

1-1-2005

Can Assembly Performance and Work Environment be Jointly Optimized? An Example Discreet Event Simulation Study

Patrick Neumann

Ryerson University, pneumann@ryerson.ca

P Medbo

Follow this and additional works at: <http://digitalcommons.ryerson.ca/ie>

 Part of the [Ergonomics Commons](#), [Industrial Engineering Commons](#), and the [Operational Research Commons](#)

Recommended Citation

Neumann, W.P. and P. Medbo. Can assembly performance and work environment be jointly optimized? An example discreet event simulation study. (2005) 10th International Conference on Human Aspects of Advanced Manufacturing: Agility and Hybrid Automation - HAAMAHA 2005, San Diego, USA

This Conference Presentation is brought to you for free and open access by the Industrial Engineering at Digital Commons @ Ryerson. It has been accepted for inclusion in Industrial Engineering Publications and Research by an authorized administrator of Digital Commons @ Ryerson. For more information, please contact bcameron@ryerson.ca.

Faculty of Engineering, Architecture and Science
Industrial Engineering Publications and Research

Ryerson University

Year 2005

**Can Assembly Performance and Work Environment be Jointly
Optimized? An Example Discreet Event Simulation Study**

Human Factors Engineering Lab, Ryerson University

www.ryerson.ca/hfe

W. Patrick Neumann And P. Medbo

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

Neumann, W.P. and Medbo, P., 2009. Integrating human factors into discrete event simulations of parallel and serial flow strategies. *Production Planning & Control*, 20(1): 3-16. DOI: 10.1080/09537280802601444

Can assembly performance and work environment be jointly optimized? An example discreet event simulation study



Neumann, W. Patrick

National Institute for Working Life / Box 8850, 402 72
Gothenburg / Sweden
E-mail: patrick.neumann@ali.se



Medbo, Per

Dept. of Logistics and Transportation Dept./Chalmers University
of Technology / Gothenburg / Sweden
E-mail: per.medbo@chalmers.se

ABSTRACT

We demonstrate here how discreet event simulation can be used to integrating ergonomics into design processes. In this case we test the effect of two different ways of organizing work within a conventional production line layout. We pay special attention to the sensitivity of the system to human factors such as work autonomy and reduced work pace. Results indicate the general superiority of a 'dual-cell' over a 'chase-the-rabbit' organization in accommodating human variability. The study shows how human considerations can be tested in the design process using flow simulation.

Keywords

Flow Simulation, Production System Design, Psychosocial Conditions, Work Organization

INTRODUCTION

An increasing number of researchers are calling for the integration of consideration of human and technical considerations in production system design [1-3]. Discreet event (or flow-) simulation is a technique that can permit the testing of production system design options and creates potential for jointly optimising human and technical aspects during the early stages of system design. While these tools are being increasingly applied by industry the integration of human factors in their use appears uncommon. *This paper presents a demonstration of how discrete event simulation can be used to testing the impact of both human and technical system features on total system performance.*

In a study examining a change in production strategy from parallel flow cell assembly to conventional serial flow line assembly we observed significant reductions in psychosocial indexes of job control and worker autonomy. These psychosocial factors are connected to a number of health problems [4, 5]. In addition corporate management reports problems with staff turnover on the line as operators dislike being "bound" to the line system and seek other positions that provide more work autonomy. The view that production lines are bad workplaces is nothing new and indeed is reported as one of the reasons Henry Ford felt obliged to offer the famous '5 dollar work day' [6] – an immense compensation in it's time. Thus we ask: *Is it possible to design production systems that support worker*

autonomy while maintaining high productivity?

