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"CYCLE TIME VARIATION" IN AN ERGONOMIC AND PRODUCTION EFFICIENCY CONTEXT

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ABSTRACT

In industry, work pace for operators performing repetitive assembly work have been estimated primarily through mean cycle time defined as the actual time required for performing one complete repetitive work task. However, since work tasks are performed by humans "cycle time variations" will always occur. This variation might influence the production output depending on the choice of e.g. product flow pattern, buffer location, and buffer size. "Cycle time variation" would however, be judged positive from an ergonomic point of view because it suggests that the work task allows for some autonomy and hence variation in physical workload (mechanical exposure).

This paper reports on the observed "cycle time variation" registered by video recordings from two workstations in an electronic assembly plant. For one of the workstations the intra-operator "cycle time" standard deviation was 15% of the mean "cycle time", and for the other workstation it was 7%. The corresponding inter-operator standard deviation in mean "cycle time" was 9% and 30% for the two workstations respectively.

From an ergonomic point of view variation in "cycle time" would be a considerable source for variation in mechanical exposure, which ought to be positive and worthy of preservation in future design of assembly systems.

1 INTRODUCTION

The origin of work-related musculoskeletal disorders is multi-factorial and complex, and involves both physical and psychosocial factors at work, as well as individual factors. Repetitive light assembly work is associated with an increased risk of developing shoulder-neck disorders [1]. Winkel and Westgaard [2] stated that three dimensions of physical workload (mechanical exposure) influence the risk of contracting shoulder-neck disorders: exposure level, repetitiveness and duration. In this study we focused on repetitiveness.

Repetitive work has often been defined as repeating a certain task for a long period with a short "cycle time". In a laboratory simulation of a whole working day of light assembly work, an increase in "cycle time" from 68 seconds (a work pace of 120 MTM) to 82 seconds (a work pace of 100 MTM) was associated with a reduction in mechanical exposure [3]. Other laboratory studies on changes in shoulder muscle load according to work pace in repetitive work support that muscle load decreases with decreasing work pace [4, 5], at least when "cycle time" is an independent variable, controlled by the experimenter. These results [3 – 5] suggest that "cycle time" variation may result in variation in mechanical exposure, which would be beneficial from an ergonomic point of view.

Manufacturing engineers generally use mean operation times based on time-and-motion studies when determining "cycle times". Accordingly, on a serial flow assembly system they focus on dividing ("balancing") the assembly work evenly between the workstations along the serial flow, disregarding the effects of "cycle time variation", i.e. the fact that operators have an inherent variation in work pace and efficiency in the performance of repetitive work. Such variation occur both as inter- and intra-operator variation, i.e. variation between the mean cycle time of different operators performing the same assembly work as well as variation between successive work cycles for a particular operator. The actual time required for the repetitive work task will also vary between work cycles and operators as a result of e.g. product variation and process variation [6].

Assembly systems that fail to accommodate inter-operator and intra-operator variation generate idle operator time and/or a need for re-work. In both cases, extra manpower is required [7, 8]. Thus, assembly systems allowing large variability between and within operators, which must be considered by the manufacturing engineers, but at the same time implies a potential for good physical work to the ergonomist.

The aim of this paper was to study and discuss "cycle time variation" at two repetitive assembly workstations, with an emphasis on the contrast between ergonomics and production.

2 METHOD

The study was performed at a plant producing electronic components for the automotive industry. The studied work group of operators assembled and tested instrument panels for trucks. The assembly system comprised six workstations along a serial flow, with both standing and seated work (Figure 1). The work consisted of repetitive assembly and control work (Table 1). At workstation 3, two product variants were assembled, one with 6 and one with 15 diodes, but at workstation 2 only one product was assembled.

Table 1. Some characteristics of the assembly work on the two workstations.

	Assembly methods:	Materials:
Workstation 2:	Semiautomatic pneumatic screwdriver for 19 screws Soldering at 27 points	5 Coils and 3 lamps
Workstation 3:	Manual pneumatic screwdriver for 6 screws Soldering at 16 or 34 points	6 or 15 small diodes

Three male and three female operators participated in the study. Two workstations 2 and 3 were studied (Figure 1). At both workstations the operators were seated and the work pace was mainly controlled by themselves since the intermediate buffers were large.

