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Integrating Flow and Human Simulation to Predict Workload in Production Systems

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

Kazmierczak, K., Neumann, W.P. and Winkel, J., 2007. A case study of serial-flow car disassembly: ergonomics, productivity, and potential system performance. Human Factors and Ergonomics in Manufacturing, 17(4): 331-351. DOI: 10.1002/hfm.20078

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

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Integrating Flow and Human Simulation to Predict Workload in Production Systems

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Flow simulation is increasingly used in the early stages of production system design when basic flow patterns are chosen. This paper describes and discusses a linear approach to integrating load information – based in biomechanical assessment of a work cycle - with the output from a flow simulation to predict cumulative workload. Integrating ergonomics information in these early design processes represents an opportunity for the joint optimisation of ergonomics and productivity in system design.

Keywords: flow simulation, human modelling, industrial engineering

1. Introduction

Simulation is becoming an increasingly important approach in the design of production systems. Simulation and predictive models allow one to evaluate the consequence of design choices before financial resources are committed to constructing either prototypes or actual systems. The rapid adaptation of these tools pose an opportunity to integrate the consideration of ergonomics into early design stages (Mathiassen et al., 2002).

Commonly used simulation tools include flow simulation – also called discrete event simulation, and human simulation. Flow simulation allows the examination of time aspects of production to determine the relative effects of different flow strategies. These design decisions influence both the psychosocial conditions and physical loading pattern of operators in these systems (Neumann, 2004). We have recently presented a demonstration of how flow simulation can be used to examine work environment issues such as autonomy at work might be considered in the design of a production line (Neumann and Medbo, 2005).

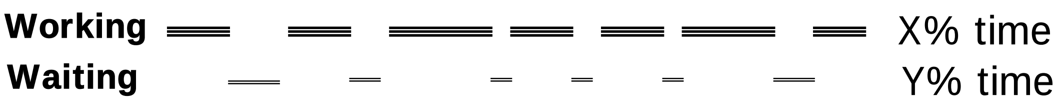

Figure 1: Flow simulation generally presents operators as either 'working' or 'waiting'.

Human simulation allows the prediction of postures, reach envelopes, line of sight, and biomechanical loading for a 'virtual' human. There is a wide range of human simulation products available including simple biomechanical modelling tools to advanced, CAD (computer aided design) based design tools that can integrate the human with computer representations of workspaces and products. While the flow simulation tools are based around time and it's variation in the system, the human simulation tools are generally based around exploring the consequences of geometry. While some attempts have been made to add time aspects to biomechanical models (Neumann et al., 1999; Frazer et al., 2003), the two types of tools operate in different domains and are not connected.

This paper explores and discusses how physical workload information might be connected to flow simulation in order to interpret alternative design options in terms of their effects of physical workload.

2. Sources of Time Information

Flow simulation with detailed inputs of process flow logic, cycle times, and cycle time variability will return a wide range of information on system performance including the system's throughput, product throughput times, workstation or operator utilisation patterns. Ergonomically, the system throughput (total volume produced) provides an indication of the number of work cycles performed at the workstation of system level. The utilisation pattern of the operator is particularly interesting from an ergonomics perspective as it indicates the 'active' periods and the pattern of inactivity. Flow models generally only report the operator as 'working' or 'waiting' creating a binary work-rest type pattern (figure 1). Variation in the working time, specified as a model input, is often modelled as a normal or a slightly skewed distribution.

Other potentially important sources of time information are predetermined motion time systems, such as MTM, SAM, or MOST, that specify how much time different activities will take (Mathiassen et al., 2002). Production engineers when allocating work to particular workstations generally use these tools to ensure workloads are 'balanced' across workstations. These tools account for the work and time 'inside' each cycle in the flow simulation.

3. Connecting Biomechanical Data to System Outputs

Epidemiological studies have shown both peak and cumulative load to be risk factors for low back pain – the world's most expensive musculoskeletal disorder (Norman et al., 1998). Peak load, defined as the single highest load experienced in a shift, is generally unrelated to the time and frequency related information available from the flow simulation. This paper will focus on cumulative loading, which is determined by both duration of work and the number of cycles performed – both of which are available from flow simulation.

