Human Factors Assessment of Scenario-driven Training in Web-based Simulation

Bharvi Chhaya[1], Shafagh Jafer[1] and Stephen Rice[2]
[1]Department of Electrical, Computer, Software, and Systems Engineering, Embry-Riddle Aeronautical University, 1 Aerospace Boulevard, Daytona Beach, U.S.A.
[2]Department of Human Factors and Behavioral Neurobiology, Embry-Riddle Aeronautical University, 1 Aerospace Boulevard, Daytona Beach, U.S.A.

Keywords: Simulation Training, Usability Testing, Subjective Workload Measures.

Abstract: Usability testing of products has commonly been used to test desktop applications, websites, online tools, and various types of learning platforms. This paper discusses usability and workload testing for a portable training simulation technology for Air Traffic Control (ATC) trainees. The NASA-TLX (Task Load Index) was developed for the purpose of measuring user subjective workload, and is useful for a variety of tasks, including online or computer-based training sessions such as the one being described in this paper. This multidimensional assessment tool rates users' perceived workload, which is then correlated with other aspects of performance such as accuracy, speed, response times, etc. At the conclusion of the human factors experiment, the data indicated that participants found the simulation software to be relatively easy to learn and use, and did not experience high workload while using it.

1 INTRODUCTION

Usability testing of products has commonly been used to test desktop applications, websites, online tools, and various types of learning platforms. It has traditionally been conducted in the restricted setting of the laboratory, where potential external variables and other confounds can be controlled for in order to prevent loss of internal validity. This allows the developers to maintain stable environmental factors and restrict the amount of social influences that might impact users and their performance.

Scenario-based training and particularly scenario-oriented exercising is highly valuable in training professionals who will operate under sensitive and risky environments. Pilot and air traffic controller training programs highly benefit from modeling and simulation where trainees are provided with realistic but simulated scenarios to master their knowledge and learn in a risk-free environment (Updegrove & Jafer, 2017). While scenario-based training is currently used in full fidelity simulators for trainees, this technology is not readily available in a portable environment, so studies on the usability and advantages of such scenario-driven training are limited.

This paper aims to describe a case study detailing the human factors assessment of the use of a web-based scenario-driven simulation training environment for air traffic control (ATC).

2 BACKGROUND

The training technology used as the tool for the case study has been described in detail in this section along with the measures being used to determine usability as well as stress and workload undertaken.

2.1 ATC Scenario Training Technology (ASTT)

Simulation-based training and particularly scenario-oriented exercising is highly valuable in training professionals who will operate under sensitive and risky environments. The performance and realism of any simulation requires a clearly-defined scenario articulated with all involved factors. Any aviation related simulation scenario must be defined with clear expression of the specification of initial and terminal conditions, aircraft specifications, airport and

Chhaya, B., Jafer, S. and Rice, S.
Human Factors Assessment of Scenario-driven Training in Web-based Simulation.
DOI: 10.5220/0009820301890196
In *Proceedings of the 10th International Conference on Simulation and Modeling Methodologies, Technologies and Applications (SIMULTECH 2020)*, pages 189-196
ISBN: 978-989-758-444-2

airspace configurations, significant events, failure modes (if any), instructions, clearances, and the environment, as well as the major actors, their capabilities, behaviour and interactions over time (Moallemi et al., 2018).

To develop training scenarios, domain experts and software developers collaborate closely to bridge the gap between the domain and the simulation world (Chhaya, Jafer, Coyne, Thigpen, & Durak, 2018). This often requires tremendous amount of effort and manual work. One of the main challenges that scenario-oriented training programs face is the lack of diverse pool of scenarios. Limited variety of training scenarios put trainees at the risk of unprepared circumstances that might arise in the actual field. On the other hand, the underlying simulation infrastructure (bot software and hardware) hinders trainees' exposure to the training material, since training could only take place in specialized laboratories equipped with necessary technologies and only under supervision/mentoring of an instructor/lab technician (Cummings, 1970). The above capabilities were recently developed for a funded project for the FAA Academy En-route Controller Training Program.

