8.0 ROLE OF COMPUTERS IN TEAM TRAINING: THE AIRCRAFT MAINTENANCE ENVIRONMENT EXAMPLE

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ABSTRACT

Research on civil aircraft inspection and maintenance has shown the importance of teamwork in accomplishing aircraft maintenance tasks. Training has been identified as one of the primary intervention strategies in improving team performance. Moreover, if training is to be successful, it is clear that we need to provide aircraft maintenance technicians with training tools to help enhance their team skills and improve team performance within the aircraft maintenance environment. In response to this need, this research looked at the role of team training and specifically that of advanced technology for team training. A controlled study was conducted to evaluate the effectiveness of advanced technology for team training. The study was conducted in two phases: the instructional phase, wherein 18 subjects received training through a computer-based team training program; and the remaining 18 subjects received training using a traditional instructor-based equivalent team training program. In the evaluation phase, the subjects were divided into three member teams and performance of the teams was evaluated as they completed a routine and a non-routine maintenance task. The results of the study are reported as part of this paper.

BACKGROUND

In order for the Federal Aviation Administration (FAA) to provide the public with a continuing safe, reliable air transportation system, it is important to have a sound aircraft maintenance system.[1] The maintenance system is a complex one with many interrelated human and machine components. The linchpin of this system, however, is the human. Recognizing this, the FAA (under the auspices of the National Plan for Aviation Human Factors) has pursued human factors research.[1,2] In the maintenance arena this research had focused on the aircraft maintenance technician (AMT).[3,4,5] Since it is difficult to eliminate errors altogether, continuing emphasis must be placed on developing interventions to make the maintenance procedures more reliable and/or more error tolerant.

Task analyses of aircraft inspection and maintenance activities have revealed the aircraft inspection and maintenance system to be complex, requiring above average coordination, communication and cooperation between inspectors, maintenance personnel, supervisors and various other sub systems (planning, stores, and shop) to be effective and efficient.[1,2,6,7] A large portion of inspector and maintenance technician work is accomplished through teamwork. The challenge is to work autonomously but still be a part of the team. In a typical maintenance environment, first, the inspector looks for defects and reports them. The maintenance personnel then repair the reported defects and work with the original inspector or the buy-back inspector to ensure that the job meets pre-defined standards. During the entire process, the inspectors and maintenance technicians work with their colleagues from the same shift and the next shift as well as personnel from planning, stores, etc., as part of a larger team to ensure that the task gets completed.[1] Thus, in a typical maintenance environment, the technician has to learn to be a team member, communicating and coordinating the activities with other technicians and inspectors. Though the advantages of teamwork are widely recognized in the airline industry,[8] the work culture assigns responsibility for faulty work on individual AMTs rather than on the teams in which they work. The reasons for this could be the individual licensing process and personal liability, both of which often results in AMTs and their supervisors being less willing to share their knowledge and work across shifts with less experienced or less skilled colleagues. The problem is further compounded since the more experienced inspectors and mechanics are retiring and being replaced by a much younger and less experienced workforce. Not only do the new AMTs lack knowledge or skills of the far more experienced AMTs they are replacing, but they are also not trained to work as team members.

The earlier problem of the development of individual AMT skills has been continually addressed by FAA. For example, the proposed FAR Part 66 (new AMTs certification requirements) specifically addresses the significant technological advancements that have taken place in the aviation industry and the advancements in training and instructional methods that have arisen in the past decade. The FAA, through the Office of Aviation Medicine, has also funded efforts for the development of advanced training tools to train the AMTs of the future.1,2,9 These advanced tools (e.g., Boeing 767 Environmental Control System tutor -- ECS and multimedia System for Training Aviation Regulations -- STAR) will be available to A&P schools. It is anticipated that the application of these new training technologies will help reduce the gap between current AMT skills and those needed for the maintenance of advanced systems.