The assessment of loading requires a determination of postures and forces adopted during work. This information might be determined by the use of direct measurement using data loggers (Hansson et al., 2003), or using workload estimator such as ErgoSAM (Laring et al., 2002), or as is used in this paper, from biomechanical modelling such as WATBAK (Neumann et al., 1999; www.uwaterloo.ca) or other human models. While the WATBAK model is configured to calculated cumulative loading (Norman et al., 1998) based on repetitions, we will discuss the process more generally here based on the flow simulation model's output of time spent working.

The first step is to establish loading for each relevant job task and the average time spent performing each task, in this case for a 'representative' operator (See T1, T2,… Tn in figure 2). It is usually necessary to add a neutral posture activity to account for periods with

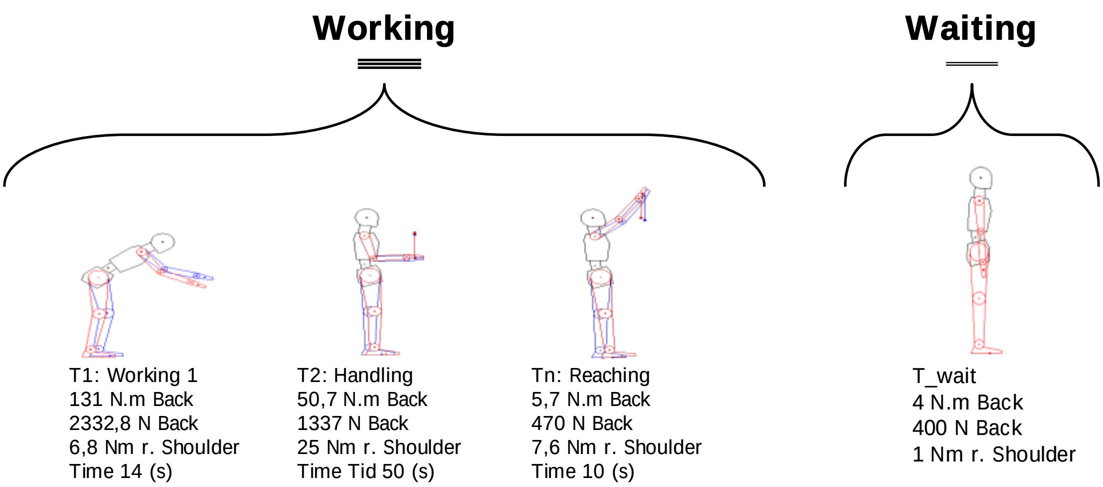

Figure 2: Biomechanical analysis for each task with distinct loading characteristics (T1… Tn) as well as waiting (T_wait) to create a profile of loading and cumulative load for the whole cycle.

low loading. This provides an estimate of loading for a single work cycle. In order to account for the non-working time a neutral posture is taken (T_wait in figure 2).

This analysis allows the calculation of both cumulative and average load for the working portion of the cycle. The average of load for the work cycle can then be applied to the time spent in ‘working’ (x% in figure 1) as reported by the flow simulation. The loading during non-working time is, in turn, applied over the shift according to the ‘waiting time’ (y% in figure 1) from the model output. Alternatively, the cumulative load per cycle could be multiplied by the number of cycles per shift as reported by the flow model and the remaining shift time can be multiplied by the ‘waiting’ load amplitude according to the results of the model. While these two calculation approaches should yield the same result, one may be easier to apply depending on the source or type of load information being used. In either case the result will be an estimate of the total loading for the shift depending on the outputs of both the flow and human simulation models. Using this simple approach different production models can be tested using flow simulation and interpreted for ergonomics consequence in using biomechanical modelling.