The ATC Scenario Training Technology (ASTT) tool has been developed as a portable training platform for ATC trainees (Shannon et al., 2018). ASTT provides an online environment allowing trainees to practice Air Traffic Control (ATC) concepts at their own pace without the need to utilize instructional lab space and instructor's time. It involves development of a training tool that emulates En Route Automation Modernization (ERAM) and en route lab interfaces. ASTT provides "instructor" and "student" modes of operation, allowing for instructors to monitor student performance, and providing students with an on-demand training environment to practice various en route scenarios. This technology allows trainees to respond to a given scenario using their acquired skills and receive feedback on their performance (B. N. Chhaya et al., 2019). ASTT is a high-fidelity web-based simulation tool for practicing ATC en route scenarios utilizing interactive computer-based system replicating the actual En Route Automation Modernization or ERAM ATC system.

The ERAM system requires coordination between two controllers managing the same space and looking at two different monitors: (1) the Radar-Position (R-Position) which contains an interface with a radar display, and (2) the Radar Associate-Position (RA-Position) which has an interface to the ERAM Decision Support Tool (EDST) (Richard et al., 2019).

The R-Position interface shows the data blocks of all flights within the sector airspace and in its immediate surroundings, as well as trailing lines. An image of this interface screen can be seen in Figure 1. The data blocks can be expanded if needed and show details such as the aircraft ID, speed, sector control and other remarks.

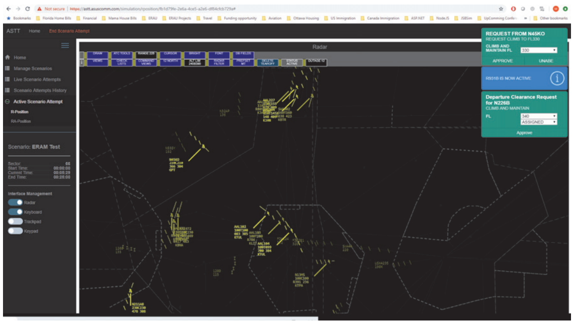


Figure 1: View of ASTT R-Position interface. It shows the radar screen with the airspace and aircraft within it along with flight properties.

The RA-Position lets the radar associate look at several screens, including the radar screen pictured in Figure 1, along with a list of all flights, altitudes, directions, routes and remarks. EDST warns the associate in the event of potential issues such as an Inappropriate Altitude for Direction of Flight (IAFDOF) or varying levels of conflict alerts. It also gives the controller the option to edit any of the fields or to trial plan a change in altitude or route (Richard et al., 2019). An image of this interface screen can be seen in Figure 2.

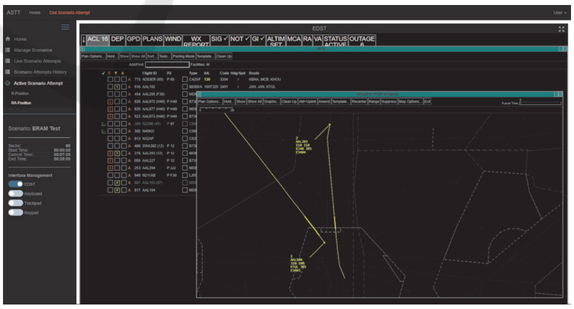


Figure 2: View of ASTT RA-Position Interface. It allows the controller to see the radar screen, a list of flights and to communicate changes to the flight plan.

The controller interacts with the screen using a virtual keyboard that is identical to the ERAM keyboard to avoid confusion because the keys are different from those on a standard keyboard attached to the computers running ASTT. This virtual keyboard can be seen in Figure 3.

Figure 3: View of ASTT virtual keyboard.

Upon navigating to the tool through the web, the users are first greeted with a login screen as seen in Figure 4. Once their credentials have been authenticated, they can access a list of scenarios they are able to run as seen in Figure 5. At the conclusion of any attempt, they can check their attempt history in order to get feedback on their attempt. This screen is shown in Figure 6.

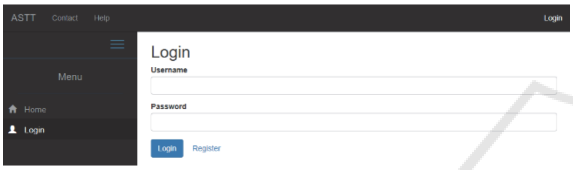


Figure 4: ASTT login screen.

