ADVANCED MACHINE TOOLS: HOW BEST TO TRAIN OPERATORS

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Modern machine tools are very intelligent and capable of fine levels of adaptive control. Without proper training, the ability to operate these machine tools is difficult and critical in operator's day to day schedule. A mental model developed by the operator's to understand the work flow can be simplified for the better understanding of the work flow with training. With the developments in the current technology, computer based interactive training seems to be the future and effective way for organizations. A relevant issue is the question of displaying the image appropriately on the computer screen, so that operator control action is facilitated /learned has been discussed briefly. The purpose of this study was to compare different training methodologies assisting the operators and equip them with new set of skills to improve work efficiency. The results from the comparison have been discussed by implementing training procedure on two machines to train the operators in handling the machine. A detailed comparison methodology has been illustrated. The results indicate that training using simulation methods are the best in all measures of performance. However, experienced operators preferred traditional methods compared to computer based methods. More research is needed for generalizing the findings.

Significance: This paper establishes a need for a new and improved training methodology to modify the present training methods and increase worker efficiency.

1. INTRODUCTION:

The present situation of globalization and competition, the need for an organization to plan for future and sustain with the existing technology is the major area of concern. Organizations to in order to overcome this situation continue to make investments to increase plant reliability and to improve profitability using state of art technologies. In a survey conducted by Lund, Bishop, Newman, and Salzman (1993) on sixty-three companies, the authors report that nearly all companies have spent more than $10 million on new equipment in past three years. In those sixty-three companies, nearly 66% of the companies had their 50% production equipment computer based or programmable. While these have improved productivity and made them stay competitive, the role of operators handling these state of the art machines cannot be understated. The impact of humans is essential and will remain essential in manufacturing environments as mentioned in Mital et al. (1994c, d). The worker or operator is an active participant in complex man-machine system and training methodology adopted by the organizations to train the operator on these complex machines is a challenging task. Most of the complex machines come with a training manual, which can some times be difficult to read and understand by the operators. Knowledge and expertise of the operators continue to be one of the most valuable resources in development of the necessary skills without which the training methodology may be difficult and time-consuming.

In order to impart the needed skills to operate the complex machines, one has to understand how operators use these machine tools. Simple explanations of how one controls machines have stemmed from information processing models. In the last two decades, operator behavior on machine tools has been explained by mental models. Mental models are the operator's representation of the system (Norman, 1983; Stevens and Gentner, 1983). Mental models provide most of the operator's behavior (Norman, 1983; Wilson and Rutherford, 1989). The knowledge gained from years of manufacturing experience helps in the development of the mental models (Norman, 1983). Operators use mental model to interact with the system. These mental models are used to plan and make decisions and to explain unexpected situations (Van der Veer, et al., 1990). When operators understand a system, they can predict system behavior. In other words, their mental models map to the appropriate conceptual models.

So training can be viewed as an effective way of improving operator efficiency. While considerable research has been done on training, mainly in fields like behavioral science, social science, and psychology, systematic investigations of training methods in the manufacturing context that have been few and far in between. It is reasonable to assume that any training method designed to impart the needed skills to operators, should facilitate formation of mental models. In other words, it should provide the basic structure of the experience that the operator would get during operation of machine in real time.

In the United States, 90 percent of private organizations offer employee training, and more than $55 billion is spent on training annually (Bassi and Van Buren, 1998). Organizations spend an average of $645 to $1641 per employee on training (Van Buren, 2001). These organizations use a variety of training methods to enhance workers' skills. For example, 99 percent of organizations use traditional classroom-based training; of these, 93 percent use lectures, and 52 percent use case studies (Bill Communications, 2001).

Read and Kleiner (1996) report top ten training methods that are popular, i.e., videotapes, lectures, one-on-one instruction, role plays, simulation, case studies, slides, computer based instruction, audio tapes and films. One-on-one instruction (on the job training) is typically followed in the manufacturing domain. The value of on-the-job training is becoming limited, because the feedback which is very important in this method may sometimes get delayed or infrequent. In certain cases feedback is economically not feasible because of the nature of the task. The actual plant no longer offers an adequate basis for training. Economics and safety dictate that the plant cannot be used as a test bed. Consequently, one of the most viable approaches for training machine operators is development of a Computer-Based Training (CBT) program which offers several advantages over traditional training approach. CBT is being applied to a variety of technical training applications, including computer based simulation, interactive videodiscs, and other computer based applications such as Compact Disc Read Only Memory (CD-ROM) and Digital Video Interactive (DVI). A number of published studies have been reported on CBT. Benefits of CBT may include improving trainee confidence, decreasing training time, decreasing training costs, engaging trainees in interactive tasks making them active participants in learning, using information that can accommodate differences in individual learning styles by presenting multi modal information, and motivating trainees (Barron and Orwig, 1995; Tannenbaum and Yuki, 1992; Donohue, et. al., 1994) Desai et al (2000) conducted a research to compare Instruction-Based Training (IBT) with computer-based training (CBT) in corporate settings. The overall results indicated that the completion time in CBT training to be less than IBT. The results also showed that there was no statistical difference in performance accuracy of the subjects' one-month-after-training versus end-of-training.

