Controller response behaviour during procedural control with surveillance information

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Abstract. Air Traffic Controller (ATCo) duties are challenging due to their heavy task demand. ATCo needs to monitor air traffic while ensuring a smooth flow of traffic and also maintaining safe separation between aircraft. In this study, a human-in-the-loop experiment was carried out to assess the controller response behaviour during procedural control with radar information assistance. Lumpur Sector 4 in Kuala Lumpur Flight Information Region (KL FIR) has been chosen as the assigned sector to study ATCo reactions during control activities. The sector was characterised with two intercepting inbound flight routes and two sets of traffic feed: high traffic feed with incoming feed rate of one aircraft for every 60s and low traffic feed with incoming feed rate of one aircraft for every 70s. The experiment was conducted with two controllers (expert subjects) from the Department of Civil Aviation (DCA) and two students (trained subjects) using a customized air traffic radar and either a Procedural Control Bay or an Electronic Flight Strip Bay. To monitor controller reactions, a heart rate sensor monitoring device was chosen as a primary monitoring tool. Additionally, the controller subjective workload was measured using the Instantaneous Self-Assessment (ISA) workload rating and NASA Task Load Index (NASA-TLX) questionnaires. Based on the results, the ISA workload rating can be observed to be fluctuating throughout the experiment sessions. The fluctuation was also captured to be in agreement with the response gathered from heart rate sensor monitoring device. Overall, the subjects were observed to exhibit a lower stress level for the low traffic condition than for the high traffic condition. In the future, it is recommended that more subjects should be included in the research in order to better conclude on whether workload can indeed be assessed by monitoring subject’s heart rate or response.

1. Introduction

One of the key challenges of Air Traffic Controller (ATCo) tasks is to ensure safety of flight crews and passengers onboard through safe and efficient flow of air traffic [1]. They have to maintain situation awareness in condition of rapidly changing information [1]. ATCo have the responsibility to decide with conflicting goals and high responsibility under tight time constraints, which causes them a tremendous cognitive workload [1]. Important and quick decisions have to be made such as deciding on suitable flight level, speed and heading to prevent future separation minima infringement between aircraft.
These decision making skills are included in cognitive complexity of a controller, which describes as the relationship between the controller tasks to handle traffic and the corresponding mental workload [2]. Previous studies on cognitive analysis have demonstrated that controller duties are related to high pressure while monitoring traffic and interacting with pilots [3]. Consequently, unwanted consequences may occur due to the controller’s error. Human errors may occur especially during interactions between the pilots and the controllers, which are most likely to threaten the flight safety [4].

1.1. Air traffic control

Air Traffic Control (ATC) is the service provided by ATCo, who is responsible for assisting, dispatching and maintaining a secure, safe and systematic flow of air traffic [3]. Generally, there are three different levels of air traffic operations that correlate to the major phases of flight: (i) aerodrome control for take-off, landing and ground movement of aircrafts, (ii) approach control for arriving and departing aircrafts, and (iii) area control based in the Air Traffic Control Center (ATCC) for handling the en-route phase of flight [5]. This research only focuses on the duties of controller in the en-route phase that also known as area control. En-route controllers resume control of aircraft from approach controller and are required to maintain adequate separation from other traffic during the climbing, descending and cruising phases through projection of aircraft position and trajectory in time and space [6].

In ATC system, surveillance and procedural control are two commonly used control strategies in managing traffic movement within a specified airspace. Procedural control method depends largely on the ATCo’s mental capacity where they need to imagine the position and the trajectory of an aircraft. Future conflicting traffic shall be estimated manually. To help with this process, a Flight Progress Strip is commonly used to continuously update aircraft position and movement. Flight Progress Strip used in Malaysia consists of twenty-four fields’ information that is printed on a rectangular-shape paper strip as shown in Figure 1. Flight Progress Strip provides essential information of an aircraft such as call sign, planned route, aircraft type, filed airspeed, assigned altitude, estimated time over certain waypoints and other relevant information [7]. Procedural control and surveillance control can co-exist together where procedural control is used to determine future conflict and surveillance control is used to resolve on time conflict. However, in certain geometrical area or circumstances where the surveillance coverage is not available, ATCo is provided with limited option in controlling traffic movement.

