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Cognitive Aspects Affecting Human Performance in Manual Assembly

Anna BROLIN[a,b,1], Keith CASE[a] and Peter THORVALD[b]
[a] *Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Loughborough LE11 3TU, UK.*
[b] *School of Engineering Science, University of Skövde, Skövde, Sweden.*

Abstract. This paper concerns the handling of information in assembly work environments. Several studies involving both literature reviews, case studies and observations were conducted to find factors that affect human performance in manual assembly. The main experiment with 36 subjects used a mixed method design with a quantitative study, including time and errors as dependant measures, a qualitative study, including workload ratings, and a questionnaire. The experiment involved the assembly of a pedal car and the components were presented using structured kits, unstructured kits and material racks. Assembly information was presented as text & component numbers or photographs, and situations with and without component variation were considered. Among the results it was found that assembly times and workload ratings were lower when using a kit, whereas using a material rack resulted in perceived decreased workflow and increased stress and frustration. Assembly times and workload ratings were lower when using photographs, whereas using text and numbers increased mental workload.

Keywords. Manual assembly, cognitive workload, information presentation.

1. Introduction

Various investigations have shown that increases in product variation adds to the complexity in manufacturing [1, 2]. In addition, increased product variation has a negative effect on overall performance, i.e. quality and productivity [3] as well as human factors aspects in manual assembly [4-6]. Other aspects of manufacturing include for instance the field of logistics which is relevant when looking at the handling and flow of material. From a human factors perspective, the flow of material is highly connected to the assembler’s situation (i.e. at the workstation), and assemblers are often faced with a larger number of components at the workstation, due to increased product variation.

One interesting area within material supply systems is the principle of kitting, where pre-sorted kits of components are delivered to the workstation [7]. Contrary to continuous supply, which traditionally has been the predominant way of presenting material to the assembler at the workstation by using material racks, kitting entails the required components for one product being stored together, usually in a box. A kit can also be regarded as a carrier of information that complements, supports or even

[1] Corresponding Author. anna.brolin@his.se

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replaces conventional assembly instructions [8]. The benefit, from an ergonomics perspective, is that the assembler only has to focus on the assembly process, i.e. *how* to assemble, and does not need to be concerned with *what* parts to assemble, which ultimately can result in higher product quality [5]. This insight seems to be in line with the subject matter of this research, to improve the human performance in manual assembly. Further, two types of kits have been identified: unstructured and structured kits, both of which can be perceived as carriers of information, albeit differently organised [9]. However, to investigate their discrepancies and argued effects, in terms of cognitive aspects, as well as assembly time and assembly error, these kits should be tested against the use of continuous supply.

The factors considered within this manufacturing research area provide valuable and useful understanding of the manufacturing and assembly work environment. However, it is necessary to also consider usability and design principles [10, 11] to provide understanding of how to best present information, so that the assembler is able to perform the task efficiently, based on the given information. It has also been noted in earlier studies that component variation is a factor that potentially could affect the assembly operator [9, 12, 13]. It has also been suggested in other, earlier studies that high component variation greatly increases complexity of work [14, 15].

This paper describes an experimental study where material and information presentation and the effects of mixed mode assembly are evaluated. The purpose of the study was to investigate the performance outcome of these factors (i.e. assembly time and assembly errors) as well as perceived mental workload.

2. Experimental set up

The experiment used a mixed method design [16] which included both a quantitative study, including time and errors as dependant measures, and a qualitative study, including workload ratings and a questionnaire. The quantitative study acted as a base for the hypotheses whereas the qualitative data mostly acted as support to verify and strengthen the quantitative study and thus the hypotheses.

The experiment took place in an advanced assembly laboratory environment. The experiment made use of an assembly workstation at an assembly line laboratory where a pedal car was partly assembled (Figure 1).

Figure 1. The assembly product used in this experiment, a pedal car.

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The independent variables that were used in this experiment were:

- Material presentation;
  - Material rack
  - Unstructured kit
  - Structured kit
- Information presentation;
  - Component text & numbers
  - Photographs (in combination with a brief descriptive word or number)
- Component variation;
  - No component variants
  - Component variants

The three factors were tested through a full factorial experimental design, consisting of 2x2x3 factors, where the levels of the three factors involved in the experiment were combined in all possible combinations to be able to study both main effects and interaction effects. However, only the results from the main effects are presented here.

The primary measurement used in this experiment was *time*, since it was considered reliable and easiest to measure but also expected from industry in terms of productivity. Since productivity is such an important aspect in many industries, it can be argued that stress, and subsequently, workload, comes along with this, making this a valuable measurement. To verify and strengthen the results of the quantitative study, additional qualitative data was gathered to capture the user experience and assemblers' opinions.

- *NASA TLX workload rating*, a workload assessment tool to assess both the mental and physical workload that the subject perceived during the assembly task
- *Questionnaire*; gathering the users' opinions and experiences regarding the different ways of presenting and perceiving the information and material

The subjects were trained on 3 pedal cars before the experiment started, and were then instructed to assemble twelve randomized pedal cars. After the entire assembly operation, which was estimated to take about 60 minutes, all of the subjects answered a questionnaire. A few randomly selected subjects also answered the NASA TLX workload rating.