Kamouri and Smith (1986) conducted experiment to verify the influences of two training approaches - instruction and exploration. Results of the experiment indicated that individuals using instruction approach were efficient in terms of time in completing a given task, and the one using exploration was better in terms of score.

Given the fact that contemporary machine tools are complex and are constantly changing, there is tremendous need for designing effective training methods. Computer based delivery is perhaps the most preferred form of training. This delivery can be web based or through desktop application. In a manufacturing environment the content method gets decided by the processes. Once delivery and content are fixed, the issue is how to present the content? This study deals exactly with this question. Two experiments were performed, in which different methods of presentation of content were investigated. Experiment one dealt with electro discharge machine, while experiment two dealt with an optical inspection machine.

2. EXPERIMENT 1:

2.1 Equipment:

Electro Discharge Machining (EDM) is a Non Traditional Manufacturing process (NTM) that was developed fifty years ago. EDM differs from traditional processes such as milling, turning, drilling and grinding in that it employs electrical and thermal energy to remove material. Visualizing and understanding complex relationships of process parameters are more difficult for EDM. Machinists need to develop mental models of NTM processes. Training is an issue when NTM processes are introduced to machine shops that traditionally employ traditional processes. Improved quality in manufacturing is based on a better understanding of the manufacturing process. Many of the NTM parameters are difficult to visualize, therefore conceptual visualization is the key. Training is a facilitator for understanding. Training and skill enhancement are critical, due to uniqueness of these processes. Transferring both skill and knowledge through personalized training has been a long sought goal. Advances in computer capabilities allow more of these processes to be carried out in a multi media environment. This has the potential for accommodating different learning styles by providing self paced interactive instruction.

2.1.1 EDM TRAINER:

This is an interactive software program that was designed to present users with conceptual information about the EDM process (Donohue, 1995). This program presented the process in six instructional screens. The screens were designed to build the process knowledge in a progressive fashion. Published studies suggest that visual representations may enhance model development. For example, Mayer and Gallini (1990) proposed that illustrations could enhance conceptual model development during learning. They showed that illustrations were effective for conceptual recall and creative problem solving, but not for verbatim recall. Hence, two versions of the screens, a graphic version and an alpha numeric version were designed. Contents were identical across the two versions of screens.

In the graphical display, pictures were arranged in a progressive story of machines' action. Appropriate labels were provided. Graphs were also provided in the end as feedback for operators' action. Graphical information was provided through sequential drawings which displayed the same concepts as alpha-numeric dialog. Cause and effect relationships were compared using bar graphs. Positive values were indicated through upward arrow while negative values through downward arrow. There were six screens in all. However, the input action was on an alphanumerical format.