A further problem in production system operation lies in the placement of workers who cannot perform at a full work-pace. This may include older workers, new employees, or individuals undergoing therapy for work-related or other disorders that can greatly reduce operators working pace. Placing these workers on a line can greatly compromise total system performance and requires careful management. In this study we ask: *Can the production system be designed to be relatively immune to reduced performance of individual operators?*

The departure point of this demonstration project was to examine the organization of work along a conventional production line layout. In discussion with a production system design team we assumed a given line-type layout and examined two possible approaches to organising the work within the same basic layout. This paper is not intended to provide a final 'optimal' solution to this problem. Instead we attempt to demonstrate how human and technical factors can be considered jointly in the design process using flow simulation approaches to judge the impact of both human and technical factors on system performance.

METHODS

The given layout consisted of a series of four assembly areas, separated with an intermediate storage (buffer) of 2 products, each staffed with a team of six operators. Products were modelled as carried by an Automated Guided Vehicle (AGV) system with a downtime of 2%, a mean time between failures of 50 minutes (exponential distribution) and a mean time to repair of 1 minute (SD 5 minutes, lognormal distribution). Product assembly time was based on company motion time studies.

The model included a number of 'design' factors – system features to be considered for possible use in an eventual design, as well as a number of 'sensitivity' factors that were used to test the stability of the model.

According to Law and Kelton [7] sensitivity analysis is one of the most useful tool during the process of validation. This can be used to test if simulation output changes significantly under varying model assumption. If so, this indicates that the aspects of the model concerning these assumptions must be model with great care to attain model validity.

DESIGN FACTORS

Factor A: Work Organisation inside each zone was explored using two strategies, a 'chase the rabbit' approach where the operators moved along the line with their product and a 'dual-cell' approach in which three operators each worked in parallel assembling the 1st half of the zone's load with product forwarded to the second group of three operators for completion of that zone's assembly work. Conventional line flow with one worker staying at each station was not modelled as such a fragile production approach cannot cope with operator autonomy as modelled in Factor 3

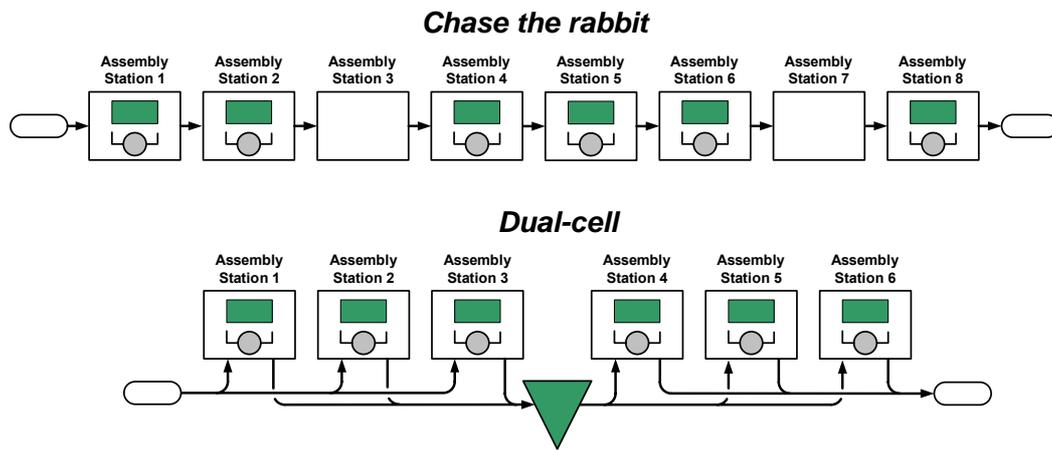


Figure 1: Illustration of work organisation within a single zone including ‘chase the rabbit’ (top) shown here with two buffer positions, and the ‘dual-cell’ organisation also shown with a buffer between each side. Both forms were intended to fit in approximately the same basic linear system layout.

Factor B: Buffer capacity within each zone was modelled as either being absent (0 buffer) or present with space for 2 products in the line as illustrated in Figure x.

Factor C: Operator Autonomy was operationalised as the ability to take permitted rest breaks as desired, rather than just as scheduled. In this example operators break time was 10% of the total working time. In the ‘low’ autonomy condition operators took 80% of their break time as scheduled (e.g. lunch time) with the final 20% of rest time was taken randomly. In the ‘high’ autonomy condition allowing operators to take all rest breaks as desired (modelled as random) with the restriction that now break last longer than 10 minutes. While there are many other ways ‘autonomy’ might be modelled (and indeed should be investigated) we attempt here to demonstrate the approach *in principle*.

