Ergonomic systems design in two maintenance departments : theory and practice

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Ergonomic systems design in two maintenance departments Theory and practice

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An ergonomic approach to man–machine systems design is illustrated by two examples, both in maintenance departments of the Netherlands Railways. In both situations (the departments for the maintenance of roller bearings and of doors of rolling stock) the application of the ergonomic systems design methodology was made possible because of a planned rebuilding. The projects also were a manifestation of the cooperation between a university department and an ergonomic group in industry.

1. Introduction

In ergonomics the 'systems approach' has been explicitly introduced during the last 10 years. Already in 1967 Singleton used the expression 'systems ergonomics' to refer to ergonomic involvement in the design of man–machine systems (Singleton 1967). To speak about 'systems ergonomics' in this respect, however, is somewhat misleading in that all of ergonomics is related to systems (i.e. man–machine systems). We prefer to talk about 'ergonomic systems design' to refer to the process of designing man–machine systems from an ergonomic point of view.

In this paper we shall deal with two projects, both in maintenance departments of the Netherlands Railways, where an ergonomic approach to the (re)design has been carried out. The first project took place in the roller-bearing department (1977) and the second one in a department for the maintenance of train doors (1978). Both provided interesting opportunities to test the ergonomic systems design model in practice.

The projects were set up as a cooperative effort between the department of Industrial Engineering of the Eindhoven University of Technology and the Central Ergonomics Group of the Netherlands Railways. The main parts of the investigations were carried out by two students of the department of Industrial Engineering under the supervision of members of the IE Department (the first author) and the Central Ergonomics Group of the Netherlands Railways (the second author). Also, at the departments involved, project groups were formed. Under the leadership of a member of the local management the course of the project was evaluated periodically with the investigators, personnel representatives and some technical specialists. Decisions were taken by a specially appointed technical project-leader.

In § 2 of the paper we shall present a short description of the design phases. In § 3 a general description of the two departments will be presented. In § 4 we shall illustrate the successive design phases by the two examples of the roller-bearing department and the door department. Sometimes the comments on the two departments will be taken together, at other times they will be split up, because both illustrate different aspects. Finally, in § 5 we shall present some concluding remarks.

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2. Ergonomic systems design phases

In figure 1 a schematic overview is given of the various phases in the ergonomic systems design process.

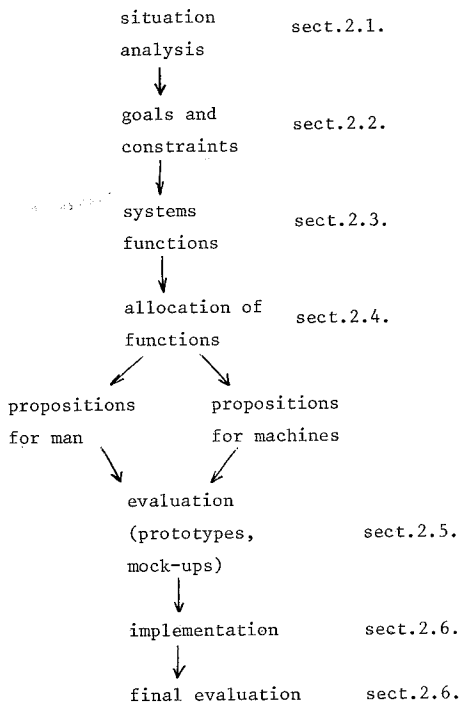


Figure 1. Ergonomic systems design.

2.1. *Situation analysis*

The design of man–machine systems almost never starts from scratch, but is nearly always a matter of *redesigning* in a more or less radical way an already existing system. So in most projects it is necessary to carry out some preliminary analyses in the existing situation. In our view the most important analyses are as follows:

(i) *Process analysis.* One cannot start a systems (re)design before having performed an analysis of the process in terms of inputs, transformation processes and outputs.

(ii) *Ergonomic analysis.* For example an ergonomic work-station analysis by means of an ergonomic checklist.

(iii) *Task analysis.* An analysis of tasks that are performed by the personnel involved. A suitable task analysis method has to be chosen.

(iv) *Opinion analysis.* By which we mean any analysis of subjective feelings, attitudes and opinions of the personnel involved about aspects of their jobs.