Identical information, as in graphical format, was in Screens 1 through 6 of alpha numeric format. Alpha-numeric screens provided information that was read through scrolling dialog. Interaction was achieved through placing values in text entry fields and observing output in another text field. Comparison between last observed results and current results were provided directly below the current value field. Feedback was in alphanumeric format. Figures 1(a), 1 (b) and 2 (a), 2 (b) show a snap shot of a sample screen in graphic display and alpha numeric display respectively.
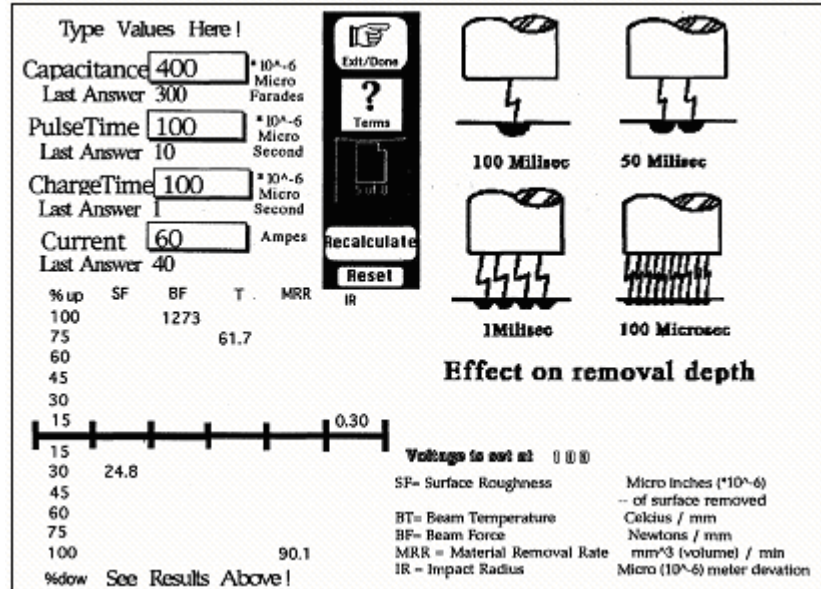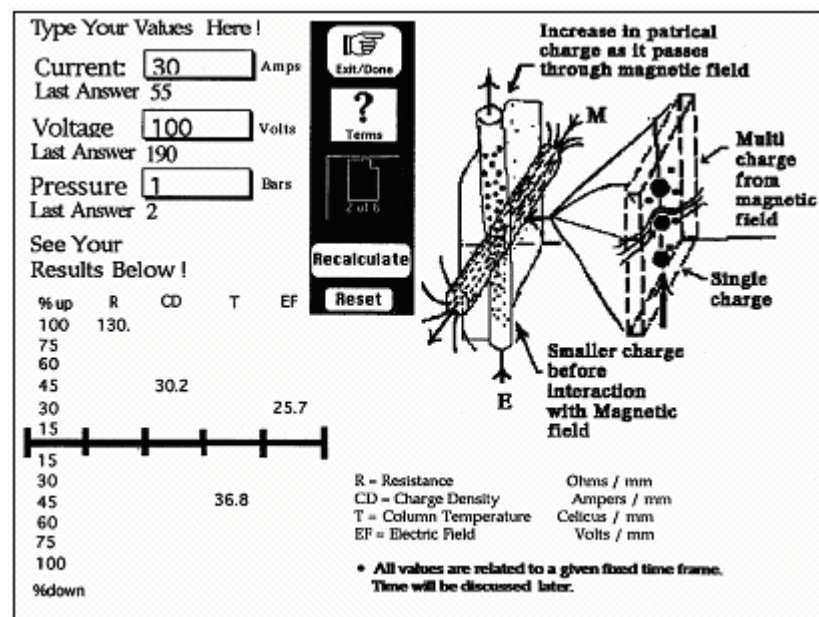

Figure 1 (a): Samples of graphic display.

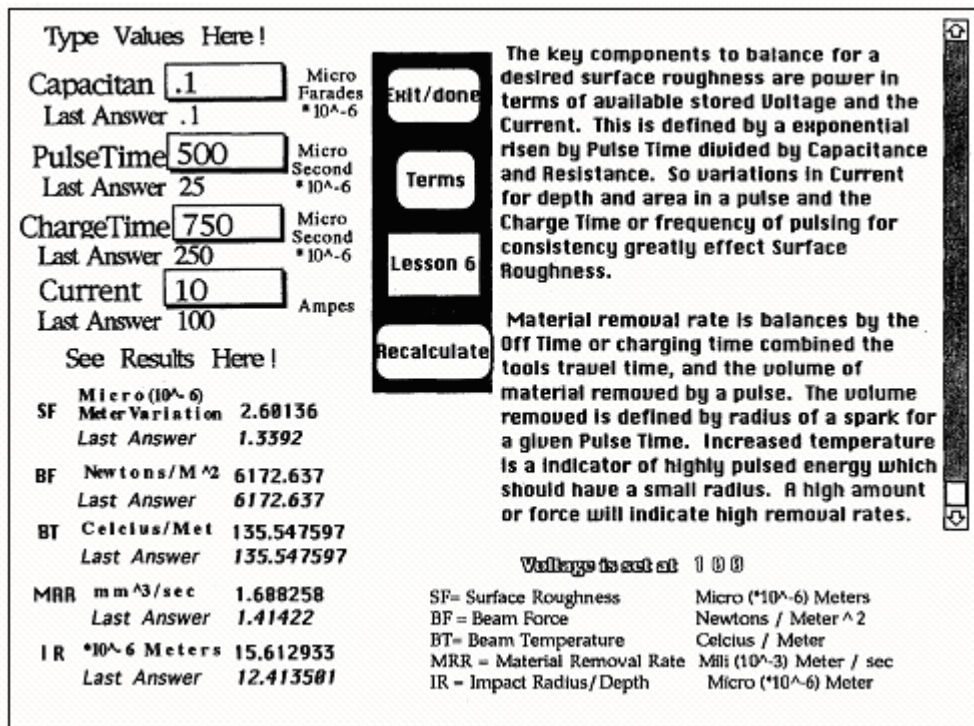Figure 1 (b): Samples of graphic display.

Type Values Here!

Capacitan [.1]   Micro Farades *10^-6
Last Answer .1

PulseTime [500]   Micro Second *10^-6
Last Answer 25

ChargeTime [750]   Micro Second *10^-6
Last Answer 250

Current [10]   Ampes
Last Answer 100

See Results Here!

