Ergonomics and effective production systems
– moving from reactive to proactive development

Experience and results from a collaboration between the Swedish National Institute for Working Life and Volvo Powertrain in Skövde, Sweden

Arbetslivsinstitutet

National Institute for Working Life

The National Institute for Working Life is a national centre of knowledge about working life issues. The Institute is commissioned by the Swedish government to carry on research and development, disseminate information, and hold advanced, specialised training courses.

The institute's prime objective and mission is to contribute actively to a working life that offers good conditions and development opportunities for women and men. We work to promote a healthy working environment that is adapted to people's different physical and mental needs and capacity. This we do in collaboration with the social partners and professionals who are actively involved in issues concerning working life.

Our research focuses on areas such as occupational health, the labour market and employment, labour legislation, work organisation, ergonomics and strain, physical and chemical health risks, integration and diversity, and development processes in working life. We endeavour to ensure that our research is multidisciplinary and benefits people in their working lives.

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Since 2002, the production ergonomics research team at the Institute for Working Life, in close collaboration with Volvo Powertrain in Skövde and Chalmers University of Technology, has investigated the opportunities for creating industrial workplaces that are both effective and healthy. This project, which is funded by Vinnova, has resulted in a series of research reports as well as a doctoral thesis.
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Ergonomics and effective production systems

The competitiveness of Swedish manufacturing industry is crucial for our current and future welfare. To follow the development within production technology and other productivity-related fields is an important task for every manager.

Automation is one type of measure, changing work organization is another. The main issue is to maximize the working time that generates added value while eliminating or reducing operations that do not generate value.

During the past decade, a change or return to serial production has become apparent in Sweden. In the same period we have seen improvements in productivity, but also increased reporting of occupational health problems.

Disorders and illness give rise to costs related to loss of competence, production and quality deficits, as well as the hiring and training of new staff.

This has led to an increased focus on ergonomics and other work environment factors. However, these are usually limited to management at the individual level including workstation redesign.

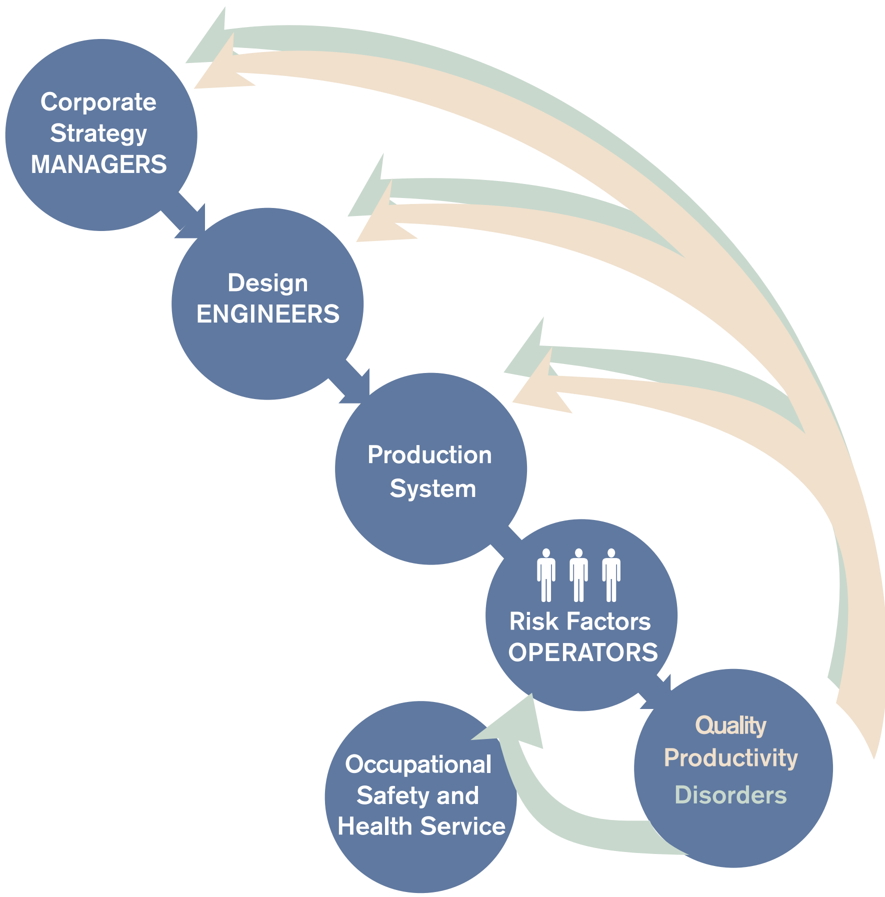

Fig. 1. Strategic and design based decisions are of importance for productivity and quality as well as disorders. The line organization in itself deals with issues about productivity and quality, while ill-health lies within the companies' Occupational Safety and Health Service sector. In an ideal situation, even the ergonomic risk factors behind ill-health are considered in production strategy, design and the layout of the production system.


