INVESTIGATION ON CORRELATION BETWEEN MENTAL WORKLOAD AND SITUATION AWARENESS OF PILOTS BY SIMULATION EXPERIMENT

Shun-Ting Kuan\textsuperscript{1}, Wen-Jiang Chang\textsuperscript{1}, *Min-yang Wang\textsuperscript{1}, Wen-Ling Tsai\textsuperscript{2}, Wei Hsu\textsuperscript{2}, Jin-Ru Yen\textsuperscript{3}, Hero Ho\textsuperscript{4}

\textsuperscript{1}Department of Industrial Engineering and Engineering Management
National Tsing Hua University
101, Section 2, Kuang-Fu Road,
Hsinchu, Taiwan, R.O.C.
E-mail:mywang@ie.nthu.edu.tw

\textsuperscript{2}Department of Applied Foreign Language
Shi Chien University
Ta-Chih Street, Chung-Shan District,
Taipei, Taiwan, R.O.C.

\textsuperscript{3}Department of Shipping & Transportation Management
National Taiwan Ocean University
No.2, Beining Rd.,
Keelung, Taiwan, R. O. C.

\textsuperscript{4}China Airlines
No.3, Alley 123, Lane 405, Dunhua N. Rd.,
Taipei, Taiwan, R. O. C.

\textbf{Abstract:} Due to vigorous development of the commercial aviation enterprises, aviation safety becomes more and more important. From the literature review, it was found that situation awareness has a great influence on aviation safety. Since the occupational characteristics of pilots are quite special, including great responsibility for aviation safety, once they encounter an emergency situation, they have to deal with higher mental stress than ordinary level. This study investigates the correlation between mental workload and situation awareness of pilot by the aviation simulation experiment. The mental workload variations of the pilots and their corresponding situation awareness performances were evaluated using the scenarios in which the accident types involved were those happened most frequently in the past few years. From the experiment, it was found that work complexity, experience, and mental workload might affect the situation awareness performance of the pilots. As the result of this effect, pilots’ failure in making judgments and predictions under high stress situation was caused by the increasing of mental workload and the decreasing of the effectiveness of situation awareness.

\textbf{Keywords:} Situation Awareness, Mental Workload, Air Traffic Control, Simulation Experiment

\section{INTRODUCTION}

During these years, the commercial aviation enterprises develop vigorously, including internal and international airlines. However, from the frequent aviation reports during these years, aviation safety becomes more and more important in this kind of high transportation, speed and density transportation industry. Once the aviation accident happens, 70\%-80\% is involved in serious deadness and injury. Since the occupational characteristics of pilots are quite special, they have to communicate with controllers while operating the aircraft. Once they encounter an emergency situation, they have to deal with higher mental stress than ordinary level. These complicated procedures will raise their workload and pressure. In a study of United States based on National Transportation Safety Board (NTSB) accident investigation reports among major air carriers, Of the 71\% of the accidents that could be classified as having a substantial human error component, 88\% involved problems with SA, seventy-two (72\%) were attributed to problems with Level 1 SA, twenty-two (22\%) involved a Level 2 error and six (6\%) involved a Level 3 error. Based on these information, we can see the importance of situation awareness to aviation.
As the automation of aviation is getting mature, the interaction factors among human, machine and environment become more and more important. The cognition model development and behavior variations under scenario stress of operators are all related with aviation safety. This study investigates the correlation between mental workload and situation awareness of pilot by the aviation simulation experiment. The mental workload variations of the pilots and their corresponding situation awareness performances were expected to evaluate using the scenarios in which the accident types involved were those happened most frequently in the past few years.

2. LITERATURE REVIEW

2.1 Mental Workload

Sanders and McCormick (1999) give a clear definition to mental workload. They think it is a measurable quantity of information processing demand while mental task. McCloy, Derrick and Wickens (1983) think that mental workload is the difference between useful information of human and demand information required by the task. Moray (1988) defines the mental workload as the rates of information processing, decision-making and degrees of difficulty with decisions based on the human information processing model. The basic concept of mental workload comes from divided attention model. It metaphors attention as a kind of resource, and it will increase the mental workload degree with the difficulties of work that is cognitive by individuals.

According to Human information processing model (Wickens, 1984), human need limited attention resources in cognition, decision-making and feedback except STSS (Short-Term Sensory Store). Therefore, when information required to process increase, attention resources decrease comparatively and mental workload getting higher.