Factor D: Operator Work Pace, another ‘Human’ Factor, was also modelled at two levels. At the ‘optimistic’ level all operators were capable of working at the planned upon working pace. At the ‘pessimistic’ level one operator in each zone (4 in total) could only work at 50% of the planned working pace.

SENSITIVITY FACTORS

Additionally the model included the following ‘sensitivity’ factors. These were included to account for uncertainties in the model assumptions. These factors, along with random variations, accounted for the variability in model results.

Factor E: *Distribution shape*, the shape of the distribution in operators’ performance times, was modelled using both a ‘normal’ distribution and a ‘Gamma’ distribution in order to test the sensitivity of the model these time variations.

Factor F: *Distribution scale*, the extent of time variability, (actually a third ‘Human’ factor) is known to contribute to the large system losses observed in traditional line systems. Operators assembly times were modelled with using a CV of 16%.

Factor G: *Product Variants* were modelled as either absent (a single product) or a present; a main product plus a variant making up 30% of total volume and requiring

12% more time to assemble. Product variants, if present, entered the system in a random sequence according to the set volumes.

ANALYSIS

All design combinations (2^7 or 128) were simulated with 5 repetitions for each condition. A fractional factorial analysis was used to test the effect of all factor on system output measured in terms of engines per hour. From this analysis we observed the relatively small contribution of the 'Buffer capacity' factor in this example. We thus treated buffers as a 'sensitivity factor' which contributed to the variability within each case in the subsequent ANOVA analysis; used to test the output expected from each combination of the remaining 'design' factors. The ANOVA analysis included 8 cases (based on the three remaining 'design' factors) each containing 80 trials: combinations of the (now) 4 sensitivity factors with 5 trial repetitions.

RESULTS

Results of the factor design are presented in table 1, while ANOVA results are presented in table 2. Results indicate that the *Work Organisation* had the largest effect on system output. The 'dual-cell' approach outperformed the 'rabbit chase' in all conditions including being less sensitive to operator autonomy in work schedules (Figure 2) or the presence of a slower 'injured' worker on the line (Figure 3). This simulation illustrates how human factors can be 'designed in' to the production system when considered in concert with other technical system factors.

Table 1: Results of the factorial design testing the impact each factor has on system output (only main effects are presented. Non-significant interaction effects have been deleted leaving 'Assembly time distribution shape as the only non-significant ($p < 0.05$) result.

Factor or interaction	Description	Effect [engine / h]
A	Work Organisation	2.07
D	Work Pace	-1.83
C	Rest Breaks	-0.42
B	Buffer Capacity	0.28
G	Number of Product Variants	-0.25
F	Assembly Time Coefficient of Variation	-0.17
E	Assembly Time Distribution Shape	0.02

Table 2: Results of the ANOVA test of factors showing significant impact in the factorial analysis. Mean output and 2 standard deviations of variance, based on variance from the sensitivity factors and trial repetitions, are presented in terms of engines produced per hour.

Wor Organisation	Rest Breaks	Work Pace	Case	Output [engine / h]		The mean difference is significant (p<0.05) compared to the cases:
				mean	2 σ	
Chase the rabbit	Scheduled	Planned	1	7,3	1,1	2-5 and 7-8
		Reduced	2	4,2	0,6	1, 3 and 5-8
	Random	Planned	3	6,1	0,8	all
		Reduced	4	4,0	0,6	1, 3 and 5-8
Dual-cell	Scheduled	Planned	5	8,1	1,5	1-4, 6 and 8
		Reduced	6	7,0	1,2	2-5 and 7
	Random	Planned	7	7,9	1,5	1-4, 6 and 8
		Reduced	8	6,9	1,2	1-5 and 7