For several years, the National Institute for Working Life has monitored work at Volvo Powertrain in Skövde. During 2002, a reorganization was carried out with which the earlier model with 'docks' for parallel production (left picture) with an assembly worker in each one, was replaced by a serial production system with an assembly line (right picture).

The concept that strategic decisions about production have implications for work environment is getting increased support.

The production system design is determined in a process with several stages (see fig 1 page 3). First to be discussed are production strategies, which are transformed into a production design and finally into a production system. By this process, the main features of the work environment and ergonomics are determined.

Feed-back regarding quality and productivity in the production system is managed within the line organization. On the other hand, there is often a lack of tools for both predicting and solving ergonomic problems during the design phase. Emerging shortcomings – leading to disorders in some form – are solved, when possible, *reactively* by the occupational safety and health service. This process does not necessarily have any organizational connection to production system design. Vital experience does not reach those that design the systems and significant improvements are not realised *proactively*.

The challenge is to integrate ergonomics into every phase in the design of the production system and thus to give ergonomics a proactive role in planning. In this way, the impact of production system design on ergonomics can be predicted and adjusted before changes are implemented.

In several studies, the National Institute for Working Life in collaboration with Volvo Powertrain, have investigated how ergonomics can and should be integrated into a company's daily development work. Thus production and ergonomics may be combined to develop a sustainable production system. Thanks to Volvo Powertrain, much of the experience and knowledge gained from our co-operation can now be published and discussed from a more general perspective.

Production development within Volvo Powertrain

During 2002, Volvo Powertrain in Skövde carried out a redesign of production. This involved changing earlier parallel assembly of engines to a serial production system, a so-called line.

There were several reasons for the company changing the production system, and in many respects these were the same as those guiding other companies. Material supply might be facilitated, training times shortened, and future changes might be facilitated as these then only have to be carried out at one workstation. In addition, it was assumed the cost per unit could be reduced.

In this context, a research project was carried out at the car engine factory in Skövde with the aim of investigating how ergonomics can be integrated into the company's development process.

The purpose of the project was to investigate approaches to helping companies develop their own capacity in the design of sustainable production systems considering both ergonomics and efficiency.

