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INSTRUCTOR BASED TRAINING VERSUS COMPUTER BASED TRAINING—A COMPARATIVE STUDY*

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ABSTRACT

This article describes two studies conducted to compare assembly performance and learning rate between computer based training and traditional training of skilled assembly operators. The studies were performed with pre-series production parts from a car cockpit and they were integrated as part of the overall training activities during a new vehicle product launch. The computer based training tool used was a desktop based commercial VR tool with focus on cognitive interactive procedural learning. Both studies indicate that computer based training can replace instructor based training for this level of assembly complexity and that it has a positive effect in preparing skilled operators.

BACKGROUND

The automotive industry is currently facing an increasing pressure to satisfy customer-related requirements for variants and special designs. A flexibility that enables rapid production changes both concerning order volumes and product

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changes is necessary. Another important trend is shorter and shorter product life cycles which require decreased time-to-market. These changes in product development, customer requirements, and product life cycle affect the work methods for launching new products. A transition is necessary from methods where operator training and product validations are based on a number of physical prototypes to computer based simulation technologies where it is possible to educate personnel and to evaluate manufacturing functionality.

The development described above requires that the training simulation tool can capture functionality that supports the cognitive phase and to some extent also the motor phase in the learning process. The two phases are described as the learning curve (Dar-El, Ayas, & Gilad, 1995). In early stages of learning the cognitive system dominates the process. Focus for the assembly operator is understanding and following job instructions, remembering the sequence of operations, recognizing and understanding how the tools, equipment, or assembly parts should be handled, etc. Computer based training appears to be a feasible method. However, as experience is gained through executing the task the learning process migrates from a cognitive learning focus to a motor learning focus. In this later phase when the training is focused on repeating movements so they become autonomous, physical products are necessary in order to develop the skill and necessary assembly speed (Gustafsson, Ohlsson, & Ullmark, 2003).

Computer Based Training

For training purposes virtual reality (VR) systems have been shown as a powerful tool. Examples that illustrate this are pilot training which has been used for decades for both commercial and military aviation (Lee, 2005). Another example is surgical virtual reality systems. In this case the surgeon can practice on a virtual model as a complement to training on animals before starting on human patients (McCoy & Stone, 2001).

As virtual reality has continued to develop during the last decade, applications less than fully immersive have been developed. These non-immersive or desktop VR applications are far less expensive as well as far less technically advanced and are therefore foreseen as a potential area for new applications. Desktop VR focuses on mouse, joystick, or space ball controlled navigation through a 3D environment on a standard desktop computer graphics monitor.

Several studies comparing different VR types for training with regular or non-computer based training can be found. Adams et al. (2001) compared desktop based Virtual Training both with and without haptic to regular training. The study was performed on assembly of a LEGO plane model and the subjects were engineering students. The study showed a significant positive difference when comparing: A) virtual training with haptic versus B) training by just watching an instruction video. The results regarding whether training with haptic versus without haptic were statistically inconclusive.

Boud et al. (1999) compared conventional training via studying 2D drawings versus different levels of VR (Desktop, Stereoscopic, and immersive) and Augmented Reality (AR). The study showed that all types of VR and AR applications tested were out-performing the 2D engineering drawings. The study couldn't show a statistically significant different between any of the tested VR and AR variants even if the AR alternative gave a more positive result.

Key aspects of desktop based VR training software are the character and functionality of the software as well as how the software meets the requirements of authoring. In this context authoring could be described as the process for creating a training session in the training software by defining all operations with belonging attributes.

Bluemel et al. (2003) describes such a tool created for training of maintenance and service tasks. The work points at three important main aspects:

- Interactivity—the learning processes are stimulated when the user has to be active
- Flexibility—the tool must be able to provide the user with a wide range of different training scenarios
- Authoring—the system must be easy to author so that people with specific assembly process knowledge can be involved in the authoring process.

Buck and Perrin (2004) also point out several similar functionality aspects of importance in a computer based tool for training of maintenance tasks. Interactivity and clues like correct colors, addition of a virtual hand in some operations, and usage of audio support are examples of important functionality.

Another development of the functionality aspect in an assembly operator training tool is made by Gustafsson et al. (2003) who discuss a model for an educational game. This model considers several parameters such as type of operation to be trained and the trainee skill level. With prerequisites for the specific goal for training, character of operations to be trained, and personal profile including learning progress as an input, the software creates a personally designed event to train on with a flavor of dramaturgy similar to advanced computer games.

Aspects on Virtual Training in the Automotive Industry

From an industrial perspective the approach of how virtual training should be performed is dependent on the specific conditions existing in a company. Different approaches can be seen depending on the target group for the training, costs for virtual training versus training on prototype products, and the need of skill training versus procedure training in virtual environments. When prototypes are very expensive or the conditions are hazardous, impossible, or very difficult to create in advance and the target group size is small, the training is often focused on both cognitive and motor (i.e., craftsmanship) aspects. In this approach immersive VR or AR is often used as the solution.

In contrast, the goal in automotive assembly production is to prepare a considerable amount of people (from several hundred to thousands of operators) for a change-over of production from the old to new models. The training is traditionally performed by building and tearing down prototype cars in a non-production facility which represents the production environment but does not produce salable vehicles. The challenge is defined by the limited timeframe available for training on those cars and the reduced number of such cars available for training purposes.

The traditional method for training assembly operators needs to be changed and one alternative is to use virtual methods, similar to those currently in use for engineering work, also for training. A desktop based VR solution, with described automotive assembly conditions, could be a feasible method. This approach focuses on cognitive procedural training by training the operators in the content of new operations and the new assembly sequence. It doesn't require expensive equipment and can therefore be implemented in multiple locations in parallel without exorbitant costs. The approach with desktop based VR does not cover skill training but could offer sufficient preparation to handle the new conditions with limitations in time and training vehicles. It meets the targets of low cost for equipment and the ability to train a large number of operators during a limited timeframe and is therefore an interesting alternative to investigate.