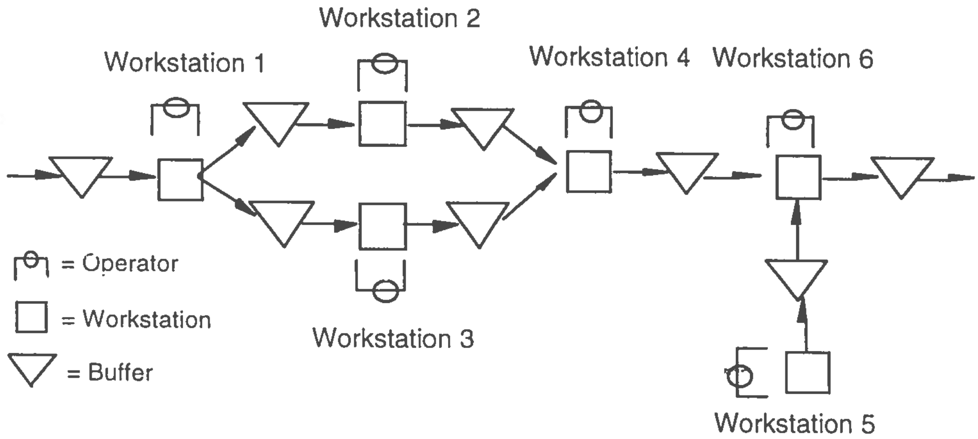

Figure 1. The assembly system comprised six workstations in a serial flow assembly system with intermediate buffers as shown above. Workstations 2 and 3 were studied.

"The cycle time", defined as the time required for performing one complete work task, was determined for each cycle during one hour of work using a video recorder synchronised with a personal computer [9], i.e. "cycle time" used in this article is not synonymous with the cycle times used for defining the product flow used by manufacturing engineers.

The video was recording at 25 frames per second, corresponding to a resolution of 0.04 s per frame. One male operator had to be excluded from the study due to malfunction of the videotape.

The inter- and intra-operator "cycle time" standard deviations were then estimated on basis of ANOVA formulae for unbalanced data [10], since the operators performed different numbers of work cycles (9 – 17) during the recording hour.

3 RESULTS

The two workstations did not differ significantly in mean "cycle time", 213 and 241 seconds respectively (Table 2). The intra-operator standard deviation was twice as large at workstation 2 than at workstation3, 15% of the mean group "cycle time" and 7% of the mean group "cycle time" respectively. The corresponding inter-operator standard deviation was three times higher at workstation 3 than at workstation 2, 30% and 9% of the mean group "cycle time" respectively.

Table 2. Mean "cycle times" in seconds for each operator separately and the group of operators at each of the two studied workstations based on one-hour video recordings of each operator. The inter- and intra-operator standard deviations expressed as percent of mean group "cycle time" are also shown.

	Operator 1:	Operator 2:	Operator 3:	Operator 4:	Operator 5:	Group:	Standard deviation:	
							Inter-oper.	Intra-oper.
Workstation 2:	213	223	188	243	196	213	9%	15%
Workstation 3:	200	359	196	283	165	241	30%	7%

4 DISCUSSION

In the ergonomic studies mentioned above [3 – 5], median muscle load increased by 20% when the work pace increased 20%, i.e. in a one-to-one relationship. The intra-operator "cycle time" standard deviation at workstation 2 of 15% of the mean "cycle time" of the group may therefore be expected to imply a muscle load variation of the same relative order of magnitude. For normally distributed "cycle times", this would mean that the "cycle time" span defined by the 5- and 95-percentiles would correspond to a range in muscle load from about 30% below to 30% above the mean value. This represents a considerable source of variability in mechanical exposure, which would be considered positive and worthy of preservation in future redesigns of the assembly system, although the introduction of more thoroughly differing work tasks would be even more preferable from an ergonomic point of view. However, the noted variability reported above might primarily depend on the two product variants manufactured on workstation 3.

However, in general it may be intriguing to design serial flow assembly system allowing extensive intra- and inter-operator variability in "cycle times". If "cycle time variation" is large, large intermediate buffers between workstations are required to avoid idle operator time. Which is possible to achieve in some cases, when the products are small and time consuming. In which case a serial flow assembly system might approach an assembly system comprising independent, workstations.

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