2.2 Assessment of Mental Workload

This field has developed vigorously since 1970 and there are many instruments to assess mental workload. Four primary methods of mental workload assessment - i.e., secondary task, subjective rating, performance measure, and physiological – are reviewed and the latest development in each one is also evaluated. In these assessments, subjective rating is discovered superior than others because of its easily operating, none interruption and lower cost etc. (Reid and Nygren, 1988). As a result, we use this method in our study. The NASA-TLX (National Aeronautics and Space Administration-Task Load Index) is a multidimensional rating scale in which information about the magnitude and sources of six workload-related dimensions is combined to derive a sensitive and reliable estimate of workload. The dimensions are mental demand, physical demand, temporal demand, performance, effort and frustration.

2.3 Situation Awareness

Situation awareness series theories brought by Endsley (1995a) applies in automatic environment when operators face unusual effects under supervising complex and dynamic systems, like nuclear power plant, aircraft and air traffic control. Situation awareness can influence operator’s behavior. Having a high level of SA can be seen as perhaps the most critical aspect for achieving successful performance in aviation (Hartel, 1991). Situational awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and a projection of their status in the near future. The definition can be explained by a dynamic model of situation awareness from Endsley (Endsley, 1995a) (Figure 1). He thinks that SA is composed by three levels:

Level 1 SA: Perception of the elements in the environment. The first step in achieving SA is to perceive the status, attributes, and dynamics of relevant elements in the environment.

Level 2 SA: Comprehension of the current situation. Level 2 SA goes beyond simply being aware of the elements that are present, to include an understanding of the significance of those elements in light of one’s goals. For example, upon seeing warning lights indicating a problem during take-off, the pilot must quickly determine the seriousness of the problem in terms of the immediate air worthiness of the aircraft and combine this with knowledge on the amount of runway remaining in order to know whether it is an abort situation or not. A novice pilot may be capable of achieving the same Level 1 SA as more experienced pilots, but may fall
far short of being able to integrate various data elements along with pertinent goals in order to comprehend the situation as well.

Level 3 SA: Prediction of future status. It is the ability to project the future actions of the elements in the environment, at least in the very near term, that forms the third and highest level of situation awareness. This is achieved through knowledge of the status and dynamics of the elements and a comprehension of the situation (both Level 1 and Level 2 SA).

---

2.4 Measurement of Situation Awareness

Measurement of situation awareness requires reliability and validity. The instrument should be provided with sensitivity and diagnosis which can evaluate the expected concepts without influencing or biasing operators. In addition, good measurement can predict operator’s performance and be consistent with other results, like mental workload (Endsley, 1995b).

The Situation Awareness Global Assessment Technique (SAGAT), is a global tool developed to assess SA across all of its elements based on a comprehensive assessment of operator SA requirements. Its characteristics include:

1. The system displays are blanked and the simulation is suspended while subjects quickly answer questions about their current perceptions of the situation to reduce numerous problems incurred when collecting data on mental events after the fact.
2. Stop the experiment randomly and evaluate by including queries across the full spectrum of an operator’s SA requirements, this approach minimizes possible biasing of attention, as subjects cannot prepare for the queries in advance since they could be queried over almost every aspect of the situation to which they would normally attend.
3. SAGAT queries allow for detailed information about subject SA to be collected on an element by element basis that can be evaluated against reality, thus providing an objective assessment of operator SA.

SAGAT emphasizes on the procedure of collecting SA information from operators. For a detailed analysis of SA requirements does not require any normal process.

---

3. METHODOLOGY

In this research, it is used to build the experiment of flight operation and air traffic control procedures. There are two kinds of software to be use. Microsoft Flight Simulator 2004 is used to simulate flight operation and VRC (Virtual Radar Client) represents the air traffic process. Linkage between pilots and controllers, intranet and automatic call distributor are used to communicate each other.

During experiment, pilots use the simulator to operate the instruments of cockpit and other input devices. First, they should prepare flight plan to input the flight computer. The paper is aid that simulation platform
used to measure the performance of situation and mental workload of pilots under three scenarios in this experiment.