PROBLEM STATEMENT

The questions investigated in the current work are: 1) does computer based training work as an effective preparation tool before the operator interacts with the first training hardware; and 2) are the effects of training found in earlier research (Adams, Klowlen, & Hannaford, 2001; Boud, Haniff, Baber, & Steiner, 1999) also valid when the subjects are skilled assembly operators and the components that are assembled are more complex. The present study has from this standpoint used skilled assembly operators, performing assembly operations in a car assembly workshop as the base.

The objective of the study was twofold. Each objective was independently evaluated in two separate tests (Test A and Test B) with different operators for each test but using the same cockpit module (hereafter called cockpit) and same computer based training tool:

- *Objective for Test A:* Compare assembly performance between computer based and instructor based training of operators. Performance is here quantified by measuring fault rate of the operator through visual assessment at the assembly station and quality problems detected and reported from inspection stations on the assembly line.

- *Objective for Test B:* Evaluate the learning rate for computer based training of operators.

METHODS

The software, Vizendo Trainer (VIZENDO AB) was used in the study. It is a desktop 3D-CAD based tool for interactive procedural training of assembly operations. The user/operator selects which procedural sequence he/she wants to train on. The training is given in four levels of difficulty.

The easiest level, level 1, has a presentation level where the chosen sequence is shown graphically with additional visual clues regarding placement positions for parts to be assembled on the car. All positions must be confirmed by the user through mouse selections at correct positions on the 3D model of the car. All necessary associated information including part, tool, process description, and clues about position in the 3D world is presented to the user.

Levels 2–4 have a step-by-step reduction of information provided with level 4 requiring the user to walk through the sequence without any assistance at all. No process description, no automatic navigation, or any information regarding parts and tools is presented for any operation. The user completes the sequence successfully first when all tools, parts, and positions are confirmed for each operation in the correct sequence. If mistakes are made by the user such as choosing the wrong tool, part, operation, or position a pop-up message saying, e.g., "wrong operation" immediately is shown on the screen. The software includes a tracking module which produces a log file unique for each user. This module is used for tracking the operator's progression in the software.

Test A—Comparison of Assembly Performance

Test A was performed during the introduction of a new vehicle into an existing assembly production line. The new operational content belonging to the cockpit was the basis for the test. The main reason for choosing the cockpit and the cockpit assembly line was that there were a significant number of new assembly operations to learn on selected stations for a specific team of operators. The cockpit is also a well defined sub-system of the vehicle which makes the study of computer based training feasible.

The assembly line, schematically presented in Figure 1, had 11 stations with 1 operator on each station. All stations had varying level of new operational content. Four of the stations with highest new operational content, 30-70%, were selected for the test. The other stations operational content were less affected by the introduction of the new cockpit. A breakdown of each selected station is presented in Table 1. The average number of operations for the selected stations were 15.5 operations per station.

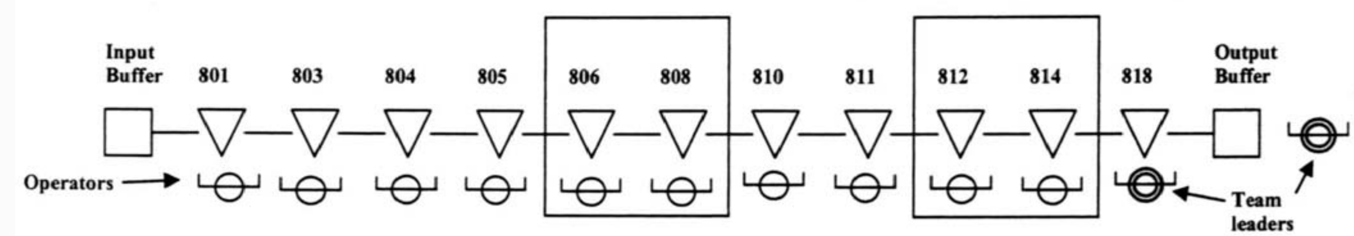

Figure 1. Schematic layout of the investigated assembly line including 10 operators, 2 team leaders, and selected (marked) stations in Test A.

Table 1. Content of Operations at Selected Stations in Test A

				Content and distribution for new operations			
Station name	Total no. operations	New operations	% new operations	Screwing operations	Clipping operations	Inspection/handling/ connection operations	Comments
806	20	6	30%	1	3	2	New clipped part assembly, New screwed part assembly
808	12	7	58%	2	0	5	New Radio, new connection of airbag
812	19	10	53%	2	4	4	New sensor, New speaker grille, new speakers
814	11	8	73%	1	2	5	New instrument panel, new clock, new control panel

The operations at the four stations were mainly traditional assembly operations, inspection operations, and connection-of-harness operations. Only a few of the new operations involved handling of compliant parts like harnesses, insulations, or tubes. These types of operations are hard to explain using only 3D solid CAD models without any dynamics involved and this type of operations could therefore be seen as representations of more complex assembly operations. Only a few operations with compliant parts were one limitation of the study. As only single operations of this type were included in the new cockpit, it was not possible to evaluate this type of operation in the present study.

The test subjects were 20 experienced operators, 10 from Shift A and 10 from Shift B. The operators from Shift A constituted the Reference Group and the operators of Shift B constituted the Test Group.

The test was performed as a frequency study where the performance of the training was evaluated by measuring the number of faults that was observed during the performance of the assembly operations. The faults were divided into two categories:

I. *"What-problems"*
Did the operator know *what* the operation content was? (Was the operator skilled in which operation to perform, which part to assemble, or which tool to use?)

ii. *"How-problems"*
Did the operator know *how* to perform the operation? (Was the operator skilled in how to assemble the part or how to use the tool?)