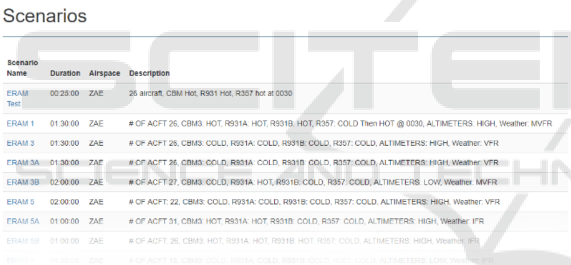


Figure 5: ASTT scenario selection screen.

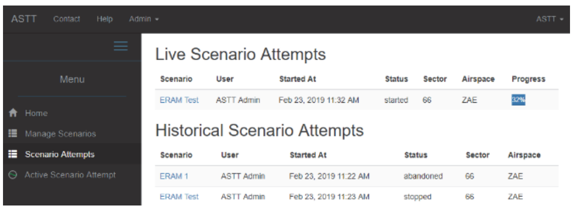


Figure 6: ASTT scenario attempt history screen.

In order to simulate real-time air traffic for the scenarios, ASTT uses accurate Flight Dynamic Models of several aircraft, each of them including simulated Flight Management System (FMS) and autopilot capable of steering the aircraft per the aircraft published flight profile (Richard et al., 2019). The simulated FMSs are capable of storing flight plans using 4D waypoint trajectories (latitude, longitude, altitude, and time constraints).

2.2 Usability Testing

There are several types of usability tests that can be conducted. The most common type is the problem discovery test, where the goal is to uncover (and potentially fix) all the usability problems that are detected at this stage. This test should be done early on in the development process, but can also be done later in the process. Once the problems are found and the new design is developed, then a benchmark study can be used to determine if those changes actually made the interface easier to use. Once it is determined that the interface is easier to use, then a competitive test can be conducted to compare the new product to existing ones. Most usability studies assess first-time use, so a follow-up learnability study might be useful to ensure that users can easily learn how to use the product and can accomplish certain long-term tasks. This is particularly useful for training platforms, where users may log in repetitively over time during the training course.

For these assessment tests, there are typically a combination of methods employed. Some of these methods are designed to capture physical measurements, and can include, but are not limited to, video recording, logged keystrokes, mouse movements, body movements, etc. Other methods might include physiological measures, including pupil dilation, heart rate, cortisol levels, O2 levels, etc. Another approach is to collect performance measures such as time to complete a task, number of errors, number of navigations needed, number of false starts, etc. Lastly, measures of subjective workload are important in order to capture how much stress and workload the user is experiencing while interacting with the product. This paper will be focusing on this last measure.

2.2.1 Stress and Workload

Stress is a state of mental or emotional strain or tension resulting from adverse or very demanding circumstances (Roscoe, 1978). Stress and workload typically correlate during training periods. Users feel under a certain amount of stress from the training itself, and workload can be unnecessarily increased by poor design. Additional stress can also be generated by environmental factors, such as heat, cold, motion, air quality, etc. Psychological stressors may include cognitive appraisal (a person’s understanding or interpretation of the situation), level of arousal (often measured by heart rate, pupil diameter, hormonal chemistry, etc.), and tunneling (a user’s tendency to focus solely on one task).

While some stress is advisable, having too little or too much stress can lead to poor performance. Figure 7 shows the Yerkes-Dodson Law (Teigen, 1994), which posits that the ideal amount of stress is somewhere in the middle of the user's potential stress levels. Having too much stress can lead to anxiety and disorganization, while having too little stress can lead to loss of alertness and even sleepiness due to boredom. It is important to note that when the task is difficult, the stress levels need to be somewhat higher than they would be if the task is easy.

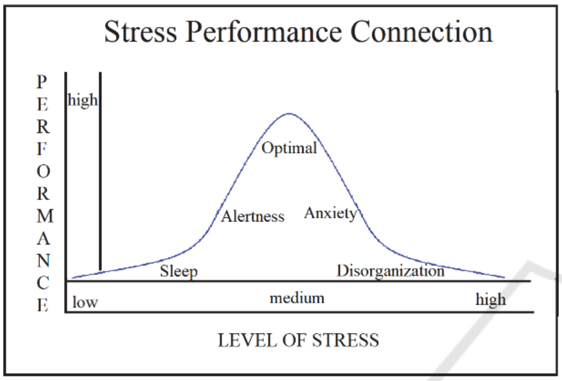


Figure 7: Graphical depiction of Yerkes-Dodson Law (Teigen, 1994).