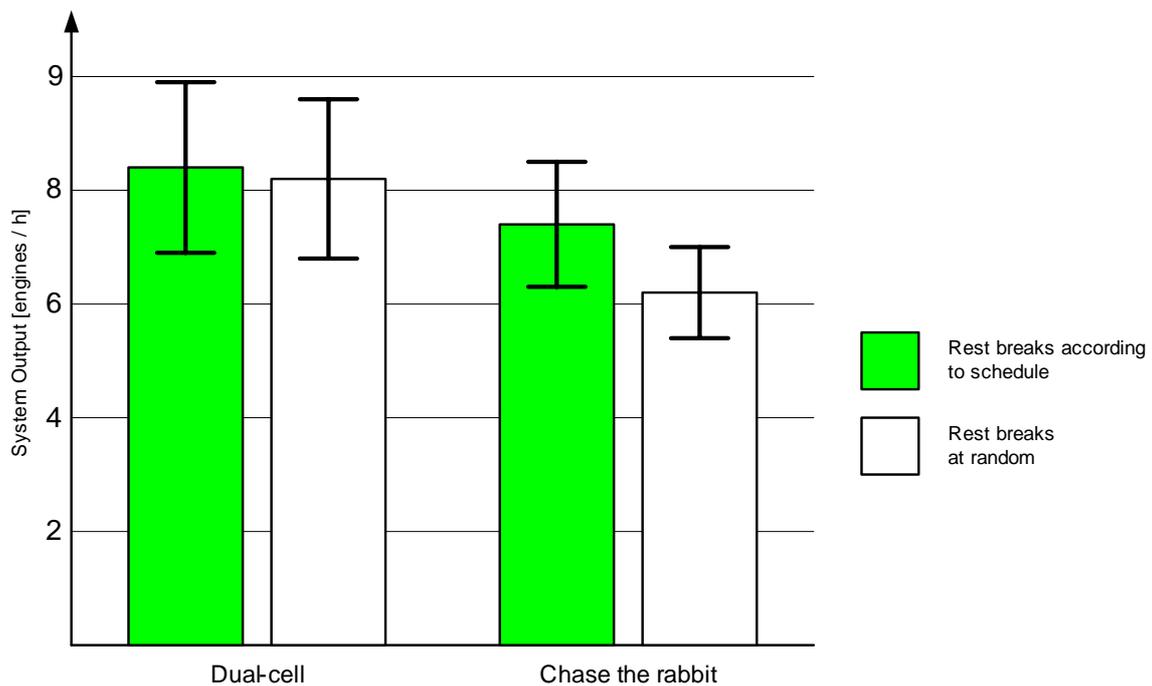


Figure 2: A Comparison of the effect of allowing breaks to be taken out randomly vs. on schedule for each work organisation approach. The I-bar indicates ± 2 standard deviations based on variance from the sensitivity factors and trial repetitions. The rest break policy created significant differences for 'chase-the-rabbit' not for 'dual-cell' organisation approaches (see also Table 2)