The operator was always accompanied by the instructor at the station. If any problems were detected, the instructor immediately gave feedback to the operator. The problems were always corrected by either the instructor or operator but all observed corrections resulted in an observed fault point for the group in the test.

The production of the new pre-series cockpits were divided into three batches containing 15, 56, and 97 cockpits respectively spread out over 23 weeks, shown in Figure 2. Assembly of any given batch was spread out from over several days to over several weeks and the production on any given day could differ from 1 to 10 cockpits.

The new cockpits were mixed into the normal production flow which meant that 10-15 ordinary cockpits were fed into the assembly line between every new cockpit. The production rate was the same for both the new and the existing production cockpits. The operators rotated between the different stations in intervals of 1.5 hours. All operators rotated throughout all 11 stations.

The only training that occurred after the first two weeks of initial training was the training that the operators got via the performed operations on the new cockpit during the production of the three batches.

Observations and measurements of the operators' performance, assessment points shown in Figure 2, were conducted three times. The first occasion was when

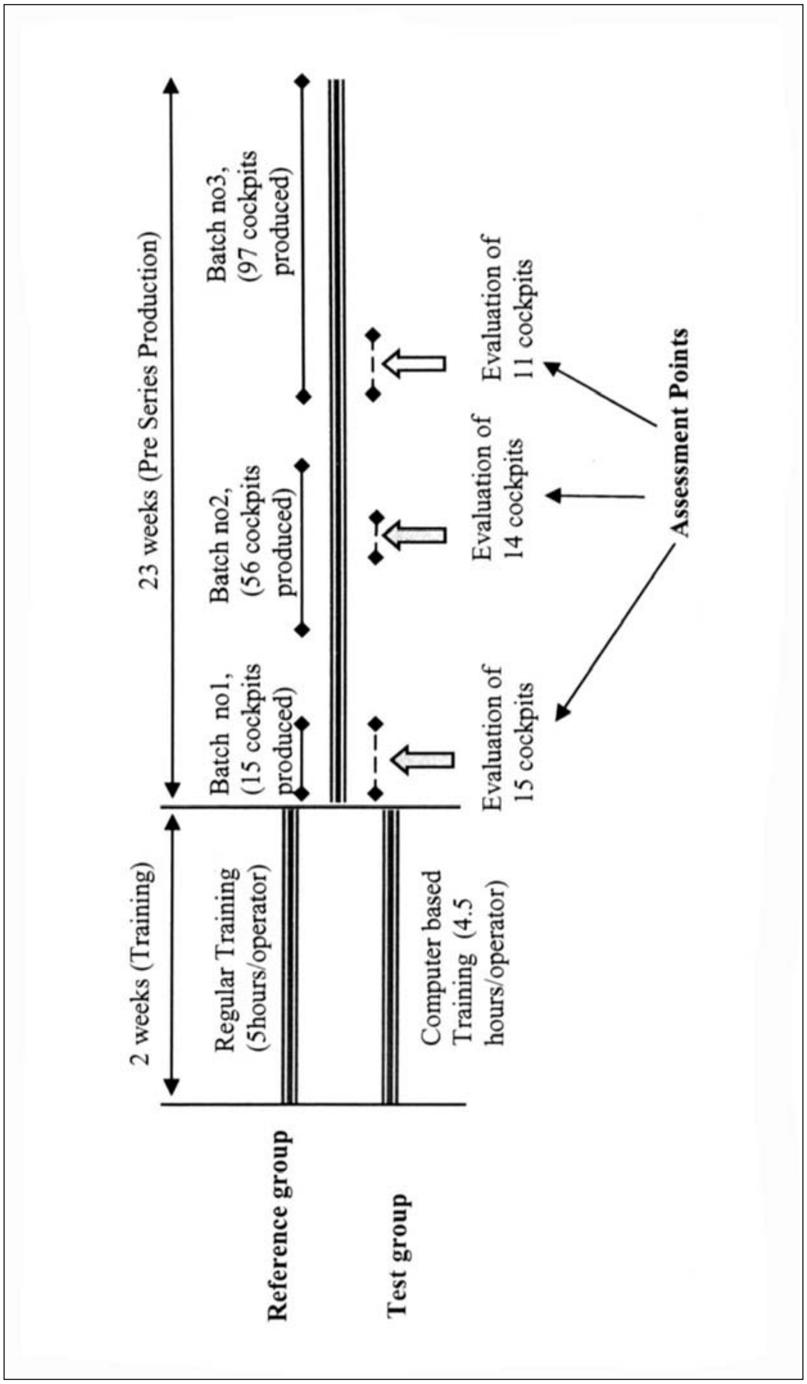

Figure 2. Organization of training and evaluation in Test A.

the first batch of 15 of pre-series cockpits was produced on the assembly line. The second occasion started in the middle of Batch 2 after a total of 30 new cars had been produced in Batch 1 and Batch 2. The final occasion started when production of Batch 3 started and 71 new cars had been produced. The distribution of evaluated cockpits between the shifts, shown in Table 2, was similar except for the first batch in which the Reference Group produced 11 cockpits and the Test Group produced 4 cockpits.

The observations were done by following selected operations at the four selected stations (806, 808, 812, and 814). Ninety percent of all new cockpit parts were assembled at these stations. The number of evaluated cockpits in the three batches was 15 cockpits, 14 cockpits, and 11 cockpits, respectively as presented in Figure 2.

The Reference Group

The 10 operators from the Reference Group (belonging to Shift A) received traditional instructor based training with several individual instructors leading training sessions over a period of two weeks prior to startup of production on the production line. The following was used for training: 1) a dedicated stand-alone cockpit, and 2) supporting documentation consisting of text documents (Standard Operation Sheets) with operation descriptions organized station by station presenting the sequence of the assembly operations. The operators from the Reference Group had on average five hours of traditional training. An estimate by the instructor stated that the content in the four selected stations were covered during four of the five hours, i.e., approximately one hour per station.

