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MODELLING STRAIN OF MANUAL WORK IN MANUFACTURING SYSTEMS

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ABSTRACT

Without the use of simulation methods and technology complex logistical issues can only be dealt with insufficiently. While current research concentrates on technological aspects in the improvement of system behaviour, vital tasks in the field of production and logistics despite of increasing automation are undoubtedly assigned to human resources. Present simulation instruments are not or just rarely considering manual activities within the simulation process. The project EMSIG, supported by the BMFT (German Ministry for Research and Technology), builds up a model for the description of manual loads that can be effectively used in planning logistic systems.

1 INTRODUCTION

Through the automation and mechanisation of transportation and production the hard manual work has been more and more reduced. However, hard manual work is still necessary. This fact will be outlined by the following reasons:

- high flexibility of humans,
- creativity of humans and
- the limit of effective mechanisation and automation.

Simulation tools support the high resolution modelling of technical systems and its control. In this field of application, workers are represented in the model often very simply and insufficiently . The worker is just modelled like a resource or a parameter of a technical device. This kind of worker description is sufficient for the modelling of highly automatized production and transportation systems. But this approach is hardly applicable for the modelling of systems with a high portion of manual work. For those systems we need a model which also considers the strain of workers. Hereby the task of defining an abstraction level for describing single working operation needs to be addressed. The abstraction level has to be chosen so that single working operations can be appropriately and sufficiently described within the model. For describing manual work which will then be integrated in the simulation model it is necessary to acquire additional input data. Furthermore the simulation results have to be prepared in a way usable for a planner, a specialist for manpower studies and/or a specialist for information science.

Simulation models with detailed worker description support the user in evaluating a manufacturing system in terms of ergonomic and economic aspects in the planning process. The future strain of workers after a planned reconstruction of a factory can be observed.

Of course one could have developed a special simulation tool. But we created a separate module as an extension to different existing simulation languages.

2 INPUT DATA FOR MODELLING MANUAL WORK

The aim of the developed simulation tool is to give the user additional informations due to the expected stress and strain situation for the workers when he plans and designs a work process. Therefore it is necessary

- to have information about the work system,
- to have ergonomic data available and
- to have an evaluation component, which gives the results in a way, that can be easily interpreted.

The main stress factors according to manual work can be devided into two classes: first there are stress factors caused by the work task, second stress factors caused by the environmental conditions. The following stress factors are taken into consideration in our tool:

- ... caused by work task
  - dynamic muscular work load
  - static work load
  - manual handling of objects
  - body posture
- ... caused by the environmental conditions
  - climatic conditions - temperature

- climatic conditions - radiation
- noise
- vibrations
- lighting

They can be seen as the main stress factors due to manual work.

Each stress factor is described by its major influence factors, that means factors, which should be taken into consideration when evaluating a work situation, the - here called - "evaluation quantities". These "evaluation quantities" are values described in ergonomic literature. They combine several influence factors in such a way that similar values give similar strain reactions.

2.1 Explanation of stress factors

The following stress factors are shortly described, to get a feeling for the factors:

dynamic muscular work load: muscular work load is normally devided into "dynamic" and "static" parts. Dynamic means that the muscles can continuously change between compressing and extending and work in a physical sense is to be done. The energy is normally put out as the result of oxidation. As most of the energy is transformed into heat (>90%), this factor also influences strain due to the climatic situation.

static muscular work load: in case of static muscular work load the muscles are used to compensate an outside force, e.g. in case of carrying weights or controlling body posture. No work in a physical sense is to be done. Already after short periods of high forces rests are necessary.

manual handling of objects: manual handling of objects is a type of combination between dynamic and static work load. The problem here is normally not the energy but the spinal. Often lifting weights means a high stress for the spinal, that's why it should be looked at separately.

climatic conditions: climatic conditions can be devided into "temperature" and "radiation", because precautions to prevent heat stress are different: in case of radiation it is often possible to shield the source (e.g. flame, stove), so that cooling is not necessary. Both factors influence pulse-rate. Working hard in hot conditions means a high risk of heat cramps and heat strokes.

noise: noise is defined as any undesired sound. The equivalent noise level combines frequency and sound intensity. High noise levels during long periods cause a high risk of loss of hearing.

vibrations: vibrations are often caused by the working equipment. High vibrations for long periods cause the risk of vibration damages. The equivalent vibration level combines the type of vibrations (whole body or local), frequency and intensity.