2.2. *Goals and constraints*

A formulation of the goals of the system to be (re)designed need to be made. It is very important, that there is unanimity about goals and constraints between the groups involved (workers, management, research team); if not, problems in one or more of the

groups involved may arise during the design process or the implementation. Also constraints should be formulated, although during the process there may be made changes (for example, more financial support may be given than originally foreseen).

2.3. *Systems functions*

Systems functions are those functions that have to be performed to fulfil the system's goal; in this phase they are formulated and broken down in operational terms, without expressing who or what performs them or how they should be performed. Often one proceeds from a global description to a more detailed level of description.

2.4. *Allocation of functions*

In this phase each systems function is analysed as to whether it should be allocated to man or to machine.

Criteria traditionally are the relative capacities and limitations of man and machine (which performs better?), costs (which costs more?) and motivational considerations (does the allocation lead to interesting and integrated tasks?). In such cases where there are conflicts between the criteria, problems may arise and a compromise should be reached. Systems tasks that are to be allocated to man should be evaluated as to whether they may be grouped to meaningful jobs and whether appropriate workers may be selected and trained. If not, perhaps the allocation should be re-evaluated.

2.5. *Prototypes, mock-ups*

The system to be (re)designed or parts of it may be evaluated by means of prototypes, mock-ups or simulators. It offers an excellent opportunity for user comments and user participation.

2.6. *Implementation and final evaluation*

The implementation phase will not be the great bottle-neck of systems design—as it is often depicted in traditional systems design—if in the phases described effective user participation has been organized and human (i.e. ergonomic) considerations taken into account. Nevertheless the final evaluation will show whether the original aims have been met.

3. General description of the two departments

3.1. *The roller-bearing department*

In the roller-bearing department of the Netherlands Railways the maintenance of wheel sets takes place. The wheel sets belong to the wagons that are revised once in every 4 years. In the roller-bearing department the axle boxes and bearings are removed from the wheel sets (about 30 every day) and they are cleaned and inspected. A wagon normally has two or four wheel sets, each consisting of an axle having wheels, bearings and axle boxes at both ends (see also figures 2, 3 and 4).

In a small number of wheel sets only the axle boxes are removed; the other operations are identical to the wheel sets of which the bearings are removed as well. Axle boxes and gearings exist in various types.

The operations in the department are:

(i) *Transport* of wheel sets, axle boxes and bearings; the wheel sets are often pushed manually to the next destination. In other instances cranes may be used. The transport of axle boxes and bearings is done with various aids.

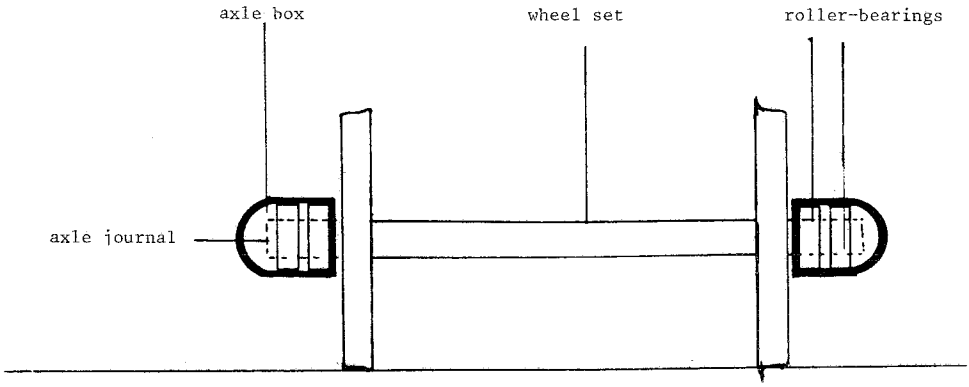


Figure 2. A wheel set (schematic).