4. Discussion & Conclusions

The simple approach described here raises a number of questions about how such technologies might be better integrated. We describe here a number of strengths, weaknesses, and opportunities that may support further development in integrating ergonomics in virtual manufacturing system design:

4.1 Strengths

- This simple linear approach allows ergonomic evaluation of design early in process when the concept is still malleable and the cost of ergonomics improvement is minimal.
- Ergonomics applications that reduce performance time can be integrated in the flow model to determine production benefits.
- The uptake of flow simulation as part of the Ergonomists ‘tool-box’, can support attention to time distribution of tasks and non-work periods that provide potential rest information.
- The approach here of combining the two models at the output level is relatively simple and does not depend on a particular pair of flow & human simulation software.
- This approach allows the application of exposure measurement tools and indicators that have already been validated in epidemiological research (Norman et al., 1998).

4.2 Weaknesses

- This simple linear approach of combining does not account for variability INSIDE each task. Variability between people in terms of either anthropometrics or work technique is difficult to account for.
- It is time consuming to create biomechanical models for all tasks in the production system, and sometime difficult to predict loading in early design phases.
- The load assessment tools (e.g. human simulation) and flow simulation tools are awkward to integrate and do not support the natural design process of the company.
- Both kinds of simulation can require specialist knowledge – not commonly found in the same individuals.
- Considering ergonomics as linearly related to output risks pitting ergonomics interests directly against production interest, since greater productivity implies worse ergonomics.

4.3 Opportunities

- Applying challenge recovery models such as the 1st order systems models explored by Krajcarski (Krajcarski, 2000) would better capture the varying effects of work-wait patterns.
- Other sources of loading information could be explored here including ErgoSAM or ErgoMOST type analyses or perhaps on the most relevant exposure for the system- e.g. nut-running, or grinder use, to accommodate pattern of exposure to that activity.

- If performance time and posture information could be combined, a better perspective of the dynamic aspects of work could be obtained. Such an analysis lies at the interface of the flow, biomechanical and detailed task-time allocation tools systems such as MTM or SAM.
- Integrating to engineering system such as ErgoSAM, which connects directly into the existing standard task breakdowns conducted by production engineers as part of their everyday process may facilitate the application of such approaches
- Flow simulation can support the assessment of ergonomics at the 'system' level, even if operators tend to rotate or shift tasks dynamically
- The joined application of simulation and predictive tools can support cooperation between Ergonomists & Production Engineers throughout the development process

While the integration of physical loading information with flow simulation in production system design shows promise, much R&D is needed if this potential is to be realised.

Acknowledgements

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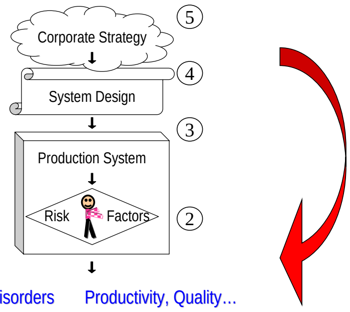
Simulation

- Flow Simulation (descrete event sijm.)
- Human (Biomechancial) Simulation

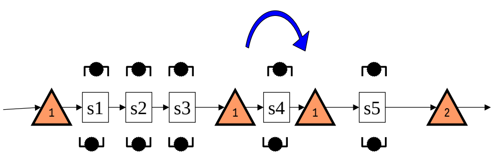
'GIGO'

Simulation allows outcome prediction



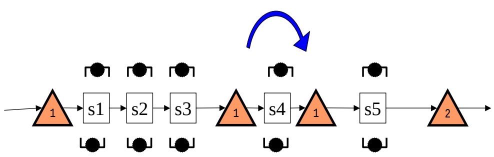
Fave.