2.2 Ergonomic data base

To get the required data in the stage of planning a work process, we have combined our tool with a database, in which several work tasks are stored. The database consists of work sequences. Each work sequence is described by the name of the work task, the used equipment and other quantities like the weight of the objects. For these work sequences a set of ergonomic data is available as results of ergonomic field studies at real work places. The database was prepared at the Institute for occupational medicine, safety and ergonomics.

The user has to choose, which work sequence comes nearest to the actual simulated situation. At the moment about 200 different work sequences are available. If a selection is not possible, because there is no similar situation available, the database can be completed by ergonomic studies.

2.3 Interpretation of ergonomic data

The next step is to get the different types of evaluation quantities in a uniform structure, which can be easily interpreted. The aim is to show the user, whether a simulated situation seems to be "critical" for the worker or not. MÜLLER and HETTINGER /MÜL81/ give a seven-point scale by which the evaluation quantities can be directly transformed into a textual evaluation scale. The given limit values are based on ergonomic knowledge and have been proved at about 650 workplaces. This scale was integrated in our tool.

Figure 1 gives the categories for several evaluation quantities. The input values are the mean values of a whole work shift. For each quantity category IV gives the borderline range, meaning, that the stress comes near to "critical", the situation should not get worse. Above category IV the situation is marked as "critical" and should be changed, below category IV the situation is marked as "uncritical", changes are not necessary.

If the situation is marked as critical, in the stage of planning several types of changings are possible. One way is to allow the workers to have breaks (rest-pauses). This form of "automatic ergonomic prooving system" is what we have included in our tool. It is explained later on. The effect is, it can be shown, that better ergonomic systems come to better economic results.

Stress intensity		Category	workload	Effective Temperature							Effective radiant heat load	equiv. noise level	working pulse-rate
			AU [kJ/min]	NET [°C]							E_{eff} [W/m²]	Lr [dB (A)]	AP [1/min]
Excessive stress	high probable	VII	AU > 25								$E_{eff} > 300$	$L_r > 95$	AP > 52
				40	36	33	30	28	26	25			
	probable	VI	23 < AU ≤ 25								$260 < E_{eff} \leq 300$	$90 < L_r \leq 95$	48 < AP ≤ 52
				37	33	29	26	23	21	19			
	possible	V	20 < AU ≤ 23								$220 < E_{eff} \leq 260$	$85 < L_r \leq 90$	42 < AP ≤ 48
				33	31	27	23	19	15	11			
Borderline range		IV	16 < AU ≤ 20								$160 < E_{eff} \leq 220$	$80 < L_r \leq 85$	34 < AP ≤ 42
				31	29	25	21	17	13	9			
stressful		III	12 < AU ≤ 16								$95 < E_{eff} \leq 160$	$75 < L_r \leq 80$	26 < AP ≤ 34
				25	22	19	16	14	11	8			
slightly stressful		II	8 < AU ≤ 12								$35 < E_{eff} \leq 95$	$65 < L_r \leq 75$	17 < AP ≤ 26
				19	17	15	13	11	9	7			
very slightly stressful		I	AU ≤ 8								$E_{eff} \leq 35$	$L_r \leq 65$	AP ≤ 17
				I	II	III	IV	V	VI	VII			
				Category of workload									

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Figure 1: Seven-point-scale according to MÜLLER and HETTINGER /MÜL81/

3. SYSTEM STAGES

For the simulation of manual work in manufacturing, it is necessary to integrate additional input data and data processing procedures. This solution is PC based and usable with different simulators running on PC's and on workstations. In order to use the EMSIG system (Ergonomic in Material flow Simulators InteGration) a simulation model with a detailed description of worker and working operation is needed.

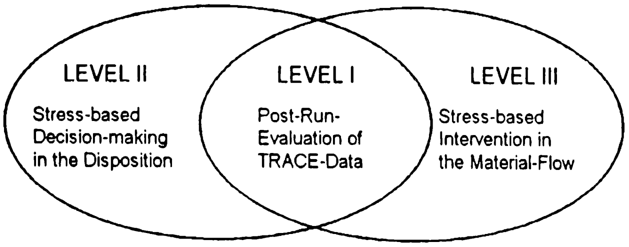


Figure 2. LEVELS of the Project EMSIG

3.1 Post Run Evaluation of Trace Data

The first stage of the system EMSIG is also called the BASIC-Module. It consists of the three following components:

- constructor for operating sequences,
- connector of simulation results with ergonomic data and
- evaluation component.