SF   Micro(10^-6) Meter Variation   2.60136
      Last Answer   1.3392

BF   Newtons/M^2   6172.637
      Last Answer   6172.637

BT   Celcius/Met   135.547597
      Last Answer   135.547597

MRR   mm^3/sec   1.688258
      Last Answer   1.41422

IR   *10^-6 Meters   15.612933
      Last Answer   12.413581

Exit/done

Terms

Lesson 6

Recalculate

The key components to balance for a desired surface roughness are power in terms of available stored Voltage and the Current. This is defined by a exponential risen by Pulse Time divided by Capacitance and Resistance. So variations in Current for depth and area in a pulse and the Charge Time or frequency of pulsing for consistency greatly effect Surface Roughness.

Material removal rate is balances by the Off Time or charging time combined the tools travel time, and the volume of material removed by a pulse. The volume removed is defined by radius of a spark for a given Pulse Time. Increased temperature is a indicator of highly pulsed energy which should have a small radius. A high amount or force will indicate high removal rates.

Voltage is set at 100

SF= Surface Roughness   Micro (*10^-6) Meters
BF = Beam Force   Newtons / Meter ^ 2
BT= Beam Temperature   Celcius / Meter
MRR = Material Removal Rate Mili (10^-3) Meter / sec
IR = Impact Radius/Depth   Micro (*10^-6) Meter

Figure 2 (a): Samples of alpha numeric display.

Type Your Values Here!

Capacita   100000   Pekio Farades
Last Answer 1

Off Time   100000   Micro Second
Last Answer 1000

Partical   1   Dibrie Percent
Last Answer 20

See Results Here!

R = Resistance
CP = Column Power
BT = Beam Temperature
MRR= Material Removal Rate
CT = Charge Time

R   3878.154603   Ohms
CP   0.48859   Volt*Ampers
T   979.332588   Celcius/m
MRR 3.839373   mm/min
CT   *10^-6 sec

voltage is set at 100
current is set at   10

Forward

Backward

Lesson

Recalulate

relationships

? Terms

? Ranges

SWAP GRAPH

INFLUENCE OF DIELECTRIC TYPE

workpiece:55NiCrMo V₇ (-)
electrode: Cu (+)
ε* = 0.5

BEPETAN
SHELLSOL T
SHELLSOL TO

pulse duration [µs]

•√ The dielectric or resistance fluid prevents sparking, is related to current density, and beam temperature.

•√ Power is related to current.

•√ The percent of a dibrie has a effect on the time in which a spark happens and the matreial removal rate on the part.

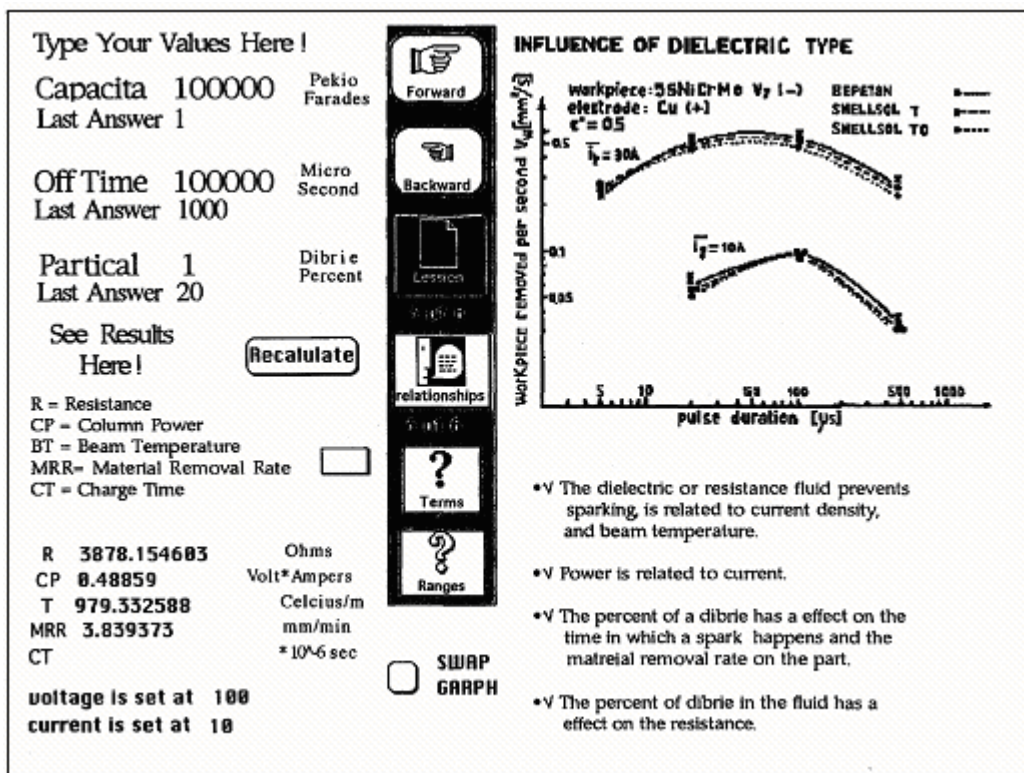•√ The percent of dibrie in the fluid has a effect on the resistance.