Flow Simulation



Traditional Objective:
- to understand how different system configurations affect system performance

Systemmodell



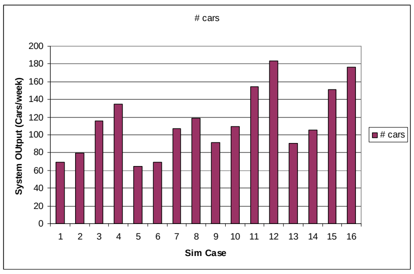
MODELL IN-DATA:
- Layout: flöde och buffertplatsen
- Cykeltid från video: t/station, t/access point, CV
- Transporttid från video
- Samarbete bland operatörer (mönstret)

Simulerings faktorer - försök

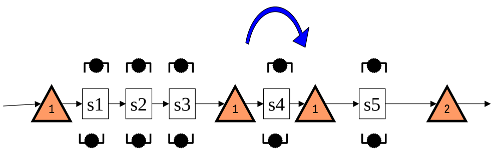
Factor	low	high
A. Experienced operators	4 at 60% + 6 at 100%	10 at 100%
B. Team	no	yes
C. Cycle times:		
Cycle time st 1-3	17 min	10 min
Cycle time st 4	13 min	10 min
Cycle time st 5	10,5 min	10 min
D. CV of cycle times	0,4	0,2
E. Distribution shape	normal	gamma

Låg nivå – observerat system från videoanalyser
Hög nivå – designat system från dokument, intervju & estimat

Model Output - # cars / week

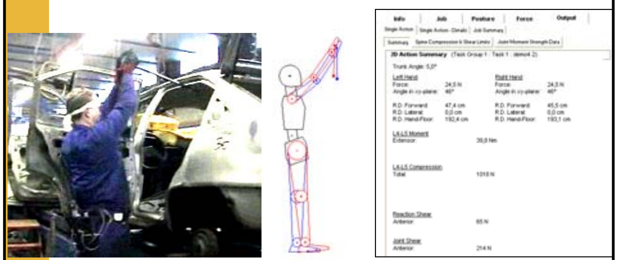


Flow Simulation



New Objective:
- to understand how different system configurations influence ***both operator loading and system performance***

Human Simulation (Biomechanics)



4D Watbak, University of Waterloo, CA

SIMULATION outputs

- Flow Simulation
  - # cars / week
  - Utilisation rate (& idle time) / operator or station
  - Throughput times
  - Blocking, starving, waiting times
- Human Simulation
  - Postures
  - Spinal (or other) Loading
  - Other? 'load' points etc.

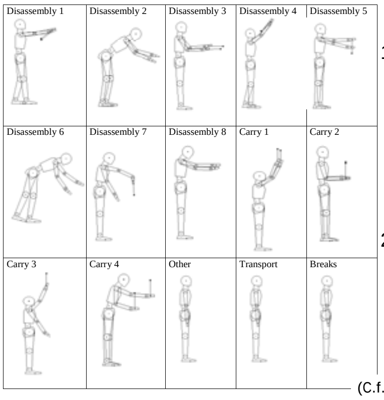
How can we combine these?

Simulering

Typical FLOW SIM MODEL OUTPUT:

'utilised' X% time
'Idle' Y% time

Physical LOADING?



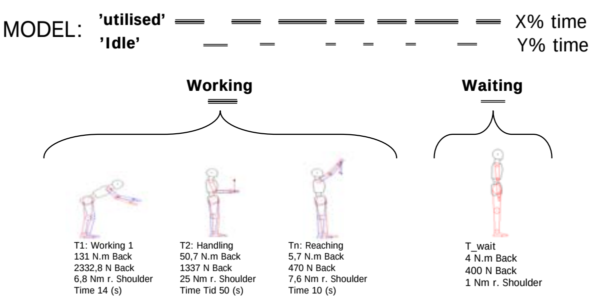
1) Biomechanical analysis for each action with a different type or level of loading
2) Time for each action

(C.f. Norman et al 1998)

Simulering + ergo: Biomekanisk model

T1: Working 1	T2: Handling	Tn: Reaching
131 N.m Back	50,7 N.m Back	5,7 N.m Back
2332,8 N Back	1337 N Back	470 N Back
6,8 Nm r. Shoulder	25 Nm r. Shoulder	7,6 Nm r. Shoulder
Time 14 (s)	Time Tid 50 (s)	Time 10 (s)