The constructor for operating sequences is a tool for assembling the necessary operating sequences from empirically gained stress data for working sequences (data base) and the data describing the work places of the modelled system. To every single working activity ergonomic data will be assigned: A file in ASCII - format is provided by the constructor.

The connector is the part that brings the EMSIG system and the simulator together. Hereby the connector uses the trace file that has to be supplied by the simulator and the ergonomic data that are provided by the constructor of the operating sequences. Within the trace file the working process is described. It includes one data set for each working operation consisting of the event time, the location of the working operation, the kind of event (start/end), the number of worker and the number of part. For each worker a protocol file is created by the connector. Each protocol file has one standard set and a varying number of further sets. The standard set contains data characterising one specific worker. These data items are, for example, number, name, age and fitness of each worker. All following sets describe working operations (one set per working operation) and include twelve data items. These data are event time, building block number, working operation index, duration, stress factor, work load, working pulse, evaluated strain, temperature, noise and vibration.

The evaluation component is the part representing the ergonomic results in a form that can be used by a planner. The work-load-diagram is equivalent to the one that is used by empirical investigations.

Because this kind of diagram is not always best suited for a planner we provide a different one. Figure 3 shows this diagram with the evaluation of influencing quantities for all workers during the simulated time.

worker 1	☐	☒	☐	☒	☐	■	■	☒
worker 2	☒	☒	☐	☐	☐	■	☐	☒
worker 3	☒	☒	■	☒	☐	■	☒	☒
worker 4	☐	☒	☐	☐	☐	■	☒	☒
worker 5	☐	☒	■	☐	☐	■	☒	☒
worker 8	☐	☒	☐	☐	☐	■	☒	☒
worker 9	☐	☒	☐	☐	☐	■	☒	☐
worker 10	☐	☒	■	☐	☐	■	■	☒
worker 12	☐	☒	■	☐	☐	■	■	☒
worker 13	☐	☒	☐	☐	☐	■	■	☐
worker 14	☐	☐	☐	☐	☐	☒	☒	☐
worker 15	☐	☒	☐	☐	☐	■	■	☐
worker 16	☐	☒	☐	☐	☐	■	☒	☐
☐ uncritical ☒ limited ■ critical	dynamic muscle work	static muscle work	load-manipulation	climate-high temperatures	climate-radiant heat	noise	vibration	workload index

Figure 3. Diagram with the Evaluation of influencing quantities for all workers

The evaluation represents critical, uncritical and limited ergonomic conditions. This representation is usable for conclusions to logistical changes.

3.2 Stress Based Decision Making

An extension to the basic module is made to create an on-line link between the simulator and EMSIG. A C-interface is developed via that the simulator can ask for the current work-load-states of the worker during the simulation process. Using a specific C-function the simulator receives the current work load code number from this interface as a response. This code number is computed by the "worker selection" component in the EMSIG module and can now be used within the second level of the simulator as a disposition criterion in the process of worker disposition. For this reason the disposition of workers can not only be carried out on the basis of criteria like availability, qualification or shortest distance of a worker to the location of operation, but can also be carried out on the basis of the current work load.

3.3 Material Flow Intervention

The stress based decision making does not bring the effect expected. Especially, if only a few workers with the same qualification are in the system the work load of the workers can not be reduced significantly. That's why other possibilities to intervent the material flow were investigated. In the third level the EMSIG basic module is extended by the ergonomic evaluation component.

