvements [18-20]. Achieving these benefits in any particular case may depend on good management of the engineering design process. As this case illustrates, HF problems (and potential gains) exist at each stage of the design process. Coordinating across the different groups and stages of the design process can pose a challenging change for companies interested in capitalising on HF in their operations.

As we observed in this case, and in similar situations where multiple variants exist, the use of large crates can cause space shortage problems along a conventional line and lead to considerable carrying for operators who must move up and down the line to acquire the needed component variant [21]. Alternative strategies with HF benefits that include decreased risk and increased performance include the use of narrower, modular containers [21], and the use of kitting approaches that separate material acquisition functions from the actual assembly work [13, 22, 23]. In the material supply system we see an example of the complex interactions between product design (component design), production system design, and the organisational aspects that include all groups involved in the development process.

Design theory suggests that, for human factors to be achieved in a cost-optimal way, it is necessary to embed HF considerations into the early stages of development where concepts are still malleable and before most costs have been allocated [24]. We see in this case how early strategic design choices of serial or parallel flow can influence both physical and psychosocial human factors for production operators. While early integration has long been a goal of the human factors community, this appears to be difficult to realise as tools and methods are either lacking [6], not being applied [5], or considered late in the process where costs of change are high [25]. This appears consistent with our case where the production management appeared to realise the need to embed ergonomics in their process, but found it challenging to realise the necessary support from upstream stakeholders. These 'strategic' stakeholders appeared to lack tools and processes to support decision making surrounding the HF consequences throughout the engineering design process. As we observed changing the development process involves many different people and calls on 'political' skills similar to Broberg and Hermenuds concept of a 'political reflective navigator' [26].

The presence of communications gaps between groups has long been discussed in the organisational literature and forms a barrier for organisational learning [27]. Other barriers to successful learning of how to capitalise on HF in production include a lack of adequate feedback expressed in terms useful for the design team, lack of understanding of HF methods and tools, and the absence of a mandate to consider HF in certain stages of development. In this case, the process of changing the organisational development process was slow and required continual support. By incorporating human factors criteria in the design stage-gate checklists it may be possible to take better account of these factors throughout the engineering design process. Coordinating HF across design stages may also be easier to support in the context of concurrent engineering allowing easier communication between groups of possible design element interactions [11, 28]. In this case, changes of this nature however would involve new stakeholders at the corporate level and with related firms Mack Trucks and Renault. Navigating these new interest groups remains a challenge for the project champion. One tactic under consideration is the development of internal educational material to assist in developing skills and knowledge necessary to implement appropriate criteria for HF into these organisational processes.

Although the patterns observed in this case seems consistent with other case studies, one must be always cautious when generalising or transferring findings from a particular case. Instead we attempt to extract lessons from the case study that we believe illustrate both theory and existing empirical observation from other cases. The framing of reports in action research is a qualitative choice made by the researcher who must transform the complex, non-linear nature of organisational practice into a linear narrative [29]. While interpretations of events may vary we have engaged the company in verifying our perceptions throughout the project. We also used the separate perceptions of different members of the research team to provide a kind of 'triangulation' of perception so as to reach a common understanding of the process of change.

5. Conclusions

The title of this paper asks: who is responsible for HF in engineering design? This case suggests the question can be answered in two ways. Firstly one can say: "no one person" is responsible for HF since HF conditions are often emergent from the interaction of many different decisions throughout the development process – including decisions as to how the development process itself is to be conducted. If however, we are to focus on improving HF conditions, with the joint aim of reducing work-related ill health and improving performance, then a more useful answer to the posed research question would be: "everyone" in engineering design influences and is thus responsible for HF in the production system .

The case study here provides concrete examples of how engineering designers influence human factors and risk of WIH for production operators. In order to obtain more sustainable solutions there is a need to improve coordination between the different design stakeholders throughout the process.

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