2.1. Equipment and environment

Thirty-six subjects volunteered for the experiment. Most were engineering students at the University of Skövde, but there were also a few students from the computer science department as well as some members of staff. The subjects consisted of 19 women and 17 men, which is a slightly more even gender distribution in this experiment compared to the reality in the automotive industry, where men are overly represented. No disabilities were reported that would have any effect on the outcome. The experiment took place in a production laboratory at the University of Skövde. The room was equipped with hand tools and machines and there were safety rules that had to be followed.

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3. Results and findings

Initial analyses of the results show that all of the main effects were significant. Analysis of material presentation using a pairwise comparison analysis (Table 1.) showed that there was a significant difference between material rack and unstructured kit ($p < 0.001$) as well as material rack and structured kit ($p < 0.001$). However, the difference between the kits was non-significant.

Table 1. A pairwise comparison of material presentation measured in time [s], corrected using a Bonferroni adjustment.

Test level A	Test level B	Mean Difference (A-B)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
		Material presentation				
Material rack	Unstructured kit	49.840*	5.290	0.000	36.537	63.143
Material rack	Structured kit	60.153	7.412	0.000	41.514	78.791
Unstructured kit	Structured kit	10.312	4.620	0.096	-1.306	21.931
		Information presentation				
Text & numbers	Photographs	16.778*	3.474	0.000	9.725	23.831
		Component variation				
No variation	Variation	-10.528*	3.270	0.003	-17.166	-3.890

Based on estimated marginal means
*. The mean difference is significant at the 0.05 level.
b. Adjustment for multiple comparisons: Bonferroni.

The table also shows that the mean difference was large between material rack and kits (49.8*s* resp. 60.2*s*). The results clearly show that there was a significant difference between using the different kits and the use of a material rack. Analysis on the main effect information presentation show that there was a significant difference between text and numbers compared to photographs ($p < 0.001$), where the mean difference was 16.8*s*. Analysis on the main effect of component variation show that there was a significant difference between using products with no component variation compared to products having component variation ($p < 0.001$), albeit small with the mean difference being ~10.5*s*.

In addition, analysis of the perceived workload was also conducted, using the NASA TLX workload rating assessment tool. In this analysis, twelve subjects were asked to rate their perceived workload on six different scales; *mental*, *physical*, *temporal*, *performance*, *effort* and *frustration*, after the assembly of each pedal car. The scales were set from 0 to 100. To highlight the most important aspects of workload, the aspects were weighted in comparison to each other, where stress and mental workload were the primary focus and physical and performance were weighted as of lesser importance. Initial analysis stated that only material presentation and information presentation had significant effects, therefore only these were further analysed.

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Test level A	Test level B	Mean Difference (A-B)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
Material presentation						
Material rack	Unstructured kit	5.671	2.034	0.053	-0.064	11.406
Material rack	Structured kit	9.392*	1.942	0.002	3.914	14.869
Unstructured kit	Structured kit	3.721	1.820	0.197	-1.412	8.854
Information presentation						
Text & numbers	Photographs	3.771*	1.387	0.020	0.718	6.824

Based on estimated marginal means
*. The mean difference is significant at the 0.05 level.
b. Adjustment for multiple comparisons: Bonferroni.

The analysis of the main effect of material presentation (Table 2) shows that there was a significant difference between using a material rack compared to using a structured kit (p = 0.002), where the mean difference was ~ 9.4 workload ratings. This means that it is possible that the NASA TLX workload ratings support the time analysis of when using a kit the performance is better compared to using a material rack. It did however not confirm the comparison between the different kits. Analysis of regarding the main effect of information presentation shows that there was a significant difference between using text & numbers compared to using photographs (p = 0.02), with a difference of ~3.8 workload ratings. This also confirms the previous analysis using time as the measurement, where workload is perceived as less when using instructions with photographs compared instructions with text & numbers.

After completion of the assembly operations each of the 36 subjects answered a questionnaire. The ages ranged from 19 – 62 years.The results from the questionnaire show that a majority of the subjects thought that using a kit made it possible to interpret if all components were assembled, compared to using a material rack which made it harder to find the right components, resulting in decreased work flow and increased stress and frustration. A majority also thought that photographs provided a mental preparation of the next assembly task compared to using text & numbers which made it hard to overview and extract the most important information, when searching for component numbers, leading to loss of track in the assembly process, resulting in too much information which affected mental workload.

To conclude, the most interesting findings from the experiment were:

- Performance, measured in assembly time, was improved when using a kit, when using photographs for information presentation and when not using component variation. The subjects also stated that these conditions made the assembly operation better, easier and faster.
- Using a kit made it possible to interpret if all components were assembled, assuming that all components placed in the box were correct. Using a material rack, made it harder to find the right components, resulting in decreased work flow and increased stress and frustration.
- Performance measured in *assembly time*, was improved when using products with no component variation. This was also favoured by the subjects. The

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workload ratings were also lower when using photographs combined with no component variation. According to *assembly time* and *workload ratings*, using either material rack or the kits was not affected by whether the assembly consisted of variants or standard components.

These results are merely a snapshot of the main findings from a much larger analysis including deeper examination of the data. Further analysis has been undertaken with regard to the combination of the main effects. Performing observations at the various factories it was possible to get a more holistic perspective of the often very complex settings. Modern production systems differ greatly depending on, for instance, company and factory size, product complexity and economics, and the several combined factors that form the complex manual assembly environment will be reported in future publications.

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