However, the AMTs joining today's workforce are lacking in team skills. The Aircraft Maintenance Technology Schools (AMTS) provide the necessary technical skills for students to receive both their airframe and power plant certificates (A&P License). The curriculum for AMTS is specified in the Code of Federal Regulations, and presently does not address any instruction in teamwork skills. In fact, the current technical school environment encourages students to compete, and as a result, the AMTs are often ill-prepared for cooperative work. To prepare student AMTs for the workplace, new ways have to be found to build students' technological, interpersonal and socio-technical competence by incorporating team training and communication skills into their curriculum. Furthermore, the importance of teams has also been emphasized in the National Plan for Aviation in Human Factors 1,2,10 where both the aircraft industry and government groups agreed that additional research needs to be conducted to evaluate teamwork in the aircraft maintenance/inspection environment. Recent work has examined the effects of team training when applied to students at an Aircraft Maintenance Technology School. Using a previously designed framework for the study of team training in the aircraft maintenance environment, Gramopadhye in a pilot study found a positive correlation between team skills training and the improvement of team performance and overall task performance in an aircraft maintenance situation.11 In addition, the study concluded that student AMTs needed to be provided with team skills instruction to prepare them for the teamwork tasks found in the aircraft maintenance environment. However, the study did not address issues related to the appropriateness of a particular training delivery system. The question that begs to be answered is: What is the best method to present team skills training?

With computer based technology becoming cheaper, the future will bring an increased application of advanced technology to training. Over the past decade, instructional technologists have provided numerous technology-based training devices with the promise of improved efficiency and effectiveness. Examples of such technology include computer simulation, interactive video discs and other derivatives of computer based application, several of which have been employed for diagnostic maintenance training.4,12,13 Furthermore, multimedia has assisted in teaching difficult and complex skills.14 Layton stated that the domain of aircraft maintenance is rapidly becoming the focus of computer-based training (CBT) aids.15 With the use of desktop computers with multimedia packages, new maintenance job aids have been developed to teach technical skills to maintenance technicians. AMTs may learn a variety of skills from CBT that range from scheduling preventive maintenance to applying expert systems for fault diagnosis and repair. Lufthansa Airlines believes so strongly in CBT that they have instituted CBT with video overlays to update the technical skills of their maintenance technicians.16 Andrew also described various multimedia technologies that have been effective in simulating combat situations for team training in the military.17 Because of the advantages offered, computer-based training may have a role to play in team training in the aircraft maintenance environment. It is important, therefore, to examine the effectiveness and applicability of computer-based multimedia team training for aircraft maintenance technicians. To date, however, no one has examined the role of the advanced technology, specifically computer-based multimedia presentation, for team skills training for aircraft maintenance technicians. The express purpose of this research was to address this knowledge gap, and to determine the best methodology to improve team training for aircraft maintenance technicians.

Thus, the general objective of this research was to understand the role of team training and specifically that of computers for team training. As part of this effort, a computer-based team training software, the Aircraft Maintenance Team Training (AMTT) software, was developed and a controlled study was conducted to evaluate the effectiveness of computers for team training.18 The study evaluated the transfer effects of computer-based team training and addressed usability issues related to using computers for team training. The methodology and results from the controlled study are described in greater detail in the following paragraphs.

METHODOLOGY

Test Site

The controlled study was conducted at the Aircraft Maintenance Technology Center of Greenville Technical College (GTC). The center houses both classrooms for A&P training and a fully equipped hangar for conducting aircraft maintenance and repairs. The classrooms at the Aircraft Maintenance Technology Center provide seating for 20 students. Each classroom was equipped with a 25-inch color television, video player, overhead projector, white and black boards, and a lectern. In addition, the classrooms are equipped with four Pentium 75 MHz computers and 15-inch color monitors (1024 X 768 resolution) installed with multimedia packages.

Test Subjects

The subjects for this study consisted of 12 students from a local aircraft maintenance technology program and 24 licensed A&P mechanics from a local aircraft maintenance facility. The subjects were compensated for their participation. The 36 subjects were randomly assigned to two groups such that each group had an equal number of subjects from the aircraft maintenance technology program and maintenance facility, respectively.