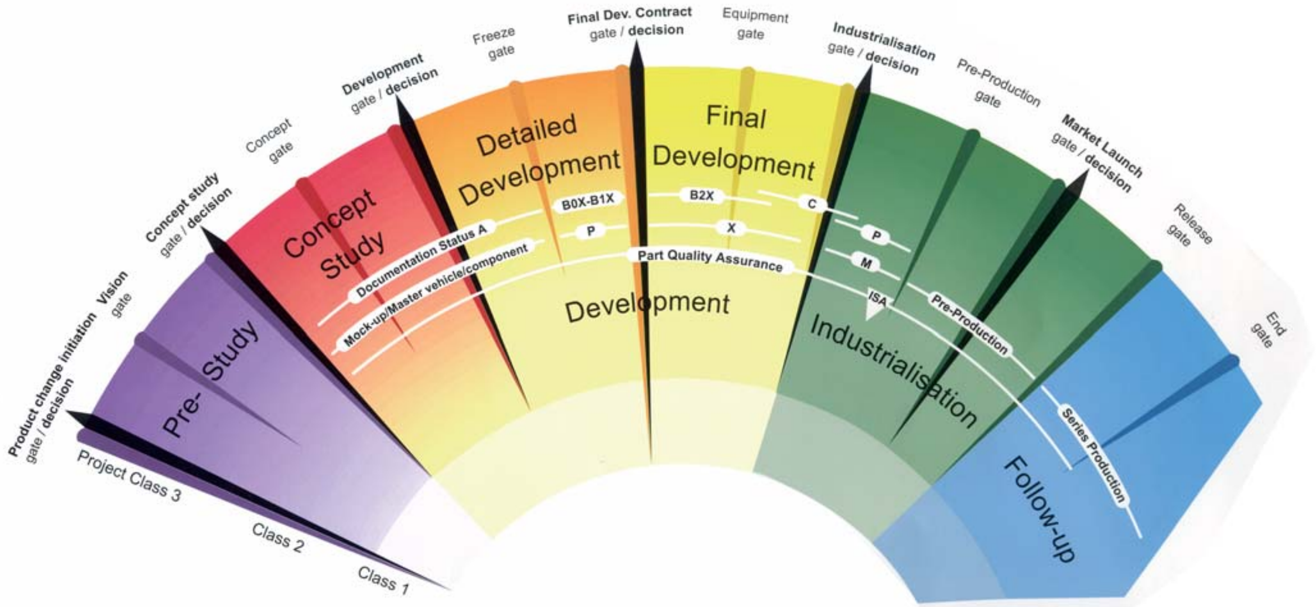

Fig. 2. The Volvo Corporation has developed a 'Global Development Process' GDP, which describes development processes with regard to new products and production systems. The built-in check-points, 'gates', cannot be passed until all demands at the previous level have been met. Volvo Powertrain in Skövde, in the light of the described research project, has begun to integrate ergonomics and working environment in the GDP.

Experiences of the transition from parallel to serial production

Volvo Powertrain in Skövde manufactures diesel engines for trucks. A production system with a number of parallel workstations, or 'docks', was replaced in 2002 by serial line production. The National Institute for Working Life in collaboration with Chalmers University of Technology has monitored these changes and documented their advantages and disadvantages in terms of ergonomics and productivity.

The trend in Sweden today is towards more serial organized production. The parallel systems have potential for a higher effectiveness, but sometimes it appears that this is difficult to achieve. Thus, a serial flow is generally chosen.

Parallel and serial productions each have advantages and disadvantages. There are also hybrids of these organizational models, but for the sake of clarity the more pure forms are presented.

A change from parallel to serial production involves opportunities and pitfalls for both productivity and ergonomics.

On the negative side there is an increased risk for the development of musculoskeletal disorders as well as reduced autonomy for operators.

Work along the line is split up into station cycle times of equal duration. However, the division of such is never perfect. This leads to 'balance losses' through assembly stations that become bottlenecks. Furthermore, the operators' natural variation in the performance of their work cycles also leads to system losses – when a worker that has finished a quick cycle has to wait for another that has a slow cycle.

These system losses can involve considerable waiting times and require extra personnel. The parallel flow system, on the other hand, is less vulnerable to these losses.

Unplanned interruptions along the line occur due to the 'system' and 'balance' losses. Operators regard these interruptions negatively even if they, in physiological, terms may imply an opportunity for recuperation.

With a parallel-organized production the same operator carries out several tasks, and thereby attains a more varied work content, greater competence and a better overview of the system. In contrast, when the same tasks are spread along a line the resulting cycle time becomes much shorter. The cycle time is often reduced from hours to minutes or even seconds. Furthermore there may be uneven distribution of workload between stations along the line resulting in different risk levels at each station (see fig 3).

In parallel production, the control-system may allow for operators to work ahead of schedule. When the production quota is reached, time can be used for other things, for instance, administration, training or a longer break. This means there can be an incentive for higher work pace under these circumstances. The same incentive is not found in a system organized so that work continues until the shift has ended.

In the earlier parallel production at Volvo Powertrain the operators worked alone, each one with a dock of his/her own. The new line system allowed opportunities for operators to communicate and support each other, even as their actual control over work pace was reduced. It is important to remember that the social work environment depends on both the organization and flow of work.

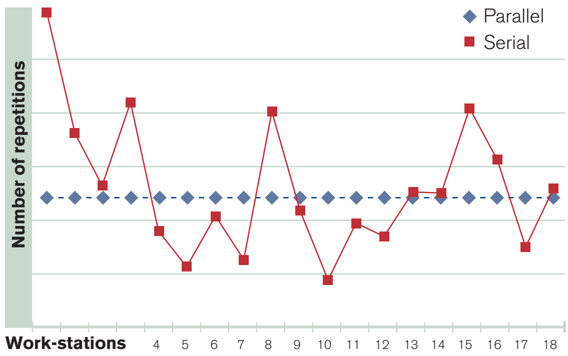

Fig. 3. The distribution of repetitive tasks (nut running) becomes uneven with a transition to a serial flow – a risk factor that is a consequence of a production engineering decision.

The staffing of the two systems was about the same in the transition from parallel to serial production. The personnel responsible for picking material kits in parallel production were no longer needed in the serial system. On the other hand, there arose a need for extra operators along the line to accommodate disturbances. These two personnel needs largely cancelled each other out at Volvo Powertrain.