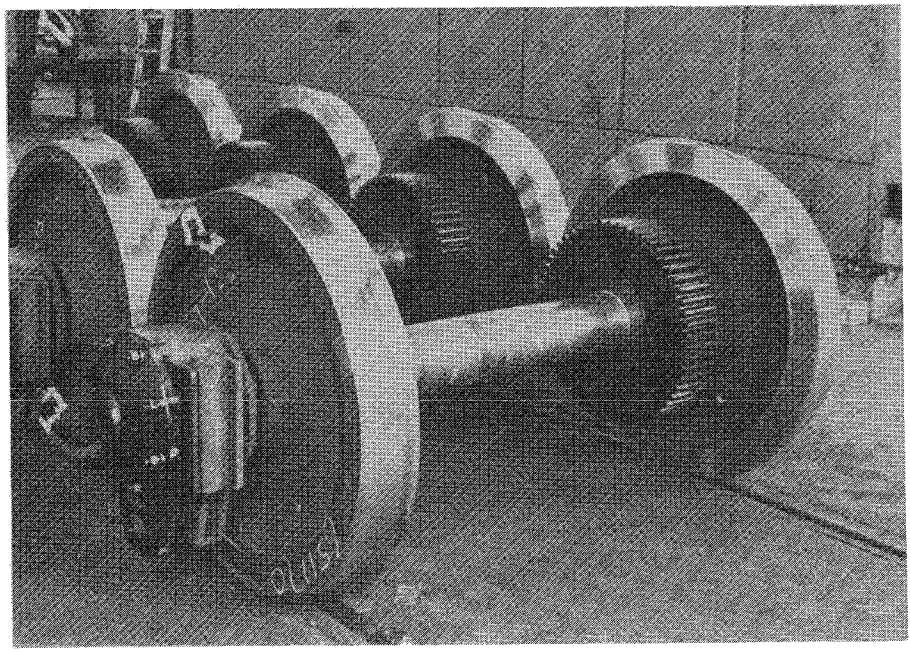


Figure 3. Wheel set with axle boxes.

(ii) *Dismantling and assembling* of axle boxes and bearings; this takes place in work-pits of about 30 cm depth, located on both sides of the rails. A wheel set is never turned around.

(iii) *Cleaning and inspection* of axle boxes and bearings; cleaning mostly is done by the 'hydromaticus' (a cleaning machine). Also a lot of scouring and inspection has to be done.

In the department the personnel consists of eight persons doing the roller-bearing maintenance; the work may be called rather heavy, monotonous and dirty.

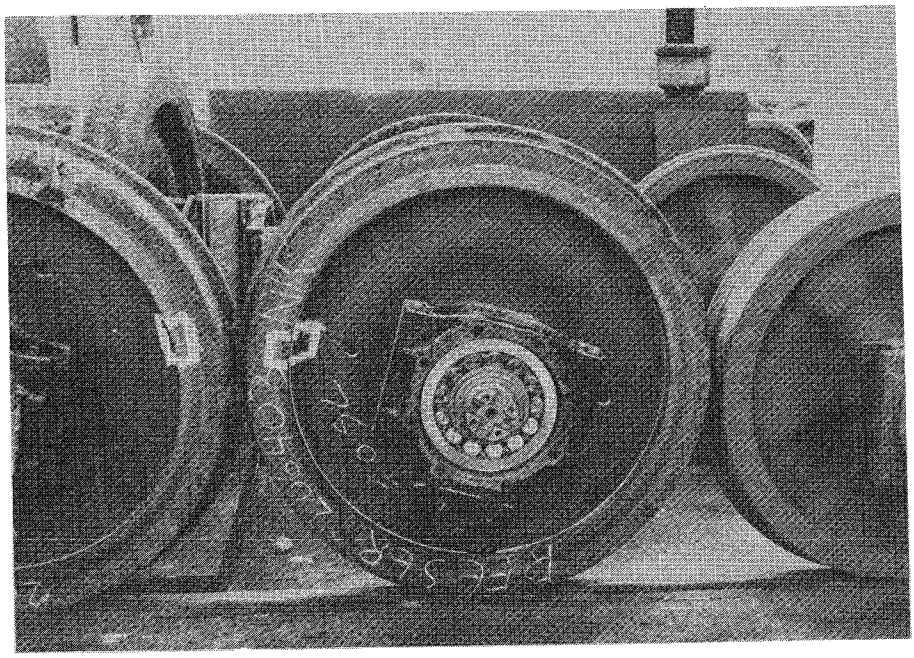


Figure 4. Wheel set with roller-bearing, axle box cover taken off.