Group IBT - Instructor-based Training: received team training instruction through traditional instructor-based training (IBT)

Group CBT - Computer-based Training: received team training instruction through multimedia computer-based training (AMTT software)

Experimental Procedure

The study was divided into two phases: the instructional and evaluation phases.

Instructional Phase

Team Training

Subjects in the IBT group were trained on team concepts using a traditional instructor-based training delivery system, while those in the CBT group received similar training on a computer using the AMTT software. Every effort was made to maintain a constant curriculum and presentation sequence for both the groups. The only difference in the training between the two groups was the type of delivery system. The team skills training focused on the following four separate skills: communication, decision making, interpersonal relationship, and leadership. More details on the structure and content of the team training program can be found in Gramopadhye.[18] It should be noted that in the instructional phase, team training was provided to individuals, and teams were not formed until the evaluation phase.

Data Collection

Data was collected on subjects' perception of each team skill before and after training using the team skills protocol report. The reports in this research used elements from the Crew Resource Management/Technical Operations Questionnaire (CRM/TOQ), the modified Taggart's questionnaire, Taylor's questionnaire, and the Critical Team Behavior Form (CTBF).[19,20,21] Similarly, changes in subject's team skills knowledge was measured using a 20-question multiple choice test administered before and after training.

At the conclusion of training all subjects completed a two-part usability questionnaire. The questionnaire collected subjective satisfaction ratings on the training delivery system using a seven-point Likert scale. The first part of the questionnaire, referred to as the General Questionnaire, contained questions relevant to both the training delivery systems, and was completed by subjects in both the groups. The General Questionnaire addressed usability issues related to: content, mechanics of presentation, format, and usefulness. The second part of the usability questionnaire was training delivery system specific, and addressed usability issues related to the presentation and format. This was completed by subjects in the respective groups.

Evaluation Phase

This phase examined the transfer effects of team training (IBT and CBT) on AMT performance. Upon completion of the instructional phase, subjects in each group were randomly assigned to six three-member teams. Following the assignments, the teams were charged with performing two tasks representative of normal aircraft maintenance.

Task 1- Routine maintenance task: determining the center of gravity of an aircraft

Task 2 - Non-routine maintenance task: trouble shooting an electrical problem on an aircraft.

The order in which the tasks were performed was balanced within each group so that three teams performed the routine task followed by the non-routine task, while the order was reversed for the remaining three teams. To reflect a true maintenance environment, work cards were supplied to all the teams which provided general instructions.

Data Collection

As the teams performed the routine and non-routine tasks, their performance on the tasks was evaluated by three independent evaluators on measures of: speed, accuracy, and safety. In addition, at the conclusion of the routine and non-routine maintenance tasks, the evaluators and each individual subject completed a questionnaire evaluating their team on the application of various team skills (communication, decision making, interpersonal relationships and leadership).

Task Performance Evaluation

Routine Maintenance (RM) Task

Accuracy: Number of errors or number of times the team's procedure differed from the work card

Number of times an improper tool was used

Number of times equipment was handled incorrectly

Safety: Number of times the safety of the aircraft was in jeopardy

Number of times the safety of an individual was in jeopardy

Speed: Time to complete each sub-task

Percent of task completed within allowed time

Non-routine Maintenance (NM) Task

Accuracy: Was the problem diagnosed correctly?

Did the team locate the problem?

Did the team fix the problem?

Speed: Time to diagnose the problem

Time to locate the problem

Time to fix the problem

Total time

Safety: Number of times the safety of the aircraft was in jeopardy

Number of times the safety of an individual was in jeopardy

Instructor's Evaluation

Upon completion of the routine and non-routine maintenance tasks, the evaluators completed a verbal protocol report, evaluating the teams on various team performance measures (communication, decision making, interpersonal relationships and leadership skills). The instructor's evaluated each team on the application of team skills using a seven point Likert scale. The score for each team was obtained by averaging the scores provided by the three evaluators.

Self Evaluation

Upon the completion of the RM and NM tasks, all subjects completed a verbal protocol report that was identical to the instructor's report. This allowed the individual team members to rate the performance of their team on the application of team skills (communication, decision making, interpersonal relationships and leadership).