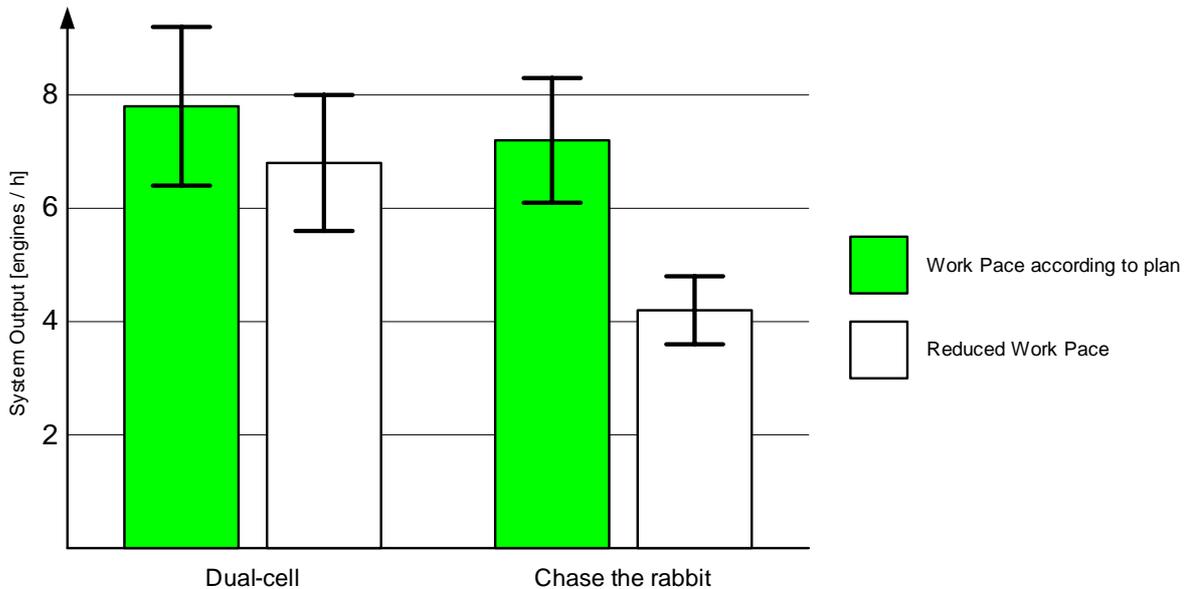


Figure 3: A comparison of the effect of having an operator with reduced work pace for each of the work organisation approaches – differences were significant for both organisation approaches. The I-bar indicates ± 2 standard deviations based on variance from the sensitivity factors and trial repetitions.

DISCUSSION

This paper presents a demonstration of how human factors can be incorporated in the testing of production system design alternatives. We also attempt to provide a model of how these various factors can be tested in a systematic approach [7]. From this perspective the *flow simulation approach* demonstrated here is more important than the specific results of the factors compared here. Nevertheless a number of interesting results have emerged from this analysis: The superiority of the ‘dual-cell’ work organization, and the relative sensitivity of these two approaches to the physical and psychological human factors tested.

The superior performance of the cellular system was not a surprise as previous simulation studies [8, 9], theory [10], and empirical studies [11] support the superior performance and robustness of these flow strategies. Nevertheless companies appear to be having difficulty realizing these gains [1, 12]. One of the criticisms managers have of these systems has been the complexity of the logistics and material supply systems [13]. Interestingly the example presented here begins with the assumption of a typical line layout and a typical ‘boxes along the line’ material supply system. It is the organization of work within each region of the line that is being changed – along with the ability for one product to ‘pass’ another inside the serial flow. In this sense we are testing a kind of hybrid design which we have suggested may be a helpful approach to capitalizing on the strengths while minimizing the problems experienced from the arch-types of serialized line production or parallelized long cycle flow [1].

Psychosocial factors at work have been associated with illness [4] and musculoskeletal disorders [14]. The attempt to operationalize ‘autonomy’ here focuses on the ability to take breaks when desired – modeled in this case as occurring randomly. There is not a deep empirical basis for this, however, we see it as one approach by which production operators might gain a better sense of control over their working days. There is certainly a need to both conduct deeper testing of alternative work/rest patterns and their consequences for operator’s quality of working life in terms that can be utilized by operations design and management

practitioners. It would be possible to extend the model here to account for different kinds of break-taking behaviors by individuals and groups, for instance if groups wish to take breaks together for social reasons. More sophisticated modeling of the 'autonomy' construct is needed here along with a more nuanced understanding of how production system features can improve psychosocial conditions. The application of flow simulation to examine psychosocial aspects at work is uncommon but poses good potential for future development.