3.2. *The door department*

Train doors at certain times need maintenance. Because of the great variety of train types (about 35) there are a lot of door types too. Generally speaking, two main types of doors may be distinguished:

(i) *outer doors*, mostly made of aluminium (40–70 kg) or of polyester (25–44 kg);

(ii) *inner doors*, almost always made of wood (13–27 kg).

Train door maintenance was always done in different departments, the reason for the project being the decision to centralize all the maintenance activities of doors in one department.

Basic operations here are transportation, dismantling and assembling of parts, revision, painting, etc.

The use of various types of handtools causes problems of noise, gases, dust, working posture, etc. In the various departments about 30 persons occupy themselves with the maintenance of the doors.

As in the roller-bearing department it was decided to start a cooperative project between the Central Ergonomic Group of the Netherlands Railways and the Ergonomic Group of the department of the Eindhoven University of Technology to advise in the (re)design from a systems ergonomic point of view.

4. The design process

4.1. *Situation analysis*

4.1.1. *The roller-bearing department*. The ergonomic analysis of the roller-bearing department revealed various problems, such as the following:

(i) *static workload* may be observed in the manual pushing of the wheel sets etc.;

(ii) *bad controls*, for example the grip of the tackle;
(iii) *heavy loads*, the axle boxes for example weigh from 27 to 44 kg;
(iv) *slippery floors* because of the grease.

4.1.2. *The door department*. Analysis of important problems in the existing situation was carried out by means of an ergonomic checklist analysis; by questionnaires to the personnel involved, asking about work attitudes and subjective feelings of load and by collecting accident records. A number of shortcomings was revealed, for example handling and transportation of doors exceeded acceptable limits of work load. Also problems concerning the use of handtools were revealed.

4.2. *Goals*

4.2.1. *Goal of the roller-bearing department*. In general terms the goal of the department is the maintenance of roller-bearings in such a way, that they are in the desired state. There are time and quality norms.

4.2.2. *Goal of the door department*. The goal is to deliver revised doors, meeting the quality norms within the time constraints (time depending on types of operations to be performed).

4.3. *Constraints*

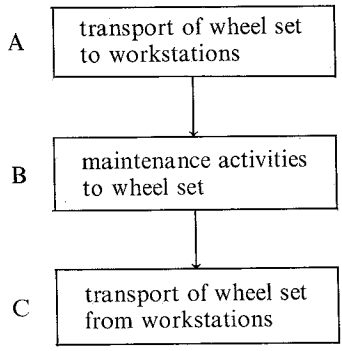
In both situations a number of constraints have been formulated. Here are some of them.

(1) The capacity of the new door-department must be equal to the sum of the capacities of the existing (dispersed) work-stations where maintenance operations are performed on doors.
(2) Workers who in the existing situation spend more than 75% of their time on doors may be transferred to the new department.
(3) The number of workers in the new roller-bearing department may not exceed the number in the existing situation. An eventual small reduction is possible because of internal replacement possibilities.
(4) There are constraints of location: in both situations the department must be projected in the assigned halls.

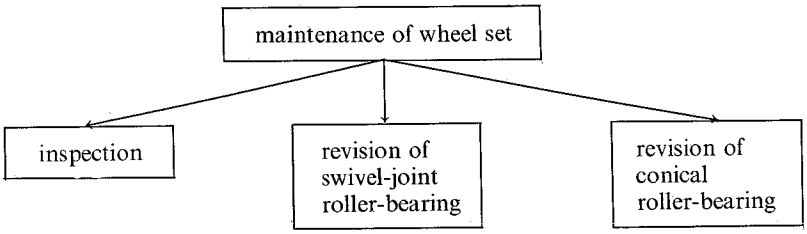
4.4. *Description of system functions*

According to the procedure described by, for example, Singleton (1974), and Coburn (1973) the system functions are described, first in rather general terms, but then in more detail and more operationally. Although there are examples of criteria to use in deciding the level of detail in the analysis (for example, Annett and Duncan 1960, their analysis being especially suited to human task analysis for training), common sense still dictates much here.