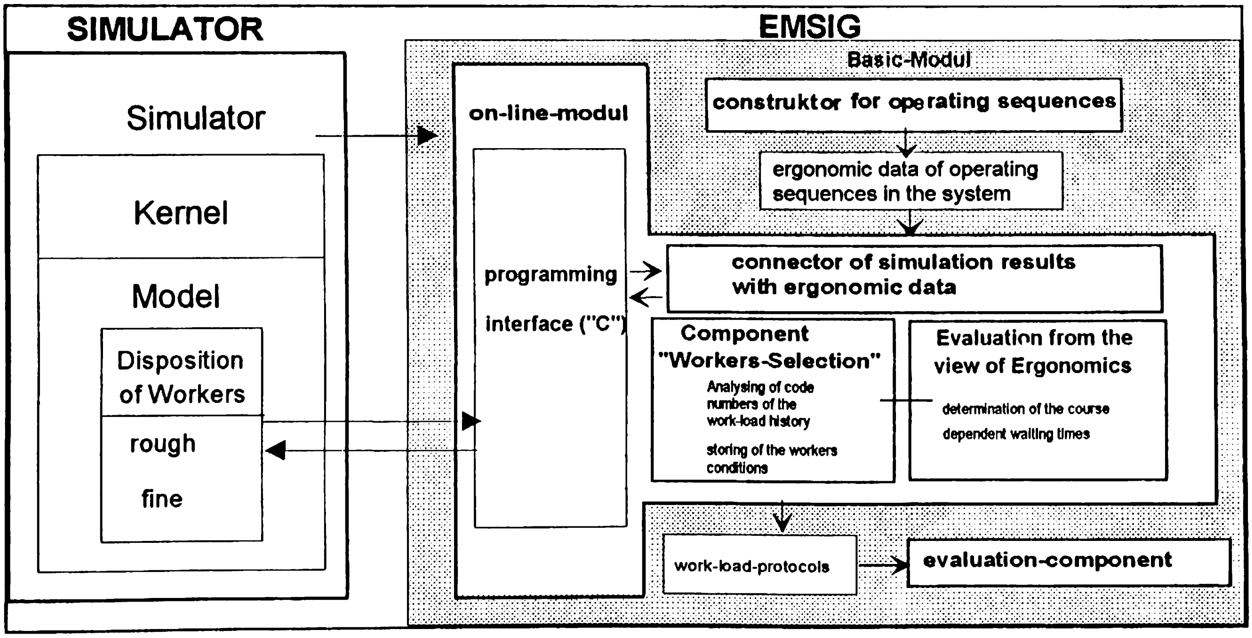


Figure 4: Structure of the extended basic module

This component determinates stress dependent waiting times for workers who are overloaded (that is their workload exceeds a certain value). The length of this waiting time is necessary for the relevant worker to come back to a normal workload factor. EMSIG returns the stress dependent waiting time to the simulator via the programming interface. The simulator can use this time to set a worker for the duration of the waiting time not available in the disposition.

Because the worker for the computed time can not work in the model the material flow is changing.

The Figure 4 shows the structure of the extended basic module.

4 MODEL OF A FOUNDRY

The tool EMSIG is used in a prototypical application of a foundry. The goal of simulation was to improve the logistical and ergonomic situation of this foundry. The realisation and the results of simulation are summarised in the following.

4.1 MODEL 1

GOALS: Modelling the current situation
- for validation of the model of foundry,
- to test the components of the EMSIG BASIC-Module and
- to investigate the work-load situation supported by the components for post-run

ACTIONS: To model the current situation the system data and the spectrum of material were recorded in a representative week.

RESULTS: The simulation shows a throughput of 633 metric ton material per week what is realistic. In an animation coupled to the simulation were logistical bottlenecks noticeable. Because of too long working times of the test stations the work on offshore workstations was limited.

The representation of the workload situation revealed critical points in the field of vibration and noise. Critical points were also revealed for some workers caused by lifting material.

4.2 MODEL 2

GOALS: - Elimination of logistical bottlenecks and
- observation of the ergonomic situation

ACTIONS: The test station in the model was removed with the help of a qualification. As a result of this measure the test stations become unnecessary because each worker himself tests the material that he treated.

RESULTS: The throughput of the system improved to 855 metric ton material per week.

worker 1	☒	☒	☒	☐	☐	■	■	☒
worker 2	☒	☒	■	☐	☐	■	■	☒
worker 3	☐	☒	■	☐	☐	■	☐	☒
worker 4	☐	☒	■	☐	☐	■	☒	☒
worker 5	☐	☒	■	☐	☐	■	☐	☒
worker 8	☐	☒	☒	☐	☐	■	☒	☐
worker 9	☒	☒	☐	☐	☐	■	☒	☒
worker 10	☐	☒	■	☐	☐	■	■	☒
worker 12	☐	☒	☐	☐	☐	■	☒	☐
worker 13	☒	☒	☒	☐	☐	■	■	☒
worker 14	☐	☐	☐	☐	☐	☒	☒	☐
worker 15	☒	☒	■	☐	☐	■	☒	☒
worker 16	☐	☒	☐	☐	☐	■	■	☐
☐ uncritical ☒ limited ■ critical	dynamic muscle work	static muscle work	load-manipulation	climate-high temperatures	climate-radiant heat	noise	vibration	workload index

Figure 5: Work-load situation in model 2

4.3 MODEL 3

GOALS: - To take the ergonomic situation (workload level of workers) into consideration in the simulation through integration of the stress dependent waiting times.