From a production perspective, there can be other advantages, beyond worker wellbeing, to a system that allows spontaneous engagement of operators in non-assembly tasks, such as development or administrative work without undue impact on the production system performance and without the need for personnel to replace the temporarily absent individuals. The need for such support personnel was the reason we did not bother testing a conventional line production scenario where the entire line would stop production – to test the work-rest schedule as operationalised here would be pointless in such a system. We should also acknowledge here that the two work organization strategies examined here may have somewhat different requirements in terms of the material supply and command-control sub-systems that have not been examined in this flow simulation example. This example does not include an analysis of all of the possible benefits and drawbacks of the various design options.

This issue of operators with reduced work capacity could apply to new operators, injured operators returning to work, older operators, or individuals with disabilities. Integrating such individuals into a traditional line flow is a classic problem. Typically managers of such systems will say they don't want an injured worker back until they are "100%". This makes rehabilitating injured workers difficult and will tend to extend absenteeism and risks establishing a pattern of extended disability. In this example we saw the superiority of the dual-cell system in accommodating individuals of reduced capacity. This can also be an important design aspect for companies that have a policy of equality and integration with regards to all employees irrespective of gender or disability. Finally a system less sensitive to reduced capacity makes it easier to train new employees and place less demands on having an extra 'trainer' available to make sure the inexperienced operator keep up with the system's pace.

We emphasize again here our primary intent is to demonstrate how human factors can be incorporated into flow simulation during design processes – not to present the case here as some kind of universal production strategy. Typically ergonomic factors are considered late in the production system development process making meaningful changes difficult since spending has already been allocated and most decisions are already locked. This is often aggravated by the positioning of ergonomics, along with health and safety, outside of companies' main developmental process. This has been described as the 'side-car' approach to ergonomics [2]. While some have suggested that engineers lack tools to integrated ergonomics into their design process [15] others have pointed out that human factors design tools exist but are not being used [2]. This may be related to the ambiguity implicit in qualitative methods. The simulation approach here provides unambiguous results in quantities forms that design engineers appear to crave. Such quantified data can be understood by different stakeholders in the design process and thus facilitate discussion on solution alternatives. Thus we see such simulation as potentially supporting operator participation in design processes similar to those described by Sundin in the context of product design[16].

Mathiassen et al. [17] have discussed the potential of flow simulation to provide information on the time aspect of operators physical work pattern, such as the utilisation time, to provide indications of the pattern of physical loading. Taken at

the surface however such data pits ergonomics against productivity – higher utilisation rates equal higher loading (worse ergonomics) and higher output. This risks placing ergonomics in a weak position in terms of negotiating priorities in design. Furthermore the non-utilisation time experienced by operators due to system disturbances is not perceived by operators as a pause and, depending on the circumstances, may not provide physiological rest [1]. Potential does exist, however, to explore physical workload patterns by incorporating physical loading data from the activities, available from human biomechanical simulations, *inside* each work cycle into the flow simulation. This is currently technically awkward as the software for such analyses are not generally designed for such a connection.

We have observed a tendency for companies to use flow simulation to assess a previously chosen design rather than to support innovative new design approaches by novel combination of design elements suited to the particular circumstances. Thus we advocate the early application of flow simulation when the design concept is still malleable and model findings can be capitalized upon. Such early attention to human factors also avoids expensive retrofitting to built systems or careful management of risks locked in to a constructed system.

We demonstrate here that existing engineering tools, in this case discrete event simulation, have potential for integrating ergonomics into design processes – if the companies choose to use them in this way. Further research and development is needed to enhance the interpretation of both time and linked physical load information in terms of ergonomics.

CONCLUSIONS

With regards to the methodological demonstration: Discrete event simulation can be used to test the impact of work organization and other human aspects of the production system for the joint optimization of ergonomics and production. We note that this technology has potential to accommodate both psychosocial and physical risk factors in the design process and allows interpretation of the impact of such factors on system performance.

With regards to the specific simulation cases: The ‘dual-cell’ approach to organizing a linear production system, with its implicit parallelization, showed superior performance and robustness compared to a ‘chase-the-rabbit’ scenario under all conditions.