Figure 2 (b): Samples of alpha-numeric displays.

The objective of this study was to compare alpha-numerical and graphical formats in computer based training for EDM.

2.2 Training Methodology:

Twelve experienced subjects and twelve novice subjects participated in this experiment. A two by two Latin square design was used to test the two training methods. One half of the participants in each group did one display first and then the other. The remaining participants followed a reverse order. The independent variables were two levels of expertise, display style, and presentation order. The dependent measures were three groups of three multiple choice questions. These groups were broken down into basic reading recall (Q1), cause-effect relationship expressed as an interaction score (Q2), and extrapolation into higher level knowledge (Q3). A nine question set was asked after the learner was finished with instructional unit. Interaction with the display was structured with twenty questions designed to create use of all parameters in controlling the process. The time subjects spent interacting with the unit, as well as the time spent in answering questions was recorded.

2.3 Results:

While details of the results are described elsewhere (Donahue, 1995), it is relevant to mention here that screen number * Screen type interaction was significant. Figure 3 shows the plot of distribution of overall score across screens for both screen types. It should be mentioned that screens one and two were overview screens while the remaining four screens were the main content screens.

It is seen from the above figure that for screens 3 through screen 6 graphical formats resulted in better performance that alphanumeric format, while the opposite was true for screen 1 and screen 2. It is to be noted that these results were consistent across the three performance measures, i.e., basic reading, interaction, and knowledge gained. The superior learning performance with graphical display is also evidenced on the order effect, which was significant. Figure 4 shows the interaction of order and screen on time to learn, while Figure 5 shows the same interaction on time to answer. It is clear from these two figures that learning from graphical screen is far superior to that of learning from alphanumeric screen.

In short, it is apparent from this experiment that better learning is achieved through graphical presentation of process details. Experiment two was performed on a different machine tool, namely, an optical inspection machine. The results from that machine have described below.
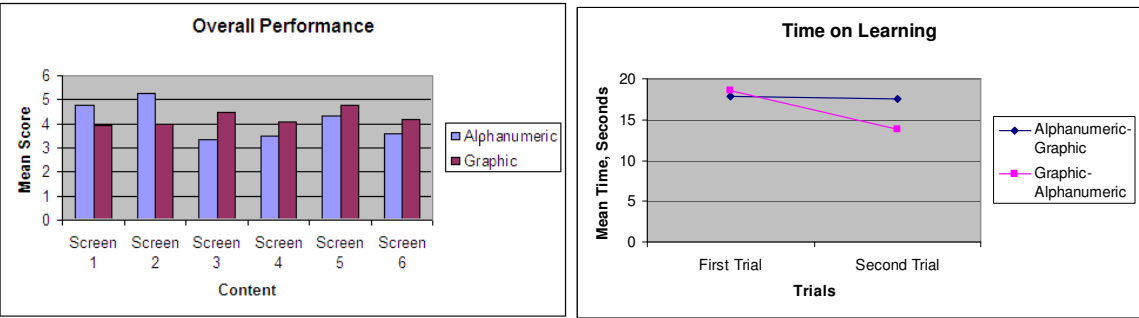

Figure 3: Plot of overall performance

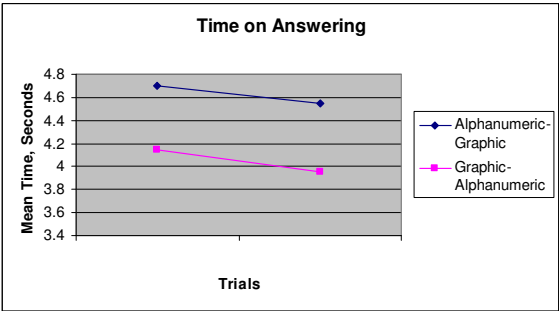

Figure 4: Order*Screen type interaction on time to learn.

Figure 5: Order*Screen type interaction on time to answer.