The Test Group

The 10 operators from the Test Group (belonging to Shift B) received computer based training by several self-study sessions at the computer. They were introduced to the software by the instructor and then spent an average of 4.5 hours on self-study training with the software. The training was available for all stations but most of the time, approximately four hours was used for the four new stations. The training occurred over a period of two weeks generally done at three separate randomly chosen occasions. The time frame between the three occasions as well as

Table 2. Number of Cockpits and Distribution between the Test and Reference Group Evaluated in Test A

	Batch 1	Batch 2	Batch 3
Reference Group	11	7	6
Test Group	4	7	5

the time frame between the last training and the startup of production differed between the operators. For all operators the last training occasion took place less than one week before startup of production at the assembly line. The operators from the Test Group did not have any access to the new cockpit parts during the training period. The average age for the operators in the Test Group was 37 years (range 24 to 57 years), and the average assembly experience as operator was 12 years (range 3.5 to 27 years). The average computer experience for the Test Group was 5 years (range 0 to 10 years).

Randomization in the test was established through rotation of operators between all 11 stations. The observations were done and documented by the leader of the test supported by the training instructor.

Quality Performance Level

As a complement to the visual frequency study, quality data was taken from the existing follow-up system. This was done in order to conclude if any differences could be seen between the two groups regarding quality output. Data was taken from all cars of the two first production batches, i.e., 71 cars.

Test B—Evaluation of Learning Rate for Computer Based Training

The objective of this test was to evaluate the learning rate for the computer based training of operators. The test subjects were six assembly operators randomly selected from another part of the assembly shop who had no experience of assembling the studied cockpit or variants of it. The operator average age was 33 years (range 28 to 46 years), the average length of assembly work experience was five years, and the computer experience was eight years (range 5 to 12 years). Two of the operators were new employees with limited assembly work experience.

The operators' learning rate was evaluated by allowing each of the computer trained operators perform the operation sequence for two selected work stations (station 808 and station 814 in Test A) and the total operation time needed was measured.

Each operator was introduced to the software by the instructor and then received computer based training for one hour on the two selected workstations. Immediately after this the operator was taken to the dedicated stand alone training-cockpit and was asked to perform the operations in the right sequence. The operator was asked to perform the assembly 2-4 times depending on the operators' progression in assembly performance. During each attempt the performance time was measured. If the operators made any faults they were corrected immediately. After each attempt feedback was given and a new attempt was carried out. When the operator made a successful operation sequence, below the available cycle time, the testing of that operator ended. Additionally the total training time (computer training and spent time with the training-cockpit) was compared with the corresponding training time used for traditionally instructor based training in Test A.

RESULTS AND DISCUSSION

Test A—Comparison of Assembly Performance

Figure 3a and 3b presents the average number of "What-problems" per assessed car for each analyzed station for the Reference Group (instructor based trained) and the Test Group (computer based trained). In 90% of the cases the "What-problems" were when the operator didn't remember the correct sequence order of operations. No clear trends can be seen from the results in Figure 3a and 3b. A reduction of problems/car can be seen at station 808-814 in Figure 3b but the expected trend would have been a reduction of problems on all stations for both groups from batch 1 to batch 3.

We assume that the lack of any clear trend was a result of too few operators and test vehicles but perhaps more importantly the randomizing of operators that occurred because of job-rotation. This effect resulted in time gaps of several weeks for an operator between working on the same station with the new vehicle. Another additional explanation to the unclear trend could be knowledge retention. The evaluation of batch 2 took place in the middle of the production of batch 2 but the evaluation for batch number 3 took place when the first vehicles was produced in the batch. Forgetfulness could be an additional parameter that affected the performance of the operators during batch 3. The reduction of problem rate that was shown for the Test Group (at station 808-810) in Figure 3b was the result of progression when getting practical experience from the operations. One explanation to this trend that is not shown at station 806 in Figure 3b can be that the new operational content only was 30% at this station.

When comparing Figure 3a and 3b the levels of problem rate was more or less the same for the both groups in batch 2 and batch 3. This means that the computer trained Test Group who had less experience from physical components or parts still was at the same performance level, regarding remembering what to do, as the Reference Group already from batch 2.

Figure 4a and 4b presents average numbers of "How-problems" per assessed car for each analyzed station for the two groups. Problems are defined as when the operator showed craftsmanship limits by failing to perform the operation in a proper way.

Similar to the results shown in Figure 3a and 3b, no clear trends can be seen from the results in Figure 4a and 4b. The trend with reduction of problems over the three batches can be seen at station 808 for the Reference Group and 806, 808, and 814 for the Test Group. The shown reduction was like in Figure 3a and 3b the result of progression when getting practical experience from the operations. One explanation to this trend that is not shown at station 812 in