ACKNOWLEDGMENTS

This project has been conducted under financing from VINNOVA - the Swedish Agency for Innovation Systems, Project d.nr. 2002-01679, and the Swedish National Institute for Working Life.

REFERENCES

1. Neumann, W.P., *Production Ergonomics: Identifying and managing risk in the design of high performance work systems*, in *Design Sciences*. 2004, Lund Technical University: Lund. p. 159. www.arbetslivsinstitutet.se/biblioteket
2. Jensen, P.L., *Human factors and ergonomics in the planning of production*. *International Journal of Industrial Ergonomics*, 2002. **v29**: p. 121-131.
3. Neumann, W.P., S. Kihlberg, P. Medbo, S.E. Mathiassen, and J. Winkel, *A Case Study evaluating the ergonomic and productivity impacts of partial automation strategies in the electronics industry*. *International Journal of*

- Production Research, 2002. **v40**(16): p. 4059-4075.
4. Karasek, R. and T. Theorell, *Healthy Work. Stress Productivity, and Reconstruction of Working Life*. 1990, New York: Basic Books Inc. ISBN: 0-465-02897-7
 5. Hoogendoorn, W.E., M.N. van Poppel, P.M. Bongers, B.W. Koes, and L.M. Bouter, *Systematic review of psychosocial factors at work and private life as risk factors for back pain*. Spine, 2000. **v25**(16): p. 2114-25.
 6. Womack, J.P., D.T. Jones, and D. Roos, *The machine that changed the world*. 1990, New York: Rawson Associates. ISBN: 0-89256-350-8
 7. Law, A.M. and D.W. Kelton, *Simulation Modelling and Analysis*. 1991, New York: McGraw-Hill. ISBN: 0070366985
 8. Sengupta, K. and F.R. Jacobs, *Impact of work teams: a comparison study of assembly cells and assembly lines for a variety of operating environments*. International Journal of Production Research, 2004. **v42**(19): p. 4173-4193.
 9. Johnson, D.J., *Converting assembly lines to assembly cells at Sheet Metal Products: insights on performance improvements*. International Journal of Production Research, 2005. **v43**(7): p. 1483-1509.
 10. Wild, R., *Production and Operations Management: Text and Cases. 5th ed.* 5 ed. 1995, London: Cassell. ISBN: 0-304-33077-9
 11. Engström, T., D. Jonsson, and L. Medbo, *Production Model Discourse and experiences from the Swedish automotive industry*. International Journal of Operations and Production Management, 1996. **v16**(2): p. 141-158.
 12. Medbo, L., *Parallelliserad produktionssystem historia eller framtid? Plan-Nytt*, 2003. **v2003**(1): p. 10-12.
 13. Kuipers, B.S., M.C. De Witte, and A.H. van der Zwaan, *Design or development? Beyond the LP-STC debate; inputs from a Volvo truck case*. International Journal of Operations and Production Management, 2004. **v24**(9): p. 840-854.
 14. Bongers, P.M., C.R. de Winter, M.A. Kompier, and V.H. Hildebrandt, *Psychosocial factors at work and musculoskeletal disease*. Scand J Work Environ Health, 1993. **v19**(5): p. 297-312.
 15. Imbeau, D., M. Bellemare, J. Courville, S. Bergeron, and L. Desjardins, *Ergonomics in a design environment*, in *International Encyclopedia of Ergonomics and Human Factors*, W. Karwowski, Editor. 2001, Taylor & Francis: London. ISBN: 0-7484-0848-7
 16. Sundin, A., M. Christmansson, and M. Larsson, *A different perspective in participatory ergonomics in product development improves assembly work in the automotive industry*. International Journal of Industrial Ergonomics, 2004. **v33**(1): p. 1-14.
 17. Mathiassen, S.E., R.P. Wells, J. Winkel, M. Forsman, and L. Medbo. *Tools for integrating engineering and ergonomic assessment of time aspects in industrial production*. in *Proceedings of the 34th Annual Congress of the Nordic Ergonomics Society*. 2002. Kolmården, Sweden.