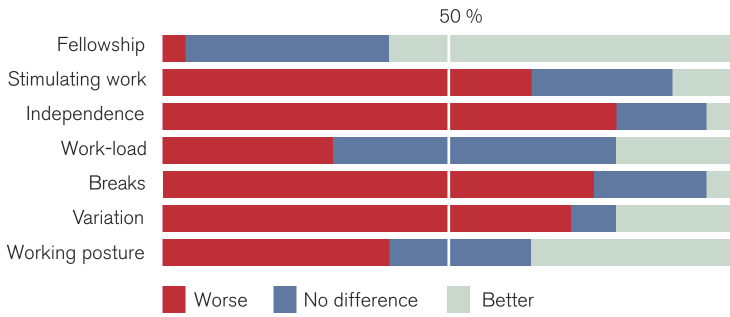

Fig. 4. The operators' ergonomic assessments about the change from parallel to serial production system.

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

CHANGE	PRODUCTIVITY		ERGONOMICS	
	+ ADVANTAGES	– DISADVANTAGES	+ ADVANTAGES	– DISADVANTAGES
SERIAL ORGANISATION	Easier to control and manage work.	Inflexible and vulnerable to disturbances.	System disturbances may offer physiological rest.	System disurbances are not perceived as pauses.
SHORTER CYCLES	Less training needed per station.	More system, handling, balance and variant losses.	None.	Reduced physical variation and increased repetitiveness
WORK ORGANISATION/ WORK FLOW	Operators work throughout the shift.	Extra operators needed to 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 work stations needed.	Some stations have lower work loads.	Some stations have higher work loads.

Simulation as a tool

Computer aided simulation can be a tool for studying the productivity and ergonomic aspects of a proposed flow strategy in the earliest phases of production system design.

The simulation studies conducted in this project included both productivity and ergonomics aspects. For example, the effect of an operator working at half-speed; a comon practical situation when rehabilitating injured operators. Another ergonomic-related goal that was tested is the possibility for the operators to decide for themselves when to take a break (see fig. 5).

The figure shows a comparison between a hybrid-system (a mixture of line and dock designs), with six operators working in a team, and a serial production system where the operators move themselves along the line during the assembly work. The concept of taking a 'break as desired' included a limitation of maximum 10 minutes per break. The study shows that the hybrid-system achieves the best results, irrespective of the break taking patterns or if an individual operator works at half speed. It can also be seen that the serial system is more vulnerable for other disruptions. A hybrid solution has now been implemented for the assembly of Volvo Powertrain's new diesel engines.

Material exposure and packaging

Traditionally the materials used by the operators lie exposed in large packages, often on pallets along the line. With an increased number of product variants this has led to a problem of space, bad working postures in order to pick up some components and a lot of walking time (time-losses) including load carrying.

In Japanese industry, the size of the packages are often smaller and the frontages narrower but deeper. A study carried out at Volvo Powertrain showed great advantages of the Japanese model with regard to effectiveness and flexibility. The resource consumption for handling the materials could be reduced by half. In addition, the workload on the back and shoulders could be considerably reduced. Thus, the study demonstrates a material supply approach that yields advantages for both production and ergonomics – a 'win-win' situation (see Fig 8, page 10).

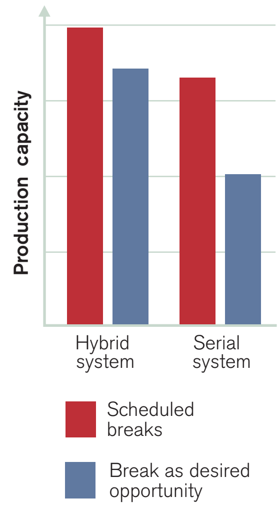

Fig. 5. Ergonomics in simulated flows. A comparison of production systems when a 'break as desired opportunity' is introduced.

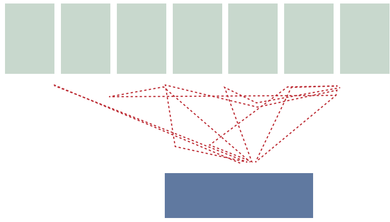

Fig. 6. Current material exposure with broad material frontages induces extensive walking time, in this example more than 30 m per cycle, with following losses in value-adding time.

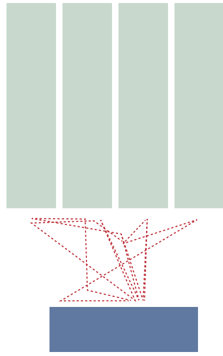

Fig. 7. Alternative material exposure after Japanese model with narrower and deeper frontages gives shorter walking-time, in this example 16 m per cycle, less load carrying, and less losses in value-adding time.