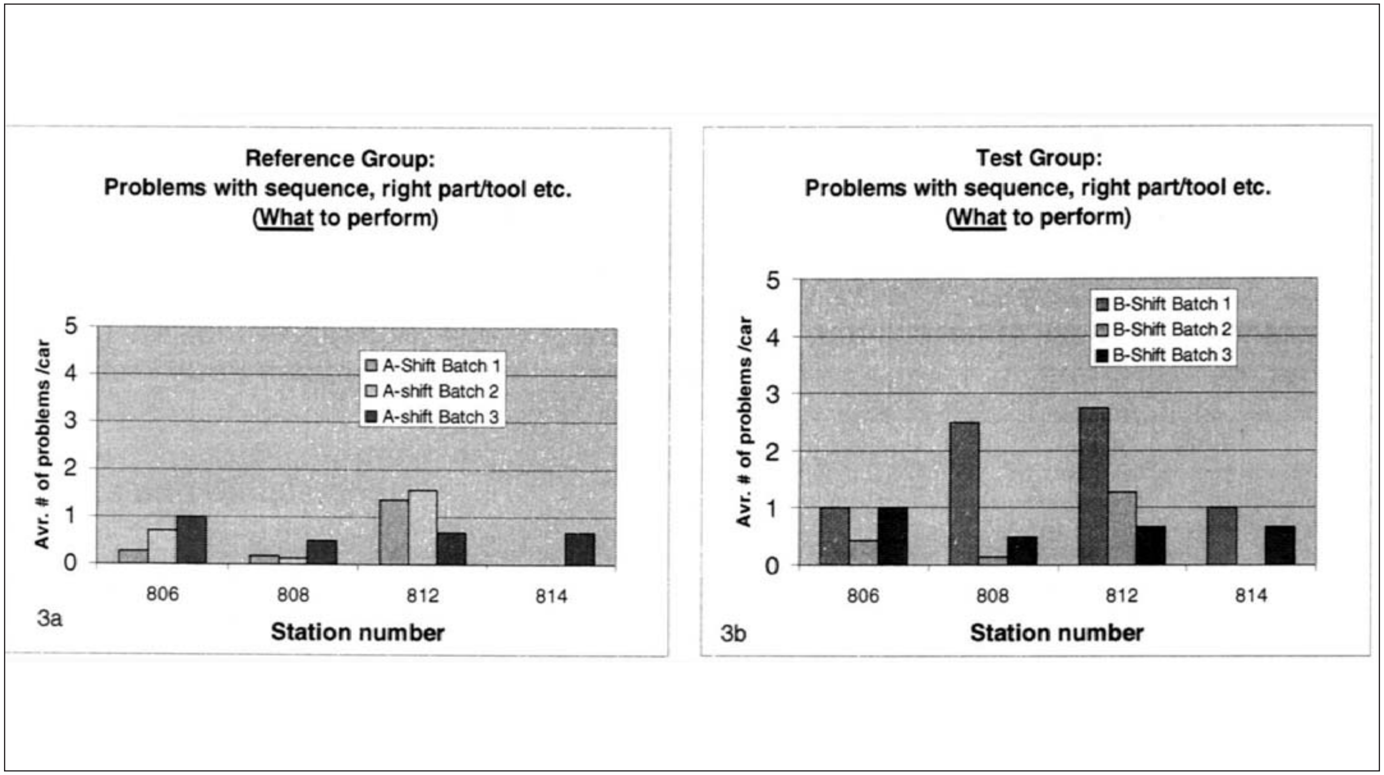

Figure 3a and 3b. Differences in Test A between the Reference Group and the Test Group regarding "What in operations to perform."

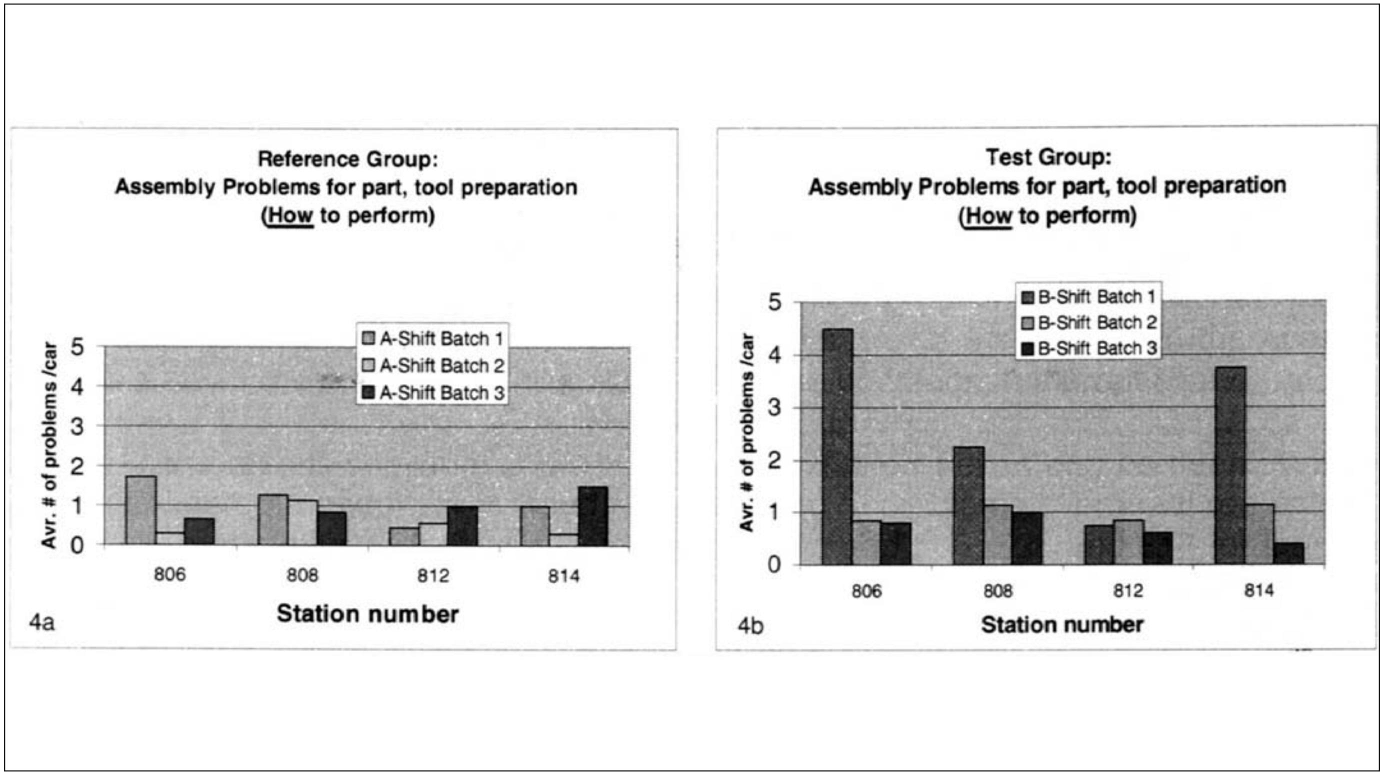

Figure 4a and 4b. Differences in Test A between the Reference Group and the Test Group regarding "How to perform the operations."