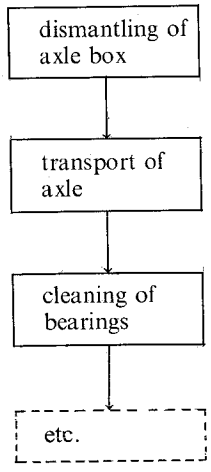
4.4.1. *The roller-bearing department*. The system functions to be performed may be distinguished as follows:



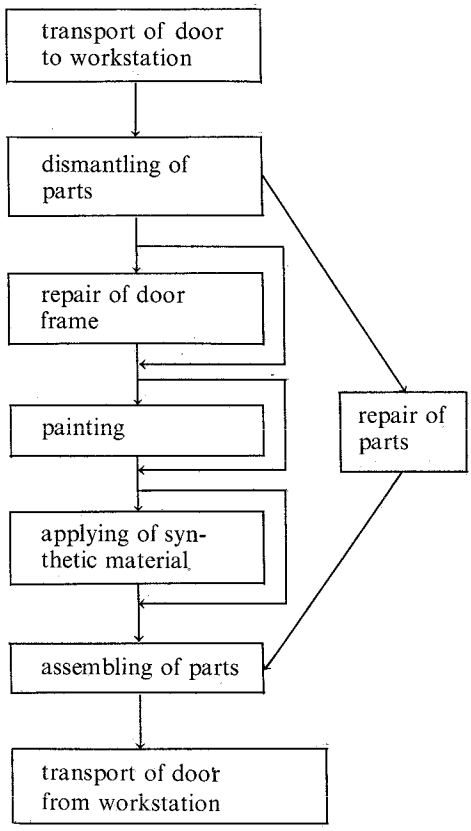
B, for example, may be split up as follows:



Again B1 may be split up,



4.4.2. *The door department.* The basic system functions in the door department are as follows:



4.5. *Allocation of functions*

4.5.1. *The roller-bearing department.* The allocation principles in the roller-bearing department led to a great number of propositions. One example: the system function of 'transport of wheel set' has been allocated to the machine (heavy work), as well as to the transport of the axle box for example. In the first case a mechanized system was designed that transports the wheel sets on rails in the floor. In the second case, a roller conveyor has been chosen as a solution.

4.5.2. *The door department.* The transport of outer doors in the existing situation caused a heavy *static load* in the back and the arms. This function then should be allocated to the machine (see § 4.6.).

To conform to *motivational consideration*, for example the system functions having to do with outer doors have been combined in one job. Also it was tried to let the workers perform a rather great number of operations at one object, to provide for task integration.

4.6. *Propositions*

After allocating system functions to man or machine, proposals have to be made concerning the actual realizations. Proposals concerning the design or purchase of machines and the methods of work have to be formulated. Also the selection, training and job composition of the human components in the systems have to be taken into account.

4.6.1. *Propositions for the roller-bearing department; an example.* Frequent pushing, pulling and lifting of heavy parts, such as the axle boxes (see figure 3), present problems of static load. Each wheel set consists of two axle boxes (27 to 44 kg), that have to be manipulated rather carefully during assembly. The capacity amounts to about 30 wheel sets per day. The task in fact is too heavy, so that it had to be mechanized.

Two solutions were developed, i.e.

(i) releasing the axle box by vibration; and

(ii) releasing the axle box by hydraulic aids.

In this way pulling becomes superfluous. Another improvement consisted of the transportation of the released axle box by means of an additional flexible construction.

The (often pneumatic) tools were adjusted to spring balances close to the dismantling working place. In this way in principle the work may be performed in a sitting position. It was decided to build a mock-up to test the two alternatives (see § 4.7.2 and figure 5). The hydraulic system proved to be constructively more favourable. The transport system had to be improved because of some mechanical weaknesses and user problems.