RESULTS

Instructional Phase

The responses on the team skills verbal protocol report were analyzed using an analysis of variance (ANOVA). Separate scores were obtained for each individual skills component after ensuring that it was appropriate to group the responses into an aggregate measure.[22] The ANOVAs showed a significant Trial effect for communication ($F (1,34) = 9.37, p < 0.05$) and leadership skills ($F (1,34) = 10.44, p < 0.05$). However, the main effect of Trial was not significant for interpersonal relationship and decision making skills. The analysis did not reveal any significant Group x Trial interaction effect or Group effect.

Similar ANOVAs conducted on the pre- and post team skills knowledge scores showed a significant Trial effect for communication (F (1,34) =, $p < 0.001$), decision making ($F (1,34) = 112.10, p < 0.001$), interpersonal relationships ($F (1,34) = 42.1, p < 0.001$) and leadership ($F (1,34) = 14.36, p < 0.001$). The Group x Trial interaction effect and the main effect of Group were not significant.

Separate ANOVAs were conducted for each usability category (general categories: content, mechanics, layout, usefulness; delivery system specific categories: presentation, format). The analyses of variance conducted on the general part of the usability questionnaire did not reveal any significant differences between the groups on each of the four usability categories. A two tailed t-test was used to compare the actual mean scores versus expected mean scores (3.5) on delivery system specific issues. The tests revealed that the subjects rated both the training programs significantly high on presentation and format related issues.

Evaluation Phase

The subjects and instructors evaluated the teams on their application of team skills. ANOVAs conducted on the aggregated self-evaluation scores for communication, decision making, interpersonal relationships and leadership did not reveal any significant differences between the IBT and CBT trained teams for both the routine and non-routine maintenance tasks. A similar result was also observed on the instructors' evaluation of the teams on the various team skills measures. ANOVAs conducted on the various task performance measures did not reveal any significant differences between the IBT and CBT trained groups. Correlation analysis performed on the various measures showed a positive correlation between the post training knowledge test scores and the time to complete the maintenance tasks ($r = 0.4683, p < 0.05$), between accuracy measure and the use of communication skills ($r = 0.4322, p < 0.01$), decision making skills ($r = 0.341, p < 0.05$) and interpersonal relationship skills ($r = 0.4661, p < 0.0042$). Similarly, correlation analysis of safety scores revealed that the teams which had higher communication, decision-making, leadership and interpersonal relationship scores had significantly fewer safety violations ($r = -0.5702, p < 0.001; r = -0.8062, p < 0.0001; r = -0.5312, p < 0.0009; r = -0.4719, p < 0.0112$).

DISCUSSION AND CONCLUSIONS

The analyses of the pre- and post-training perception verbal protocol reports showed that the training delivery system had comparable effects on the subject's perception of team skills. It was interesting to note that the subject's overall (pre- and post-training) perception of interpersonal relationships and leadership skills were much lower than those for communication and decision making skills (Figure 8.1). The subjects that made up the test Groups consisted of either students or maintenance technicians, and as such were not composed of crew leads or supervisors. It can be hypothesized that non-supervisory technicians do not recognize the importance of leadership and interpersonal relationship skills. This lack of concern for leadership skills was first noted by Taylor.7 In a survey of ten US commercial transport aviation maintenance facilities, Taylor found a lack of leadership skills in maintenance foremen. In addition, work currently being conducted under a grant from the FAA Office of Aviation Medicine has identified a need for leadership skills training for lead mechanics and maintenance foremen.23

Both the IBT and CBT groups showed a significant increase in the post-training knowledge test scores (Figure 8.2). The fact that both groups showed almost a comparable increases in test scores probably indicates the effectiveness of both the methods of delivering team training. The results are consistent with those of other researchers who have found similar results in improving team skills by training. Taylor conducted a crew resource management (CRM) training program for aircraft maintenance personnel, and found that maintenance performance measures increased after training.24 Also, in a study to improve teamwork in engineering design education, Ivaturi found that team training instruction enhances students' knowledge of team skills.25