3. EXPERIMENT 2:

3.1 Equipment:

The experiment was run on optical measuring equipment. The layout of this machine is shown in Figure 6. The equipment had the following items:
1. Precision measuring stage
2. Motion control system
3. High resolution CCD camera and vision processing circuit board
4. Programmable profile, axial and surface lighting
5. Computer system
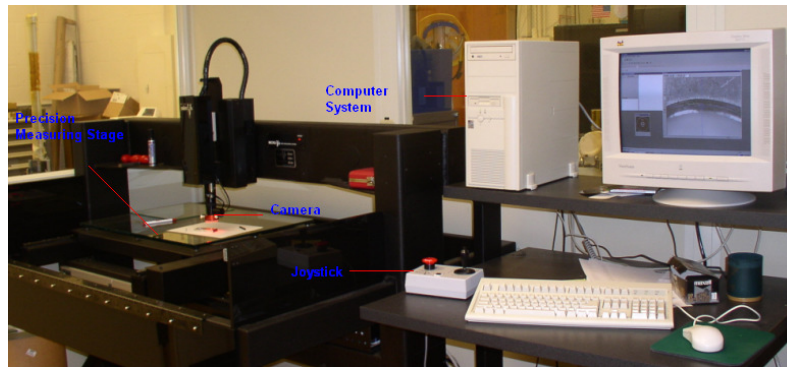6. InSpec® for Windows 32- bit metrology software
7. Variable speed joystick

Figure 6 Set up for Micro-Vu Optical™ measuring machine.

Precision measuring stage is a motorized stage, which sends accurate position (X, Y, Z) information to the measuring software. The CCD camera is the high-resolution camera, which can move in vertical axis for proper focusing of work piece. The stage and the camera are moved using a joystick. With the default setup, moving the joystick to the left moves the image of part to the left and vise versa. To control the height of the camera (Z position) the operator should press and hold the top button of the joystick and move the joystick in Y-axis direction. InSpec® is a 32-bit meteorology software application for a computer. The application is designed for a three axis fully automated vision measuring system. InSpec® supports many types of geometric features and operations. A feature is a geometric characteristic on a part for example arc, angle, circle, ellipse, point etc. when a feature is measured; InSpec® calculates the position, size, and form of feature.

Generalized steps required to measure a part on Micro-Vu Optical™ measuring machine are as follows.

Step 1: Place the part to be measured on the stage of machine.

Step 2: Focus the camera on the part using the joystick so that the part is properly visible in camera window.

Step 3: Adjust the lighting at the surface of the part if needed.

Step 4: Use the feature tools such as line, angle, or plane at the top of the schematic window, and ones on the camera window to measure the part dimensions. Once you select a feature it can be seen in instruction list in schematic window of InSpec®.

Step 5: Draw that feature in camera window. For example if one selects "Line" from feature toolbar at the top of schematic window and drew a line using mouse on the part in the camera window a similar line will be drawn in the schematic window. In other words whatever features the user will draw in the camera window will be seen in the schematic window.

Step 6: Read the value of the dimension of the part by right clicking it, which can be done in the instruction list in schematic window.

3.2 Training Methodology:

The main objective of the study was to develop best training method for machine operators. The training program should have good fidelity, texture and meaningful interaction to create a clear picture of the system. Rarely does one find standardized and consistent training programs to develop worker skills; optimal training programs are not generally known. (A.Mital et al., 1999). The best method to assess the effectiveness of training methods is to measure the after-training performance time and performance accuracy.

Three types of training program were tested among 60 subjects. They are:

1. Training by Computer based Simulation
2. Training by graphical representation of the processes
3. Training by using Manual provided by machine manufacturer.

The Simulation training program simulates the InSpec® program used by Micro-Vu Optical measuring machine and was developed using Visual Basic 6. In computer based simulation training the subject learns to measure the dimensions of two parts, one of which is simple and the other a complex part. After training, the subjects measured the dimensions for a different set of simple and complex parts. Two modules, a general module and a training module were developed. The first screen in the general module provided information on machine components. The second screen provided general information on various windows in InSpec®. The third screen in the general module provided the information on how to control lighting on the surface of a part (Figure 7 shows a snap shot of the same). The fourth screens provided the information on toolbars in InSpec® and its features. In Training module the trainee refers to the set of instructions and at the same time performs the part dimension measurements by using the simulated training program. The trainees were trained on measuring the diameter and the angle (Uttamchandani, 2005).
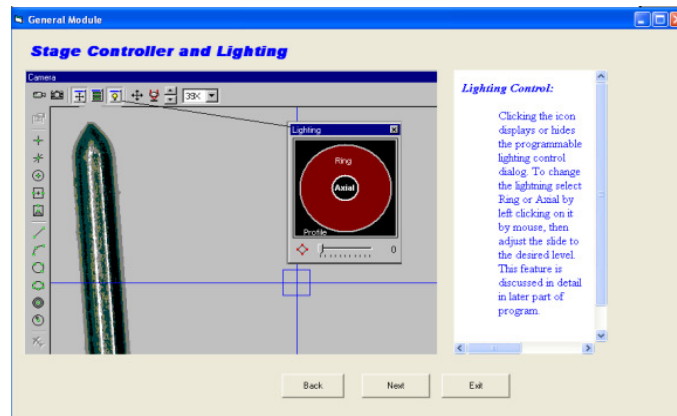