ACTIONS: EMSIG was coupled to the simulator

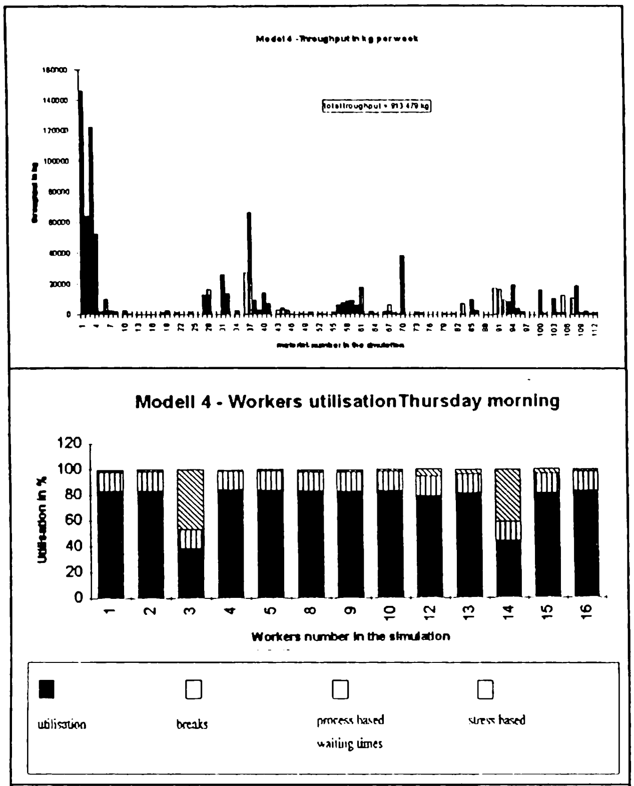
RESULTS: The workload situation does not show any critical points for the workers caused by lifting material, but does show critical points by vibration and noise. This points must be eliminated, for instance, by means of noise prevention measures. The workers utilisation decreases on the basis of stress based waiting times. The throughput of the system is with 787 metric ton material per week lower than in model 2.

4.4 MODEL 4

GOALS: Improvement of the throughput with the help of technical measures

ACTIONS: Technical measures to bring the material to the height of working stations to the workers were integrated in the model. To put this idea into practice technical devices are needed which enable to pull the materials from them to the working stations.

RESULTS: The reduction of manual work by lifting materials removed the EMSIG intervention in form of stress based waiting times. The consequence of this was that the workers utilisation in simulation was going up to the normal level. The throughput of the system is with 867 metric ton material per week by 234 t/w larger than in the current situation.



	dynamic muscle work	static muscle work	load-manipulation	inate-high temperatures	climate-radiant heat	noise	vibration	workload index
worker 1	☐	☒	☐	☐	☐	■	■	☒
worker 2	☐	☒	☐	☐	☐	■	■	☒
worker 3	☐	☐	☐	☐	☐	■	☐	☐
worker 4	☐	☒	☐	☐	☐	■	☒	☒
worker 5	☐	☒	☐	☐	☐	■	☒	☒
worker 8	☒	☒	☐	☐	☐	■	☒	☒
worker 9	☐	☒	☐	☐	☐	■	☒	☐
worker 10	☐	☒	☐	☒	☐	■	■	☒
worker 12	☒	☒	☐	☐	☐	■	■	☒
worker 13	☐	☒	☐	☐	☐	■	☒	☒
worker 14	☐	☐	☐	☐	☐	☒	☒	☐
worker 15	☐	☒	☐	☐	☐	■	■	☐
worker 16	☐	☒	☐	☐	☐	■	☒	☐

☐ uncritical
☒ limited
■ critical

Figure 6: results of model 4

The results of simulated measures are very convincing. Of course it is necessary to compare the expense for qualification and technical measures to the profit they can bring. In the described example the improvement of throughput was so convincing that the measures were just put into practice.

5. CONCLUSION

With the examples it is shown that EMSIG is usable for already existing simulation models (level I), models which will be to be developed (level I-III) and difficult simulators via the programming interface.
The results of investigations show clearly that within the framework of planning in its entirety the goals "Improvement of efficiency" and "Improvement of working situations" are not a contradiction in terms.

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