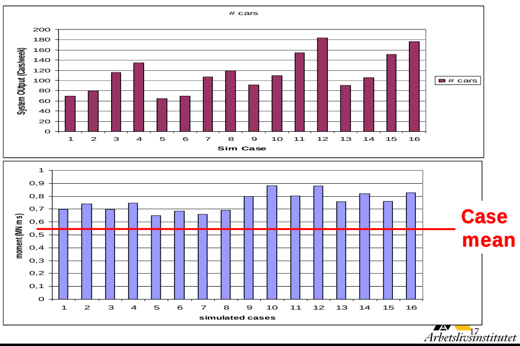
Combining Flow & Human Sim



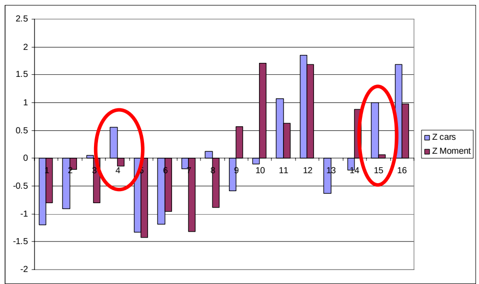
Cumulative LOAD = Work LOAD * X% + Waiting LOAD * Y%

Cumulative Moment for Each Simulated Case…

Cumulative Moment for Each Simulated Case…

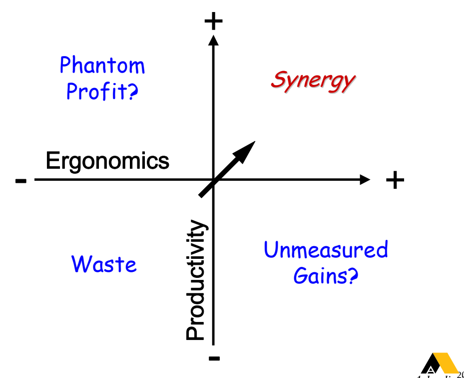


Hi Productivity & Lo LOAD?



EXAMPLE RESULTS:
Factors influencing utilisation (loading)

factor or interaction	description	effect (utilization rates)
D	CV of cycle times	9.4
A	operators' experience	7.8
B	teamwork	-2.5
AB	operators' experience - teamwork interaction	2.1
AD	operators' experience - CV of cycle times interaction	2.0
BD	teamwork - CV of cycle times interaction	-1.6
DE	CV of cycle times - distribution shape interaction	1.0
E	distribution shape	-0.8
AE	operators' experience - distribution shape interaction	-0.6
BE	teamwork - distribution shape interaction	0.5
CE	cycle times - distribution shape interaction	0.2
BC	teamwork - cycle times interaction	0.2
CD	cycle times - CV of cycle times interaction	0.1
C	cycle times	-0.06
AC	operators' experience - cycle times interaction	-0.04



Discussion- Strengths

- Simple (linear combining)
- Can account for ergonomics’ time gains
- Support focus of work-rest scheduling
- Software independent approach
- Risk-Validated measurement tools (Watbak)

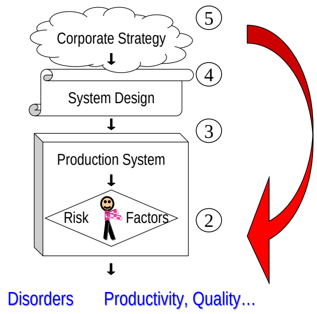
Discussion - Weaknesses

- Variability inside each task not included
- Time to create assessment of all tasks
- Tricky if tasks can’t be observed (design)
- Sim needs knowledge (specialists?)
- Ergo linearly related to utilisation time – can pit ergo against productivity

Discussion – Opportunities

- Challenge recovery models could help
- Other load measurement systems possible
- Integrating to existing measures e.g. SAM can facilitate uptake
- System level focus
- Integrates Ergo & Eng tools

Conclusions?



- Is this an approach worthy of further research?