3.1 Experiment Process

In order to make real traffic volume, there are four airports from different country to join this experiment. They are Tokyo Narita International Airport of Japan, Taipei Chiang-Kai-Shek International Airport of Taiwan, Baiyun Airport of China, Ninoy Aquino airport of Philippine and Chek-Lap-Kok International Airport of Hong Kong. Every pilot takes about two hours for this experiment. The process of experiment is illustrated as figure2. The participants would choice their most familiar aircraft types to use.

Actually, the simulation using for experiment is different to the instruments of real cockpit. For avoiding the bias from unfamiliar operation, there are thirty minutes for training before the experiment start. when experiment is accomplished, participants are asked to fill in SAGAT.

3.2 Scenario of Experiment

There are five pilots who are asked to communicate with controller and operate aircraft to participate the experiment. The flight time is an hour. The simulated scenario is based on CKS airport that is international airport in Taiwan. Runway 05 is used for departing and 06 for landing.

The flight plan is that departing from CKS airport to MaGong airport and turn around to CKS for landing. The cruising altitude is fifteen thousand. There are three scenarios to set un this experiment. According to Taiwan aviation accident database from 2000 to 2004, it is found that the most frequency accident types are approaching and runway incursion. And the single engine failure is most serious accident and influence to pilots in accident. Hence, these are designed in our research. All scenarios designed that is controlled by another pilot. Due to three scenarios, it helps to understand mental workload of pilot and the influence of oral interaction between pilot and controller. During experiment, there is one person aid to play the co-pilot to help subjects complete the experiment.

![Figure2 Experiment Flow](image-url)
3.3 Questionnaires

There are two types of questionnaire using in the experiment. One is SAGAT (Situation Awareness Global Assessment Tool) to measure the performance of situation awareness during flight task. The other is NASA TLX to evaluate the subjective mental workload. The former uses correct rate to represent the subjects’ performance of situation awareness during different scenarios. There are three parts that three scenarios are set in the experiment in questionnaire. Subjects are asked to fill the questionnaire after experiment.

4. RESULTS AND DISCUSSION

From the results of experiment, the relationship between situation awareness and mental workload is high correlation. As below, it is divided two parts to describe the results.

4.1 SAGAT Questionnaire

In the results of SAGAT, it is calculated the correct rate of three phases in situation awareness according three scenarios of experiment. It is showed the result of approaching, failure of single engine and runway incursion as Figure 3, 4 and 5. It is represented the performance of pilots’ situation awareness. From the results of Figure 6, the highest performance of pilots’ situation awareness is approaching, but the lowest is the failure of single engine. Hence, in the scenario of this pilot should comprehend from manual and instruments of cockpit and solve the problem communicating with controller about what situation of aircraft. It is showed that the complexity of operation would influence the performance of situation awareness.

![Figure 3: Situation Awareness of Pilots-Approaching](image)

![Figure 4: Situation Awareness of Pilots-Failure of Single Engine](image)
4.2 NASA-TLX Evaluation

There are six indicators to combine and calculate an integrated index represented the degree of workload. There are Mental Demand, Physical Demand, Temporal Demand, Performance and Frustration. The experiment is used to measure six dimensions that are showed the degree of participants’ workload. From figure7 and 8, it is showed that temporal and physical demand of mostly participants is higher than any others. The results are consistent with the performance of situation awareness.

Form the result of Figure9, it is showed that there are four pilots think the higher is single engine failure but the lower is the others. And the other pilot think there are less difference of mental workload within three scenarios. According the flight experience of participants, the last one has more experience than others. However, there is only a senior subject it might show that he need less temporal and physical workload than others. Compare the result of figure4, the correct rate of situation awareness of last subject is higher than others, it is showed that the performance is higher.
5. CONCLUSION

Due to the characteristics of aviation missions, there are a few mistakes that would be caused serious accidents. As a result, there are four points to conclude in this research.

1. Under the high pressure environment, the performance of pilots’ situation awareness decreased by complication of operation. In advance, it affected the ability of judgment and comprehension.

2. There are some variations in mental workload of pilots when they face different situation. As well as experience also is effected by the degree of metal workload.

3. When mental workload is high, it might influence the performance of situation awareness. And then it would cause the human errors and increase the risk of aviation safety.

The purpose of this research is to discuss the relationship between situation awareness and mental workload. In further study, it is necessary to combine the physical indexes of measurement and then analyze the correlation in both. It would be more advance to understand the behavior characteristic of participants and support or modify the results of this research.

6. REFERENCE