When stress is at its optimal level, then workload is not adversely affected, and users will tend to put forth their best effort. The amount of workload that users should be under depends largely on the task; however, it is critical to note that a good design does not necessarily attempt to eliminate workload. In fact, Csikszentmihalyi (1990) has shown that it is important to match a user's workload level with that user's skill level.

Figure 8 shows a graphical representation of this concept.

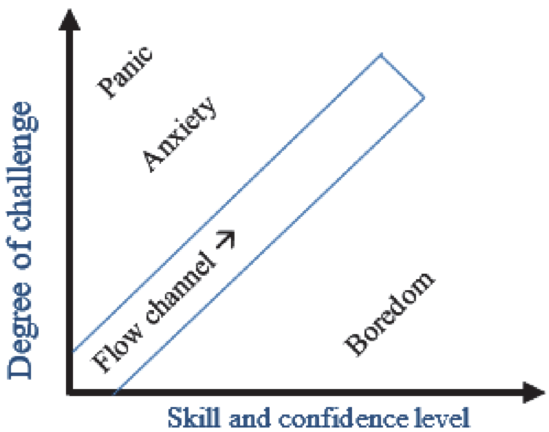


Figure 8: Csikszentmihalyi's (1990) flow model.

Here we see that when the user does not have the skills necessary for the task, then a challenging task will result in anxiety and frustration, and can lead to a user quitting the task prematurely. On the other hand, when the user's skills exceed the workload required, the user can become bored and apathetic. The goal is to make sure the user has the skills necessary for the task, and that the task generates enough workload to engage the user and keep the flow channel open. This is similar to the concept of athletes being "in the zone".

2.2.2 NASA-TLX Subjective Workload Measure

There are many ways of measuring workload, including physiological measures such as hormonal levels, pupil diameter, heart rate, sweat rate, etc.; however, many of those measures do not capture subjective workload as reported by the users themselves. The NASA-TLX (Task Load Index) was developed at NASA's Ames Research Center by the Human Performance (Hart & Staveland, 1988; NASA, 1986). This workload measure was developed precisely for the purpose of measuring user subjective workload, and is useful for a variety of tasks, including online or computer-based training sessions such as the one being developed at Embry-Riddle Aeronautical University (ERAU). This multidimensional assessment tool rates users' perceived workload, which is then correlated with other aspects of performance such as accuracy, speed, response times, etc. It is one of the most well-known and used self-report workload measures (Moroney et al., 1995; Noyes & Bruneau, 2007). The psychometric characteristics of the NASA-TLX are well documented (Yurko et al., 2010), and it has been used previously as a tool for subjective evaluation of individual's workload in flight simulation (Nygren, 1991) and air traffic control studies (Metzger & Parasuraman, 2005).

The NASA-TLX is composed of two parts. In the first part, participants respond to six subscales that are presented on a single page. These subscales include:

- **Mental Demand.** What is the required level of mental and perceptual activity? How easy, difficult, simple or complex was the task?
- **Physical Demand.** What is the required level of physical activity? How slack or strenuous was the task?
- **Temporal Demand.** How much time pressure is felt by the user? Was the pace too slow or too fast?

- **Performance.** How well does the user feel that she or he did on the task? How satisfied is the user with his or her performance?
- **Effort.** How hard did the user need to work in order to accomplish the task? This can be both physical and mental.
- **Frustration.** How much irritation, stress, or annoyance was perceived by the user?