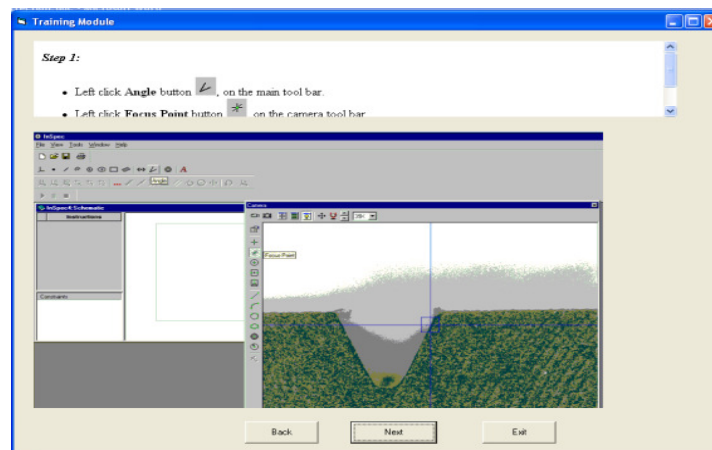Figure 7: A snap shot of the third screen in the general module

Figure 8: A snap shot of a screen in the second training method.

In computer based graphical training, which was also developed using Visual Basic 6 , pictures were used to explain the steps used in measuring. It also consisted of the general and training module. The general module was

similar to computer-based simulation training. The only difference was in training module. In this case, the trainee could just see the set of instructions required to measure a part, but cannot perform the steps simultaneously as was possible in computer-based simulation. Subjects were trained using the same parts used in computer-based simulation training. After the end of training each subject measured the dimension for a different set of simple and complex part. Figure 8 shows a snap shot of one of the screens (Uttamchandani, 2005).

In case of the training provided by using the manual provided by the manufacturer, the manual was customized and only the relevant information was provided to the trainees. The manual also included a tutorial, which described the steps required to measure a part. In this training method, subjects were allowed to read the manual and simultaneously interact with Micro-Vu Optical™ measuring machine. In case of training using a Manual, each subject was provided with a manual provided by the machine manufacturer and was allowed to practice directly on the machine. After the subject were comfortable with the machine, they were instructed to measure the dimension for a set of simple and complex part (Uttamchandani, 2005).

Out of the sixty subjects, twenty were randomly assigned to a computer based Simulation training programs; twenty were randomly assigned for computer based Graphical training program and the remaining subjects were assigned to training using the Manual provided by the machine manufacturer. The performance measures were number of wrong clicks, accuracy of measurement and time taken for measurement. Accuracy was the difference between the actual value and the measured value of the part dimension divided by the actual value. Time taken was the amount of time in seconds to measure the dimension such as diameter of pin and angle during the test session by each subject. Number of mistakes was defined as the number of wrong clicks or number of wrong steps that the subject did while measuring the part on Micro-Vu Optical™ measuring machine. In order to test the validity of the methods in real world, an additional 9 subjects were selected randomly from a manufacturing organization in Lincoln, Nebraska. These subjects were divided in three groups, and each group was trained using one of the three training methods described above. Similar performance measures were gathered. The data was gathered using the log sheet shown below in table 1.

Subjects	Training Program	Dimension Measured	Actual Value	Measured Value	Time Taken	Mistakes
Subject 1	Manual Training Program	Diameter	4.5 mm			
		Angle	30			
Subject 2	Computer Based Graphical	Diameter	4.5 mm			
		Angle	30			
Subject 3	Computer based interactive	Diameter	4.5 mm			
		Angle	30			

Table1: Data collection log sheet

3.3 Results:

The ANOVA summary is shown below in Table 2.

It is seen that the performance time is influenced by all the independent variable while deviation is not impacted by any of the variables. Figure 9 shows the plot of effect of training methods of performance time. It appears that simulation is best while manual is worst with graphical method in between. Figure 10 shows the effect of training methods on number of incorrect clicks. This will be a correlate of performance time. Again simulation is best. Finally, Figure 11 shows the effect of part complexity on performance time. As expected, complex part took longer for measurement than simple part.