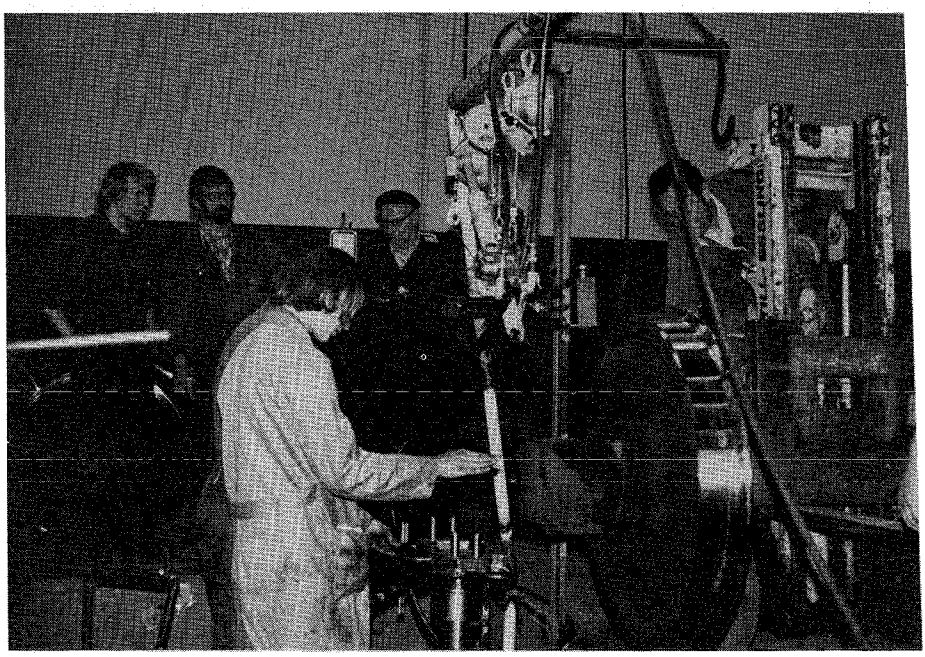


Figure 5. Mock-up of assembling and dismantling work-station.

4.6.2. *Propositions for the door department; an example.* Manipulation of outer-doors proved to be a problem because of the weight (25–70 kg) and the dimensions ($2 \times 0{\cdot}9\,m^2$). The problems arose during transportation, lifting to the working bench and taking it off. The work had to be divided between man and machine in such a way, that these problems would be removed as far as possible.

The solution was to build a construction that could combine the function of 'transportation aid' and (in horizontal position) the function of a supportive frame for the door to be operated upon. The transportation problem as well as the lifting problem at the working bench could be solved at the same time. Rollers on this 'transportation chart' made it possible to transport a door rather easily to and from a stock, the floor of which consists of rollers having the same height. Two prototypes have been built and tested. In figure 6 the old system is presented. In figure 7 the prototype of the new system is presented.

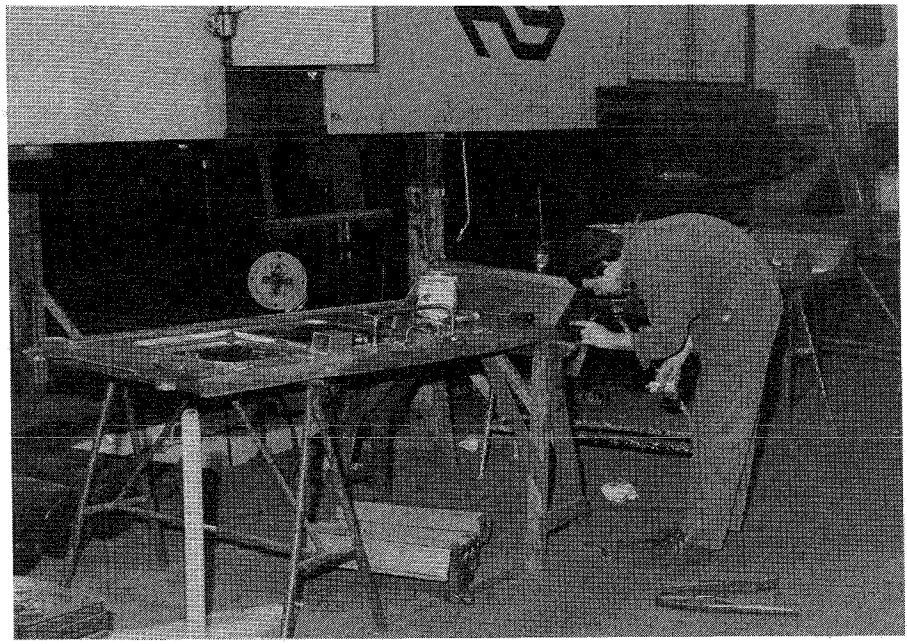


Figure 6. Door maintenance work-station, old system.

4.7. *Scale models; mock-ups.*

Mock-ups, prototypes and scale models are well-known aids in evaluating design proposals. We will give here two examples from the roller-bearing department.