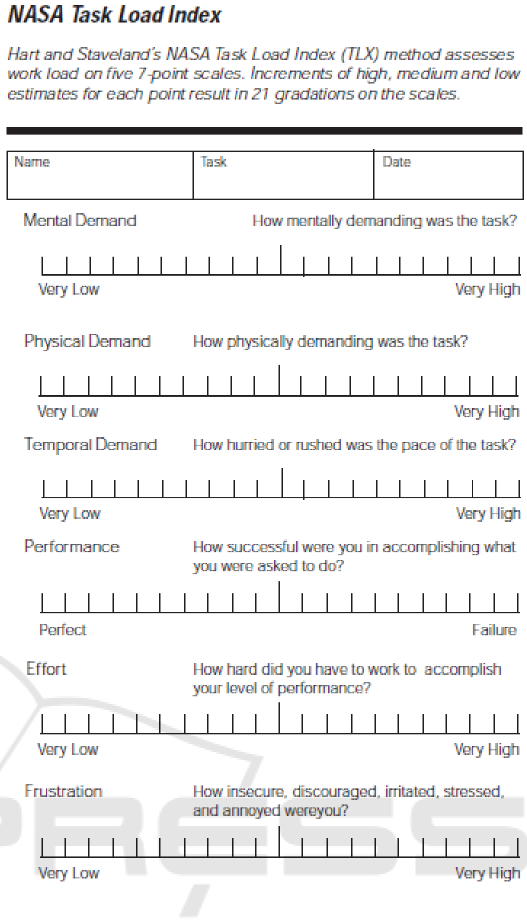
Prior to responding to the scale questions, participants read the description for each subscale. They then provide a score for each subscale by choosing one of the gradations that range from Very Low to Very High. The scores can range from 0 to 100 in 5-point gradations. Upon completion of the NASA-TLX, user scores are then combined into an overall score that measures perceived subjective workload. Figure 9 provides the actual survey that is given to users.

As with all measures of workload, and particularly with subjective workload, there are some caveats. First, the NASA-TLX relies on users accurately giving their responses, and it assumes that the users are being honest with themselves and with the experimenter. Second, it relies on the users' memory in order to accurately assess their workload. This can be problematic, especially if the survey is given some time after the task has ended. Third, the survey cannot be given while a user is doing the task in question, or else it becomes a dual-task situation. This can be problematic if the user suddenly feels a release of stress and frustration when the task is placed to the side while they fill out the survey. They may misperceive this reduction of stress as being part of the task and provide an inaccurate assessment of their subjective workload.

In order to avoid these issues, the NASA-TLX was given to some participants immediately after each task, and not just at the end of the overall session. Participants were carefully instructed that they should be rating their perceived workload during the task itself and not their perceived workload of taking the survey. Participants were also encouraged to provide honest and well-thought out responses in order to ensure validity.

3 CASE STUDY

This section details the case study for human factors assessment of the subject workload of using a web-based simulation tool for ATC. The methodology is described first, followed by the results obtained along with discussion.



NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?
Very Low — Very High

Physical Demand — How physically demanding was the task?
Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?
Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?
Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?
Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?
Very Low — Very High

Figure 9: NASA Task Load Index (NASA, 1986).

3.1 Methodology

The human factors approach to evaluating the software comprises of measuring subjective workload via the NASA-TLX survey. The NASA-TLX is designed to capture subjective workload measures and was used in our usability analysis. The study was approved by ERAU's Institutional Review Board for the Protection of Human Subjects in Research (IRB).

Participants: Eight ERAU students in the Air Traffic Management (ATM) program were recruited. These volunteers had an age range from 20 to 22. Each volunteer had successfully passed en route training in the ATM program. A one-time monetary compensation was provided for participating in the study.

Materials: The NASA Task Load Index shown in Figure 9 was used for this study. Specifically, the raw score values were collected and analyzed.

Procedure: Participants were first given a consent form to sign and were then provided with instructions about the procedures of the study. Following this, they were given a training session on the new software that lasted about one hour. The purpose of this training session was to ensure that the participants understood what they were being asked to do, and to give them time to become familiar with the software. This was meant to represent the typical training that they would receive at the Academy if they were asked to use this software later in their own spare time. All questions were answered prior to the completion of the training session.

In the second part of this study, participants were given a list of nine tasks that they were then to complete using the new software. These tasks are listed below:

[1] Log in to the ASTT system (Figure 4)

[2] Accessing available scenarios (Figure 5)

[3] Run any scenario

[4] Access the R (Figure 1) and RA (Figure 2) positions on two separate windows

[5] Access the soft controller keyboard (Figure 3) on a separate device

[6] Understand and approve a departure request

[7] Understand and approve a pilot request

[8] End scenario attempt

[9] Access the scenario history page (Figure 6)

Five of the participants were asked to complete all nine tasks prior to filling out the NASA-TLX form. The purpose of this was to get a sense of the overall subjective workload, and to avoid disrupting the tasks until they were all completed. The other three participants were asked to complete the NASA-TLX after each task. The purpose of this was to determine the subjective workload of each task, and participants were asked to stop after each task and fill out the subjective workload scale. While the scenarios selected by the students were not the same and covered different areas of training, they were all of a similar duration which would be completed within a single class period. All tasks required of the student controllers were those they would be familiar with, so while the comparison is not direct due to the nature of the scenarios being different, the level of difficulty and time taken is expected to be reasonably similar for each of the scenarios offered to the students.