Figure 4b can be that even if there was as much as 53% new operational content at this station the movements needed to perform the operations was similar to already known components on this station. When comparing Figure 4a and 4b the levels of problem rate were more or less the same for the both groups in batch 2 and batch 3. This means that the computer trained Test Group who had less experience from physical components or parts still was at the same performance level as the Reference Group already from batch 2.

A comparison between the two groups regarding both Figures 3 and 4 presents two aspects to comment:

a) The Test Group had a high problem level during batch 1 compared to batch 1 for the Reference Group. This was the only clear difference between the two groups. The explanation has its origin in the previous training that differs for the two groups. The Test Group had problems when they started to perform the operations at the assembly line because of the lack of experience with real components. Even if they had had the computer based training, which had the focus on training the procedural operation sequence as well as the cognitive knowledge about the operation content, this was still a stressing moment for the operators which affected the result. This was also confirmed orally by the Test Group operators after the batch.
b) The first new cockpits that were produced on the line were produced by the Test Group. This involved a lot of attention from other affected parts of the organization. All cockpits produced by the Test Group in the first batch were followed by 4-6 people (manufacturing engineers, designers, etc.). This audience, who was critically watching the operators, was another stressing factor for the operators and also this was confirmed by the Test Group operators.

The overall conclusion (from this part of Test A) was that the total fault rate for the Test Group already after some initial pre-series production was on the same level as that of the Reference Group. In batch numbers 2 and 3 there was no significant difference between the groups in assembly performance.

The results indicate that computer based training, as performed, combined with motor skill training given from the production of vehicle batches in the pre-series phase can given operators similar assembly skill as the operators that have traditional training. This indication was valid both for "What-problems" as well as the "How-problems."

To develop motor skills or craftsmanship skills the operators must have training on real components but the test has shown that this can be done by using the initial pre-series vehicles and still have a performance level already in the middle of the second batch that is similar to operators with traditional instructor based training.

Factors that could have affected this positive result were that all of the operations included in the test were new but mediate regarding complexity and therefore rather easy to learn. None of the analyzed operations required handling of compliant parts nor a lot of motor training to perform.

Quality Performance Level

In Figure 5 are shown all the types of quality problems reported in the company's quality follow-up system STABS (System Tracking and Build Status). The quality problems are taken from the system in existing groups. The problems are reported to the system manually from inspection stations. When a problem is detected, description, classification, car identity, etc. are reported into the system. All problems were filtered so the result could be tracked to the cockpit area, the selected vehicles, and the two test groups.

When comparing the total quality level at the cockpit the result indicated that there was no difference in quality levels between the two groups. From the categories given from the STABS system only two are of that kind that they could be related to assembly operator performance. One of the types was directly connected: Not fully assembled, and the other: Not performed, could in some cases be related to the operator performance (both types marked in Figure 5). From this data no significant quality performance difference between the two shifts could be seen. It should be noted that support from expert operators were given to the operator through the assembly which reduced the fault rate.

The conclusion from this part of Test A was that the measured quality output from the assembly line did not indicate any differences between the groups. But a measuring instrument which is product oriented rather than process oriented and the support from expert operators makes it hard to draw any substantial conclusions other than those drawn above.

Test B: Evaluation of Learning Rate for Computer Based Training

Figure 6 presents the needed assembly times when performing station 808 assembly operations for a test group of six different operators. The target time of 130 s, i.e., the available cycle time, is marked with a horizontal dotted line in Figure 6.

The assembly operations were performed three times by all six operators. The operations included assembly and connection of radio, connection of airbag, assembly and connection of steering column integrated module, and assembly of steering column cover.

Three operators managed to perform the operations below available cycle time after two attempts. Three operators required three attempts to achieve the target