Advice for practitioners

Practical solutions that work well at one workplace may not work at another. A solution that works well today may not work tomorrow. There are no simple answers. Good ergonomics is a 'perishable' commodity that must always be placed on the agenda as an integrated part of the continuous improvement of the production system.

Our studies at Volvo Powertrain and other places emphasise some prerequisites for generating competitive production systems with good work environments. These recommendations require first and foremost a *desire* on the part of the company to develop a sustainable production system in which production and ergonomics are optimised.

Create a process of change that is rooted in the entire organization. It is especially important that management is integrated in this process. Avoid a process based on separate ergonomic teams as these are vulnerable to organisational changes.

The process needs support. It takes time to find the right way of working that supports the development of a production system that is both effective and ergonomic. This process needs continuous internal support.

Emphasize the process, not the problem. Don't get too caught up in particular design problems – focus instead on improving a design process that can handle both this and future problems better. Think long-term.

Workshops and training appear to be good methods for involving those that have to act in the decision-making process. Give priority to training about the effective integration of production system design and working environment.

Shift the responsibility for the practical work on work environment from the occupational health service to the line organization and production planning department.

Measurements provide information. Quantification of risk factors provides concrete information that can be used as support for the communication and integration of ergonomics in the development of production systems. There are many tools that facilitate this integration and new ones are continually being developed.

Specify goals that can be quantified with the measurement tools related to known risk factors. Proposed changes should then reflect specified goals.

Varied tasks are of central importance. If effectiveness is increased by reducing the 'porosity' of a work task then work will become more intensive (see box page 10). Under these circumstances any gains may ultimately be lost through increased sick-leave (see fig 8, page 10: 'Phantom profits') . A variety of tasks can help ensure that no single body part becomes overloaded.

Navigate wisely between different goals in order to create a system that is sustainable in the long term. This sometimes means balancing between ergonomics and productivity goals (see fig 8). This process is facilitated by a 'navigator' within the company that is widely accepted among the majority of the groups involved.

'Navigating' is all about re-evaluating situations, finding new ways, new partners and systematically building up an understanding for the importance of integrating ergonomics in the regular development process.

Hybrid solution. The transition from a non-team based parallel system to a serial team-based line implies both advantages and disadvantages regarding productivity and work-environment/ergonomics. The actual consequences for the individual company depend on the local circumstances. It is possible that hybrid solutions with teamwork and a mix of serial and parallel flow elements have the greatest potential today.

Working proactively by integrating ergonomic concepts in the design process, offers better, cheaper and more effective solutions.

This advice aims at reducing troublesome and costly reactive measures in your company through proactive initiatives.

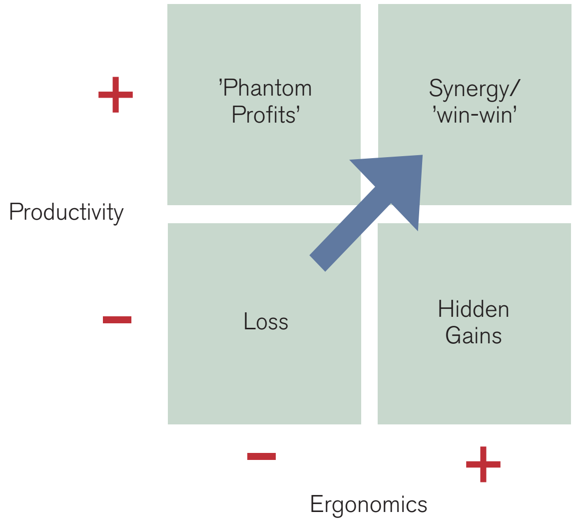

Fig. 8. A simple two-dimensional model of the navigator's maneuvering space. Synergy effects are achieved if both the ergonomic and production aspects are optimized together. Good ergonomics can give rise to 'hidden gains' that are not immediately visible in the productivity statistics. Efforts to improved productivity that result in poorer ergonomics may not reach their anticipated profits ('Phantom Profits').

Facts **Porosity**

A work period includes time that increases the value of the product (value-adding time) and time that does not increase the value of the product. The latter, for instance, applies to the handling of product components and tools as well as walking time and breaks of various kinds. Often this non-value adding time involves opportunities for recovery. This is usually called the 'porosity' of the workday. Our studies show that work at the assembly line involves greater 'porosity' than that in the dock due to interruptions. From this perspective the line thereby offers an ergonomic improvement. However, this may change with time as production engineers successively succeed in eliminating losses along the line. One can thus end up with a 'phantom profit' (top left square, see fig. 8).

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