Upon completion of the study, participants were debriefed, compensated and dismissed.

3.2 Results

The results of the subjective workload reports for the three participants who completed the scale after each task can be found in Figure 10 to Figure 13. These are "Raw TLX" score values with a minimum value of 0 and a maximum value of 100. Lower scores indicate lower perceived workload.

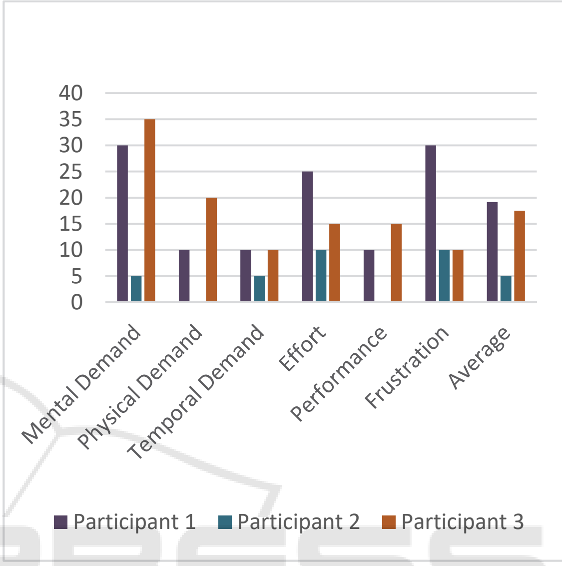


Figure 10: Raw TLX Data for Task 1.

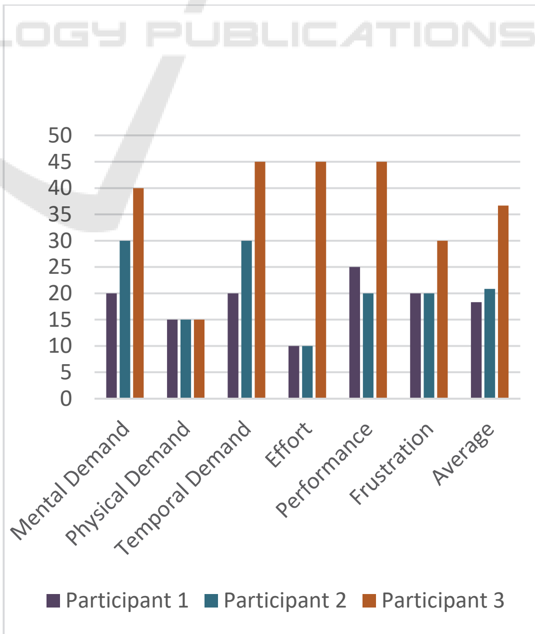


Figure 11: Raw TLX Data for Task 4.

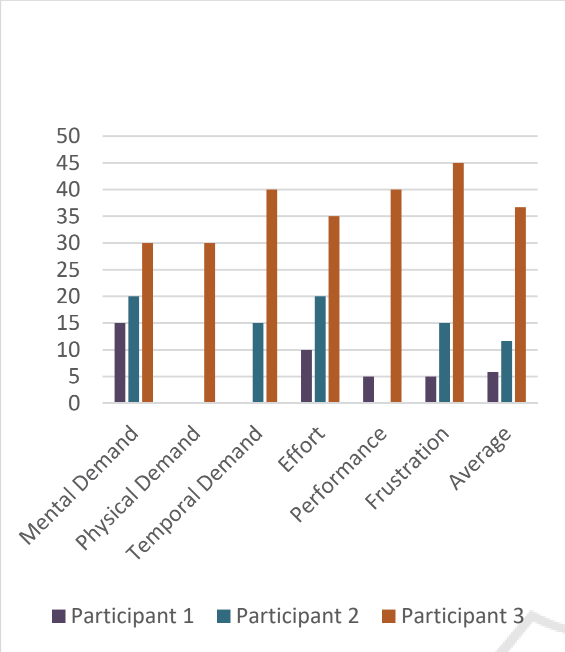


Figure 12: Raw TLX Data for Task 7.