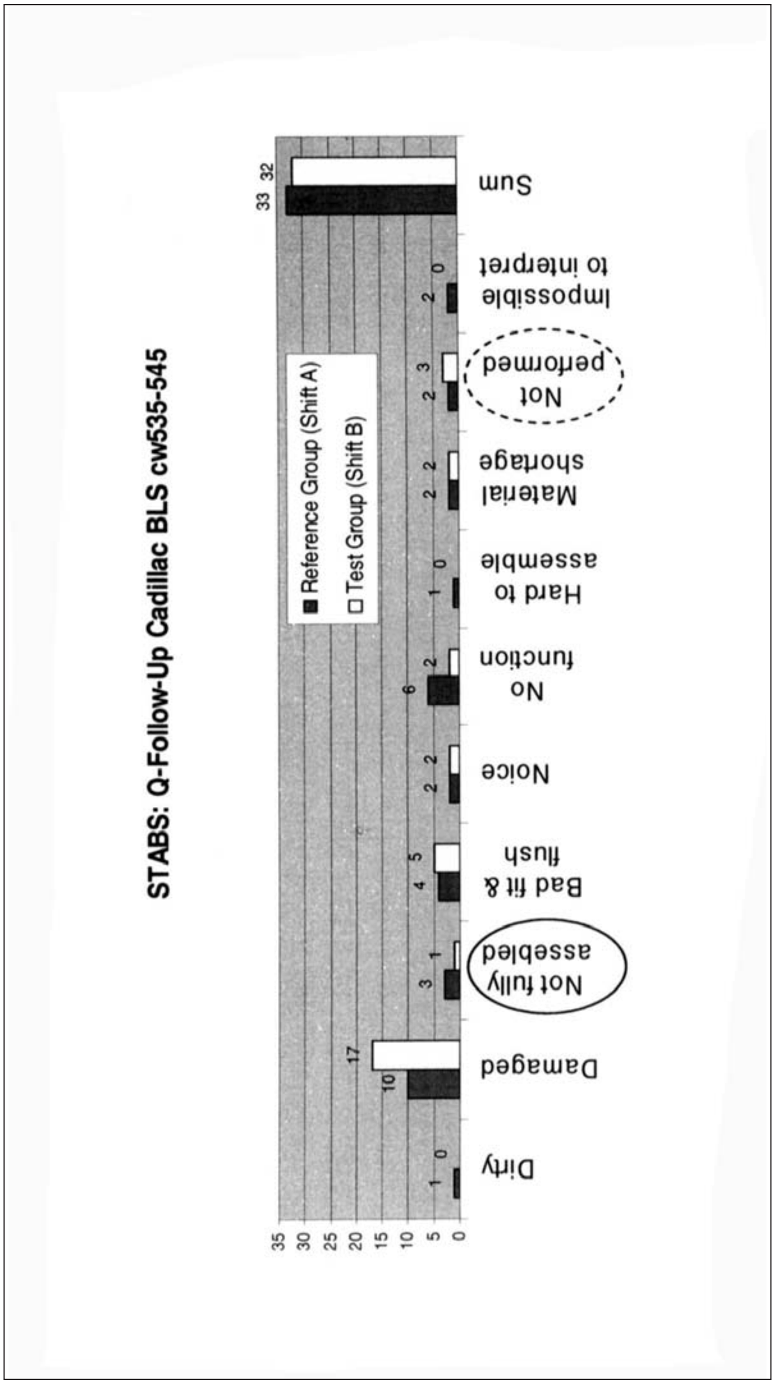

Figure 5. Comparison of reported quality problems on produced cockpits by the both groups at the cockpit assembly line.

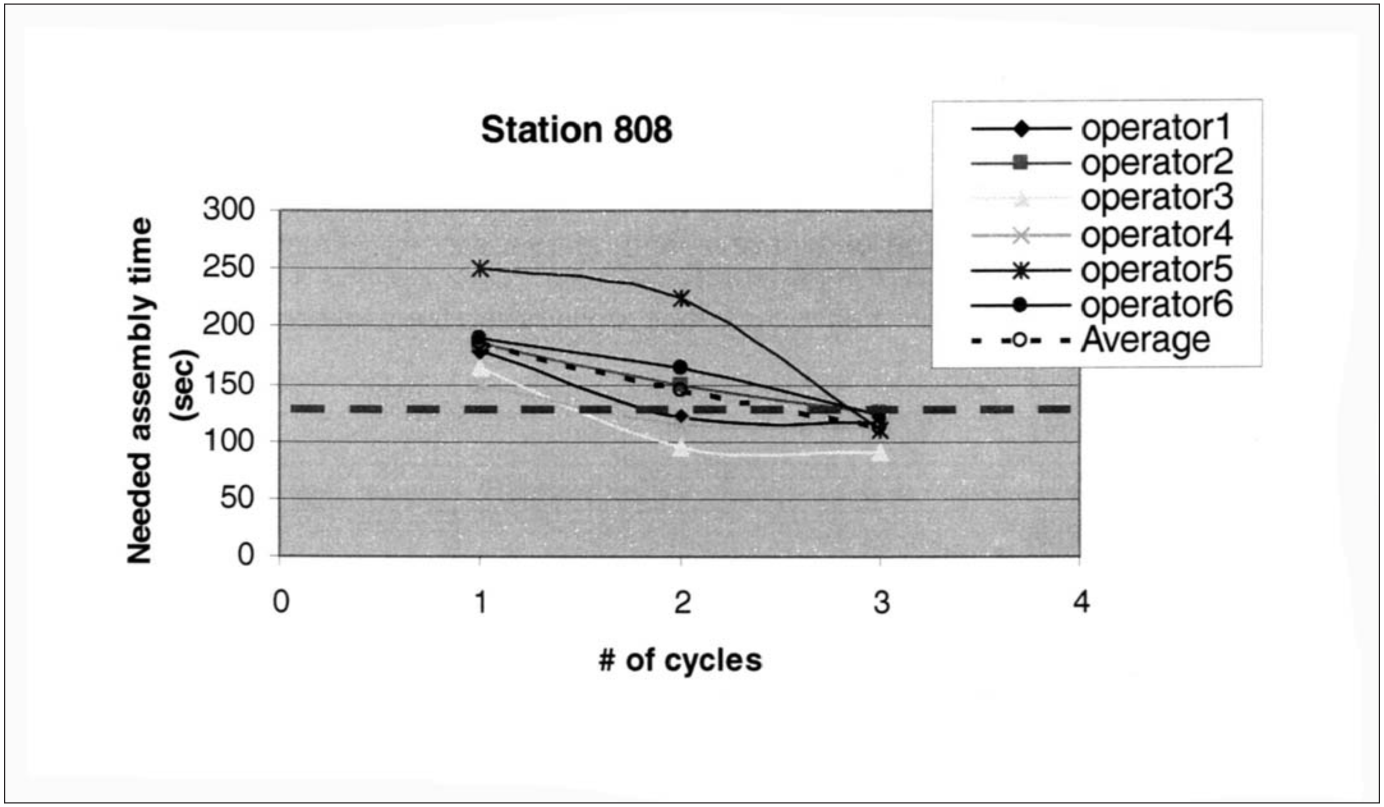

Figure 6. Assembly times for the six operator test group in station 808.

time or better. Operator No. 5 had the worst progress. However he was one of the two inexperienced operators who took part in the test.