Figure 8.1 Comparison of Team Skills Perception Pre- and Post Training for Groups 1 and 2

Traditionally, team training has been delivered in a classroom environment by role playing, games, simulations, etc.17,26 Thus, the conventional approach has been highly interactive wherein the trainees and trainers interact at different levels throughout the training process. The fact that the CBT (specifically, the AMTT software) was able to achieve the same scores as IBT (an equally well developed classroom team training program) bodes well for the role of computers in imparting team skills knowledge. At this point, it should be mentioned that the IBT portion of the team training program had the same content as the CBT portion and the only difference was in the method of delivery. This shows that, given the equivalent content of the two team training programs, a well designed interactive computer-based team training program can be as effective as a traditional instructor-based team training program.

The development of the AMTT followed an iterative design process so that the problems with the software were identified and corrected before implementation. The cycle of design, test, measure and redesign was repeated a number of times in the development process.27 Thus, the AMTT software was developed after understanding the needs of the AMT, talking with experts from Lockheed Martin and Greenville Technical College, following a process of iterative design and development and eventually resorting to detailed user testing (with instructors, supervisors and AMTs). The usability and knowledge test scores clearly indicate that the resulting product was one which was well received by the users and one that helped increase their knowledge on the teamwork skills. Figure 8.3 shows the results of the general usability questionnaire with mean scores on four separate usability issues. These results are encouraging since they indicate that the users were equally satisfied with both the training programs. Chandler found similar results using a media-rich computer software (System Training for Aviation Regulations - STAR) to teach federal aviation regulations (FARs) to A&P students.28 In her study, the subjects reported a high degree of satisfaction with interactive stories and true-to-life situations presented through CBT. Comparable satisfaction levels between users of hypermedia and paper-based team training programs were also noted by Ivaturi.25

Figure 8.2 Comparison of Team Skills Knowledge Tests Pre- and Post Training for Groups 1 and 2

After analyzing the results for both the CBT and IBT teams, the results are unambiguous. It is clear that CBT (i.e., AMTT) was as effective in delivering team training instruction as IBT. Finally, the iterative design methodology employed in this study proved to be useful in designing an effective computer based team training software. The above results have obvious ramifications for the use of AMTT for team training in the aircraft maintenance environment. In addition to being as effective as existing instructor-based team training methodologies, use of AMTT for team training has other obvious advantages:

Standardization: AMTT provides a systematic and consistent curriculum. Aircraft maintenance instructors at various facilities use their own unique training strategies (lectures, classroom discussions, video examples, etc.). In addition, some maintenance instructors who are technically competent may not have sufficient team skills knowledge to train AMTs on teamwork. The AMTT software provides a standardized and systematic team skills training program which aircraft maintenance instructors (at certified repair stations, airline companies, general aviation stations, and A&P schools) can use to provide team skills training.

Figure 8.3 Comparison of Usability Scores for Groups 1 and 2 on Training Delivery Issues

Adaptability: Traditionally, maintenance training has been accomplished via on-the-job training or classroom training, both of which are manpower intensive. It requires careful scheduling of personnel or encumbers others in the training process. AMTT is adaptive, self-paced and can be done at convenient times when trainees are available and need only involve the person being trained.

Record Keeping: The record keeping capabilities of AMTT tracks the student's progress. This information can be used by the instructor/ supervisor to design remedial training.

Cost effectiveness: Team training using AMTT can be cost effective because: (1) It can be delivered on-site thus eliminating travel expenses for the trainer and the trainee. (2) It can minimize down-time by providing training at times that are convenient to the trainee and the company's work schedule. In larger organizations, AMTT can be delivered to many people at multiple sites thus proving to be cost effective.

Use of advanced technology: Many facilities (e.g., A&P Schools and fixed based general aviation facilities) do not have access to larger aircraft. The AMTT software provides team skills training against the backdrop of maintaining a DC-9. Thus the trainees not only acquire knowledge and skills on teamwork, but gain an understanding of the importance of teamwork in the maintenance of wide-bodied aircraft.

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