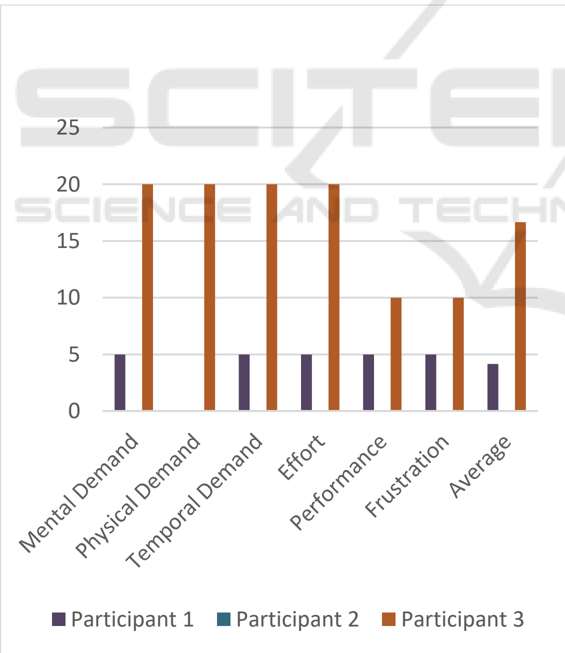


Figure 13: Raw TLX Data for Task 9.

The overall average score for all nine tasks was 14.63, which is very low compared to the possible highest score of 100. These scores ranged from 7.22 for Participant 2 to 25.37 for Participant 3. Thus, even the highest score was in the bottom quartile for subjective workload. The task with the highest subjective workload appeared to be Task 6, with two of the participants reporting scores over 35/100. Even in this case, these scores seem very reasonable given that participants only had one hour of training prior to completing the assigned tasks.

The results of the subjective workload reports for the five participants who completed the scale after finishing all nine tasks can be found in Figure 14.

Here, we see that the average is 11.83, with a range of 5.83 for Participant 6 to 21.67 for Participant 4. These scores indicate that the participants all experience reasonably low subjective workload when completing the assigned tasks, which is an indicator that they found the software easy to learn and use.

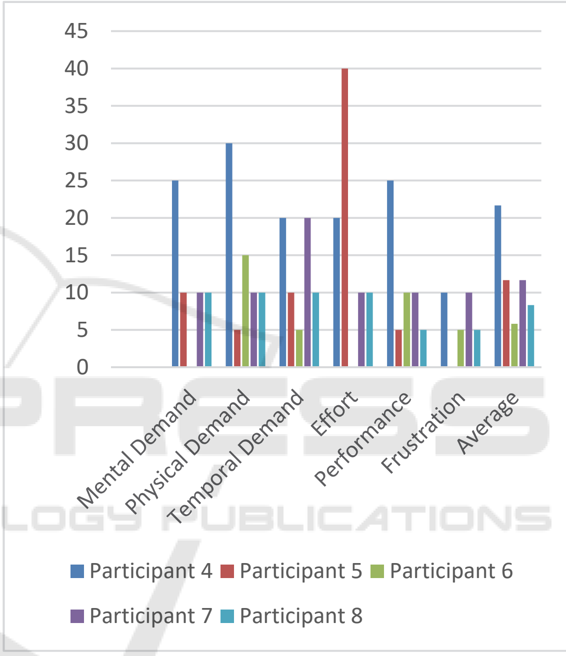


Figure 14: TLX Results of Participants after Completing Tasks.

4 CONCLUSIONS

Simulation-based training is highly valuable in training professionals who will operate under sensitive and risky environments. For this purpose, the ATC Scenario Training Technology (ASTT) tool was developed. This paper used the NASA-TLX tool to understand users' perceived workload for computer-based training sessions using ASTT in order to assess the human factors aspect of web-based simulation training. The data from this study are straightforward. When completing all nine sub-tasks, participants then reported reasonably low subjective workload on the NASA-TLX. When completing one task at a time, participants also reported very low subjective workload for most of the tasks. The highest report workload score was for Task 6, with an average score of 29.72.