4.7.1. *Scale models.* Already in rather early phases of the design process scale models have been constructed of the six work-stations involved (scale 1 : 50). They were made of maquette materials (see figure 8).

Also the resulting proposed overall layout of the new department has been set up in maquette form (scale 1 : 50). Interviews and talks with management, experts and the personnel involved led to a number of alterations during the process. Also task structures were discussed with the aid of the maquettes.

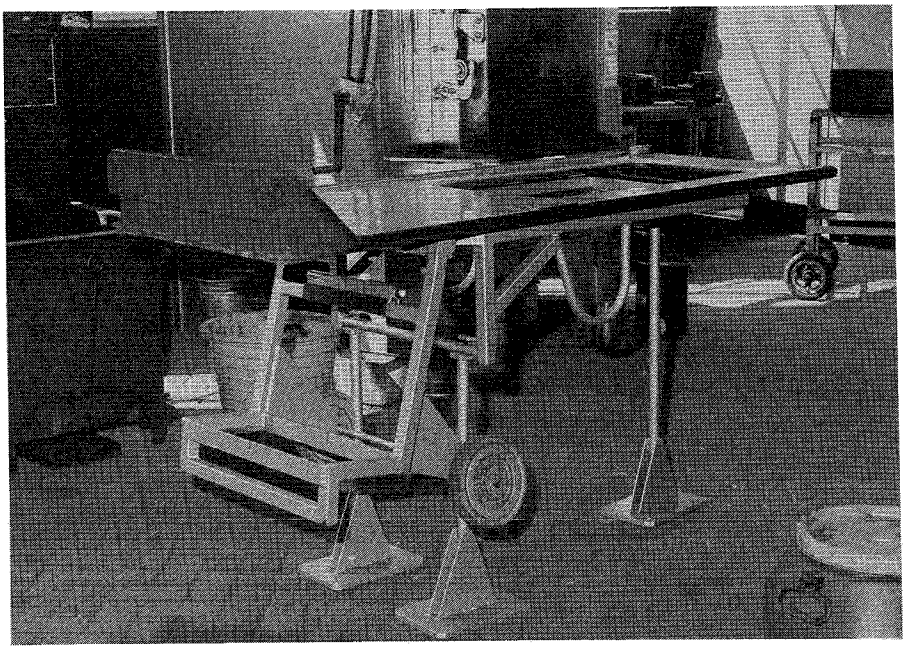


Figure 7. Door maintenance work-station, prototype of new system.

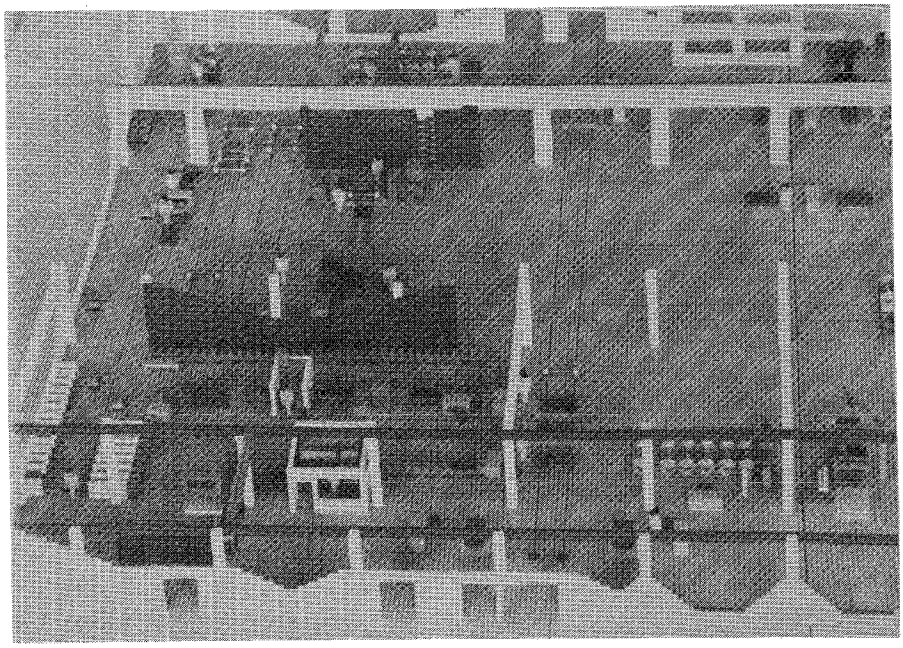


Figure 8. Scale model (1 : 50) of lay-out of new roller-bearing department.