Independent Variable	Time	Deviation	Wrong clicks
Training Method	*	NS	*
Part	*	NS	NS
Training Method*Part	*	NS	NS
Subjects	NS	NS	NS

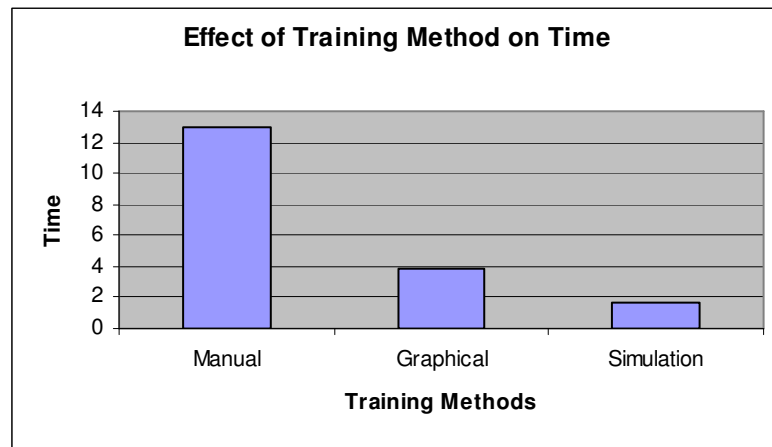- = Significant at an alpha of 0.05, NS = Not Significant.

Table 2: ANOVA Summary

Effect of Training Method on Time

Figure 9: Effect of Training Method on performance time
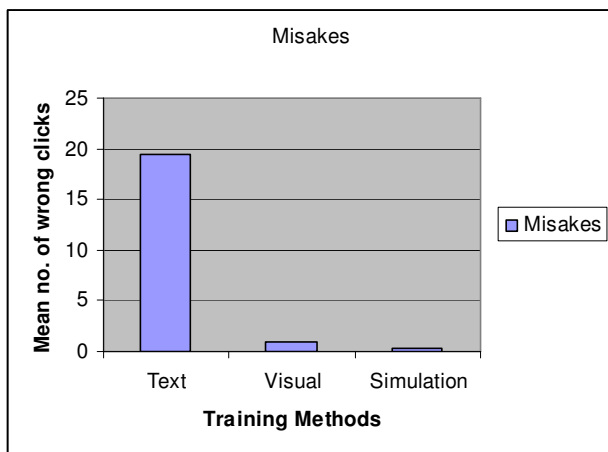
Misakes

Effect of Part Complexity

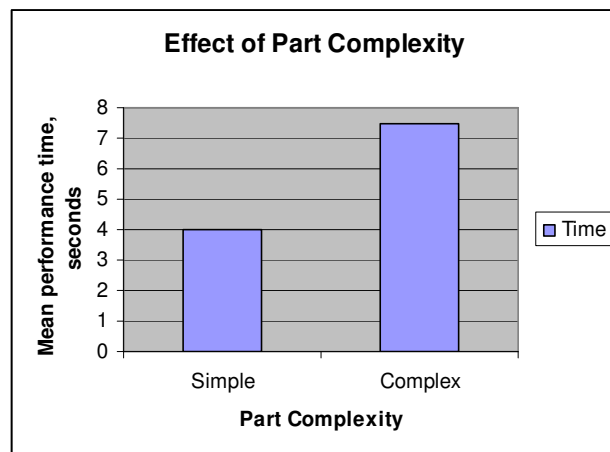Figure 10: Effect of training methods on mistakes   Figure 11: Effect of part complexity on performance time

In summary, a number of results of this study are interesting. They are:

1. Deviation is not influenced by any variables, while time is influenced by all variables. This could mean that accuracy is not compromised while measurement time reduces considerably with improved training methods
2. Simulation appears to be the best, flowed by the graphical method with the existing training through manual is distant third.
3. Simple part appears to be easy to measure than difficult part.

4. DISCUSSION:

Typically, operators develop a mental image of the process, and use that image to control the process. However, most of the present day machine tools are far more intelligent, capable of very fine levels of adaptive control. Hence, training and skill enhancement to deal with these machine tools are critical to operators, to form appropriate models. Given the current technology, computer based interactive training is the way to go. A relevant issue is the question of displaying the image appropriately on the computer screen, so that operator control action is facilitated/ learned. To the best of this author's knowledge, research on interface design for manufacturing systems is sparse to non existent.

The two experiments reported here dealt with the question of identifying the best display types to train operators. Similar concepts were tested in these. In the first experiment alphanumeric screens (similar to printed manual of second experiment) were tested against graphical screens (similar to static visual screens of second experiment). Improved computer

hardware technology facilitated development of simulation in experiment two. Across both the experiments, the following results appeared consistently:

a) Graphical screens were better
b) Simulation was best, and
c) These improvements were consistent across both experiments.

The results are consistent with the fact that processing images is less intense than textual material, and that dynamic interaction (as in simulation) is always better than static pictures. Can these findings be generalized? To an extent, the results can be generalized. Especially in case of general purpose machines, one could generalize the findings. However, in case of special purpose machine tools, where operations are machine specific, generalizability of these findings is suspect. However, it should be remembered that the differences between these types of machine tools may only be in the content matter and that at a baser template level, graphical display is recommended as compared to textual display.

5 INDUSTRYAPPLICATION:

Technology changes rapidly in contemporary world. This warrants better and more innovative training methods. Hence comparison of training methods, which is the main theme of this paper is highly relevant to the industry.

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