These data indicate that participants found the software to be relatively easy to learn and use, and did not experience high workload while using it. They all commented on the usefulness of the tool and how it can actually aid them in learning the en route concepts more effectively. They were mostly very excited about the fact that the tool is available online and allows them to practice at their own pace at any time and from anywhere.

REFERENCES

Chhaya, B., Jafer, S., Coyne, W. B., Thigpen, N. C., & Durak, U. (2018, January 8). Enhancing Scenario-Centric Air Traffic Control Training. *2018 AIAA Modeling and Simulation Technologies Conference*. https://doi.org/10.2514/6.2018-1399

Chhaya, B. N., Jafer, S., & Moallemi, M. (2019, January 7). Evaluation of Scenario-Centric Training in ATC Simulators. *AIAA Scitech 2019 Forum*. https://doi.org/10.2514/6.2019-1483

Csikszentmihalyi, M. (1990). *Flow: The Psychology of Optimal Experience*. Harper Perennial.

Cummings, R. J. (1970). Air Traffic Controller Training at the FAA Academy. *Training Technol*.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. *Advances in Psychology*, *52*(C), 139–183. https://doi.org/10.1016/S0166-4115(08)62386-9

Metzger, U., & Parasuraman, R. (2005). Automation in future air traffic management: Effects of decision aid reliability on controller performance and mental workload. *Human Factors*, *47*(1), 35–49. https://doi.org/10.1518/0018720053653802

Moallemi, M., Jafer, S., & Chhaya, B. (2018, January 8). Scenario Specification Challenges for Next Generation Aviation Technology Demonstrations. *2018 AIAA Modeling and Simulation Technologies Conference*. https://doi.org/10.2514/6.2018-1396

Moroney, W. F., Biers, D. W., & Eggemeier, F. T. (1995). Some Measurement and Methodological Considerations in the Application of Subjective Workload Measurement Techniques. *The International Journal of Aviation Psychology*, *5*(1), 87–106. https://doi.org/10.1207/s15327108ijap0501_6

NASA. (1986). *TASK LOAD INDEX (NASA-TLX) v 1.0*. https://ntrs.nasa.gov/search.jsp?R=20000021488

Noyes, J. M., & Bruneau, D. P. J. (2007). A self-analysis of the NASA-TLX workload measure. *Ergonomics*, *50*(4), 514–519. https://doi.org/10.1080/00140130701235232

Nygren, T. E. (1991). Psychometric Properties of Subjective Workload Measurement Techniques: Implications for Their Use in the Assessment of Perceived Mental Workload. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *33*(1), 17–33. https://doi.org/10.1177/001872089103300102

Richard, K., Shannon, C., Moallemi, M., Chhaya, B., Patel, K., & Jafer, S. (2019). Smart web-based air traffic control training technology. *Integrated Communications, Navigation and Surveillance Conference, ICNS*, *2019-April*. https://doi.org/10.1109/ICNSURV.2019.8735329

Roscoe, A. H. (1978). Stress and workload in pilots. *Aviation, Space, and Environmental Medicine*, *49*, 630–636. https://psycnet.apa.org/record/1980-26622-001

Shannon, C., Jafer, S., Vardhan Raja, A., Moallemi, M., & Thigpen, N. C. (2018). Software Challenges of a Web-based Air Traffic Control Training Tool. *2018 IEEE/AIAA 37th Digital Avionics Systems Conference (DASC)*, 1–8. https://doi.org/10.1109/DASC.2018.8569233

Teigen, K. H. (1994). Yerkes-Dodson: A Law for all Seasons. *Theory & Psychology*, *4*(4), 525–547. https://doi.org/10.1177/0959354394044004

Updegrove, J. A., & Jafer, S. (2017). Optimization of Air Traffic Control Training at the Federal Aviation Administration Academy. *Aerospace*, *4*(4), 50. https://doi.org/10.3390/aerospace4040050

Yurko, Y. Y., Scerbo, M. W., Prabhu, A. S., Acker, C. E., & Stefanidis, D. (2010). Higher Mental Workload is Associated With Poorer Laparoscopic Performance as Measured by the NASA-TLX Tool. *Simulation in Healthcare: The Journal of the Society for Simulation in Healthcare*, *5*(5), 267–271. https://doi.org/10.1097/SIH.0b013e3181e3f329