Figure 7 presents the needed assembly times when performing station 814 assembly operations for the six operator test group. The target time, i.e., the available cycle time, is marked with a dashed line.

The assembly operations were performed three times by all six operators. The operations included assembly and connection of instrument panel, instrument panel cluster, seat belt warning lamp, clock, and climate control panel.

Five operators managed to perform the operations below the available cycle time already at the second attempt. One of them required three attempts to achieve the target time or better. Operator No. 3 had the best result and he was also one of the most skilled operators who took part in the test. The operations had a low level of needed craftsmanship skill and, compared to station 808, the response from the operators was that this content was easy to perform, which was evident in the results.

The results from the two stations showed that computer based training can provide a basis which a positive learning rate can be developed.

The three attempts needed on average 20-30 minutes including setup and feedback time. The traditional training, given for the same operational content to the Reference Group in Test A, needed approximately one hour to reach the same results. The results indicate based on this comparison that using this type of support gives conditions that can reduce needed training time with prototypes with more than 50%.

The conditions of the test have some positive aspects to consider when analyzing the result:

a) The assembly performance test with physical components was performed immediately after the training in the software. This means that the effect of forgetting was minimized.
b) The operational content in the test was two of the four stations monitored in Test A. The same factors around the relatively medium complexity of analyzed operations mentioned in Test A could have affected this result in a positive direction.

The conditions therefore give reasons to investigate if the positive results also are valid for more complex operations.

CONCLUSIONS

This study has shown that computer based training has a positive effect on learning rate and can replace instructor based training for the examined level of assembly complexity. The approach of using a desktop based training tool with

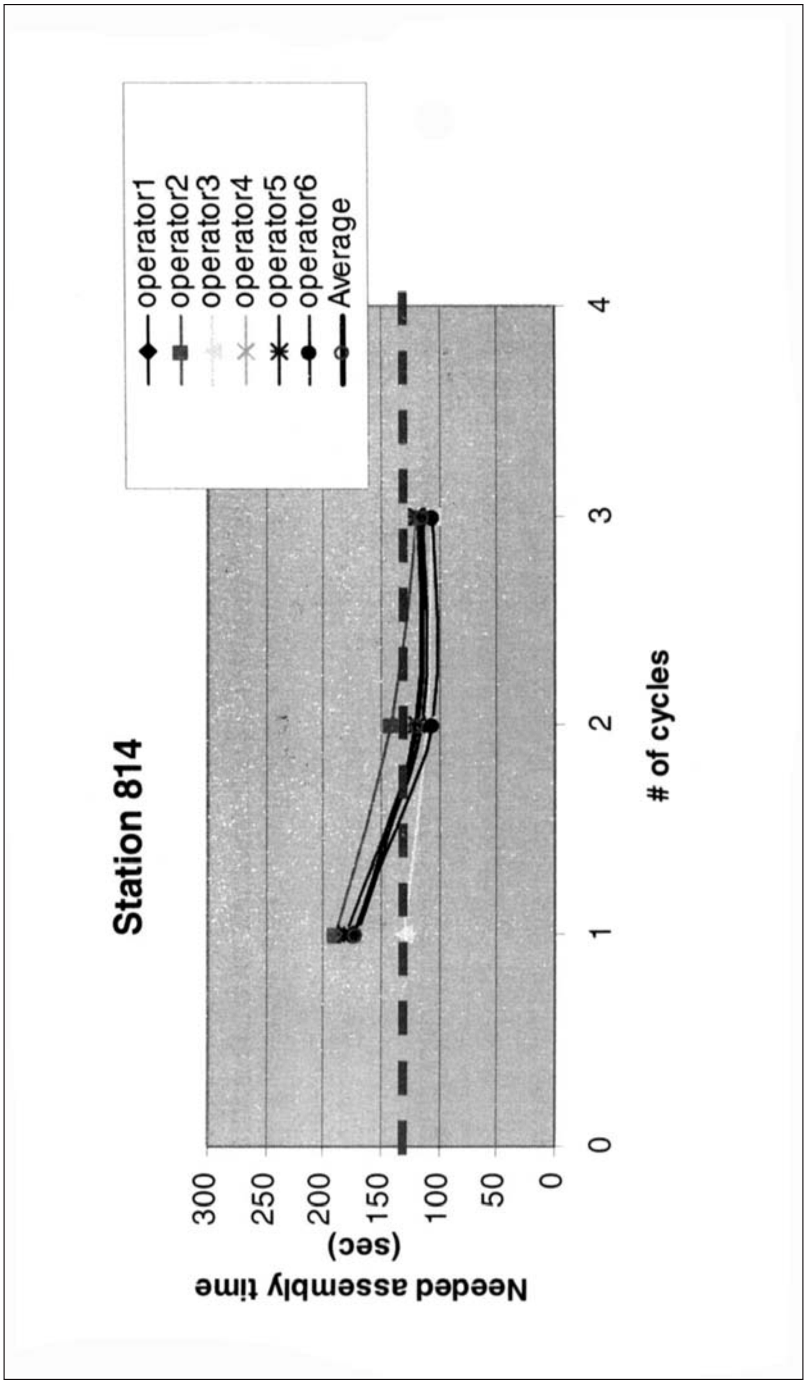

Figure 7. Assembly times for the six operator test group in station 814.

focus on cognitive interactive learning has shown to be effective in preparing skilled operators when introducing new cars in production.

The statements are based on the results from both Test A and Test B. Test A showed that the fault rate for computer based training of operators was similar to instructor based training given that the comparison was done after a volume of produced pre-series vehicles, in this case 30 vehicles. Test B showed positive results in learning rate and that the assembly performance target can, with computer based training, be reached with less "hardware" training time than with traditional training.

The results were obtained for assembly operations of medium complexity and have to be verified for assembly stations with higher complexity. Coming studies must explore whether the shown results also are valid for more complex operations with compliant parts.

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