4.7.2. *Mock-ups.* A scale model 1 : 1 is called a mock-up. A mock-up allows one to make dynamic simulations (role-playing of actual working conditions). In the roller-bearing department a mock-up was made of the work-station for the dismantling and assembling of the axle boxes (see figure 5). It has been built in a working pit; the axles may be of various heights and nearly all handtools to be used are present. Two subjects, differing in height (1·61 m (=2·5th percentile) and 1·91 m (=97·5th percentile)) simulated the work to be done.

The following techniques have been used in the evaluations:

(i) Interview; the workers involved were asked about their subjective opinions.

(ii) Observation; especially working posture and working methods were observed, for example reachability of handtools, reachability and controllability of controls, working posture while carrying out the tasks, sitting posture, and static and dynamic load.

4.8. *Implementation*

4.8.1. *The roller-bearing department.* The rebuiding of the department is almost finished, conforming generally to the guidelines resulting from the ergonomic systems design method.

Although the demands have been raised since the investigation, it is expected that the proposed system may meet them. It appeared that the project groups for the rebuilding and installation needed the active support of the ergonomist, to give advice in the phase of realization.

4.8.2. *The door department.* The new department has been in operation for a few months now. The transportation chart has been very successful. At the moment 15 of them are in use, although at the beginning eight were thought to be enough. One year after the installation a systematic evaluation is planned.

5. Some concluding remarks

(1) Because systems design more often than not is systems *re*design the design process should start with phase 0: the analysis of the existing situation. In most cases such an analysis will consist at least of the next partial analyses: process analysis, task analysis, ergonomic work-station analysis and worker opinion analysis. The distinction between curative and preventive ergonomics in our view should not be seen as a fundamental one but as a rather gradual transition from one to the other.

(2) Not only the goals of the system to be (re)designed should be formulated, but also the constraints. These constraints concern

(i) Personnel considerations: it should be clear, for example, whether personnel may be transferred.

(ii) Cost considerations: economic considerations may constrain the alternative possibilities in the (re)design.

(iii) Time considerations: it should be clear, for example, what the life-expectancy is of the system to be (re)designed.

(3) Worker participation is an essential part of the design process. Its integration should be decided upon as soon as possible. Ergonomic system design in this way is in line with modern concepts of the design of work.

(4) Mock-ups, scale models, etc. play an important role in the design process. Firstly, because they allow for evaluation of design proposals. Secondly, they have the

important function of letting the different groups involved participate in the design. More explicit rules, however, about *how* to carry out the evaluations with mock-ups are necessary.

(5) Deciding that a systems function is allocated to the machine is only the first step to specifying the form and function of the machine part. If you decide for example that the transportation function should be carried out by machine, the next question immediately arises, what machine? The same goes for the human tasks in the system.

(6) University and industry may both benefit by carrying out projects in mutual cooperation, in that theoretical or abstract considerations may be tested out in the field and industry may benefit from new insights.

Une approache ergonomique dans la conception des systèmes homme–machine est illustrée au moyen de deux exemples de réalisations effectuées dans le secteur de la maintenance des Chemins de Fer néerlandais.

Dans les deux situations (maintenance des coussinets à rouleaux et des portes de wagons), l'application de la méthodologie ergonomique a été rendue possible par une remodification achitecturale. Ces projets illustrent également un cas de coopération entre une section universitaire et un groupe d'intervention ergonomique dans l'industrie.

An zwei Beispielen aus Instandhaltungsbetrieben der Niederländischen Eisenbahnen wird die Möglichkeit ergonomischer Einflüsse bei der Gestaltung von Mensch-Maschine-Systemen aufgezeigt. In beiden Fällen (Instandhaltung von Radlagern und Wagentüren) wurde die Anwendung der Methode der ergonomischen Systemgestaltung durch die Verwendung von Modellen geprägt. Anhand der Projekte kann auch die Notwendigkeit der Zusammenarbeit zwischen Universitätsinstitut und Ergonomieabteilung in der Industrie gezeigt werden.

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