![Figure 1. Physical Flight Progress Strip](image)

1.2. Human performance measures

Evaluation of ATCo performance can be investigated under several concepts such as human behavior rather than human workload, and measurement techniques, which are subjective rather than objective, or scientifically in physiological rather than psychological, in order to obtain better result for the research [8]. The objective of this research is to assess controller response behavior in ATC during procedural control activities by manipulating few measurable air traffic factors that affects the mental capacity of a controller. Psychophysiological measures may prove especially useful in the prevention of performance deterioration in under load or overload conditions [9]. By this definition, when the workload is low, very little cognitive effort is required and the operator can easily complete the task. On the other extreme, when workload is very high, much cognitive effort is required that an operator is likely to leave the task unfinished [10]. Many studies implicitly assume that the controller workload varies as a function of both directly measurable air traffic factors (number of aircraft in the sector, speed variability, proximity of aircraft, etc.) and controller’s activity mediated by factors such as the controller’s abilities, age, fatigue, and level of experience [11].
From research by Lee, Pathirana and Caelli (2013), they have demonstrated the efficiency of Doppler Radar of 2.7 GHz operating band in analyzing breathing patterns under various breathing forms like normal breathing, rapid and slow breathing, as well as different rates of inhale and exhale [12]. In order to assess the mental state of a person for this research, the measurement of heart rate (HR) and pulse rate variability (PRV) is seen as a very powerful monitoring tool. Even though both measurement tools have yet to be conducted on the ATCo, a physiological measurement always seems as a suitable method for the evaluation of human factor. To measure the controller response behavior, a human-in-the-loop (HITL) experiment was conducted in a prototype environment of ATCC with a main purpose to evaluate the concept in terms of practicability, controller workload impact and potential benefits [13]. The HITL experiment in this research was presented through the mock-up environment of ATC. The experiment was performed by two controllers from Kuala Lumpur ATCC as expert subjects and by two students as trained subjects.

In this research, workload is measured using three different measurements through subjective ratings and behavioural/physiological recordings. The evaluation of controller situation awareness and response behavior was measured using a heart rate sensor device, whilst the evaluation of ATCo subjective ratings was made using Instantaneous Self-Assessment (ISA) workload rating together with questionnaire tool from NASA Task Load Index (TLX). The ISA workload rating tool was intended for ATCo to report their perceived workload during experiments or simulations [14]. In this experiment, the controller was prompted to give a rating from 1 to 7 of their ISA workload level at every 1 minute interval during the HITL experiment. The NASA TLX, on the other hand, is a comprehensive multi-dimensional subjective task load rating technique [15], which consist of six dimensions of the subject’s task load experiences: mental demand, physical demand, temporal demand, perceived performance, efforts and frustration level. NASA TLX has been applied extensively in similar experimental environment. The NASA TLX survey was given at the end of each session for this HITL experiment.

2. Methodology

2.1. Kuala Lumpur Flight Information Region

Flight Information Region (FIR) is the airspace of defined dimensions, which flight information service and alerting service are provided. Both services are the basic air traffic services to provide information pertinent to the safe and efficient conduct of flights and in alerting the relevant authorities for aircraft in need. KLFIR is divided into six geographical sectors in order to have a systematic framework for ATC. Based on the six sectors in KLFIR, Lumpur Sector 4 was chosen as the experimental field for this research as it geometrically located in oceanic area and partially covered by surveillance. Lumpur Sector 4 is located in between of Phuket in Thailand and Banda Aceh, Indonesia. It has a total of 7 RNAV route with 7 crossing waypoint in about 300 nautical miles range. However, in order to have a more controlled scenario, only two main inbound routes with one merging point were simulated in this experiment as shown on Figure 2.

![Figure 2. Simulated MATLAB radar of Lumpur Sector 4](image-url)
The level of traffic difficulties is then simulated with different levels of incoming traffic feed, namely high traffic with incoming traffic rate of 60 seconds per aircraft and low traffic with incoming traffic rate of 70 seconds per aircraft.

2.2. Experiment settings
Two expert subjects and two trained subjects volunteered for the experiment. The expert subjects are from KLATCC, both aged 30 and with 5 years of experience. The trained subjects are from final year students of Mechanical Engineering Faculty that was comprehensively briefed on the ATC tasks and working manner. The experiment used two distinct subject groups in order to assess whether the use of heart rate monitor is relevant for different sets of user’s background.

The experiment began with a briefing session explaining the experiment’s objective together with explaining the course of the session, followed by a training session/s for each subject to familiarize with the experiment settings. Each scenario was conducted for 15 minutes. The scenario was divided into two types of traffic feed, which were high traffic and low traffic scenarios. High traffic scenario has a maximum of 10 aircraft at one time and an incoming feed rate of 60s per aircraft, while the low traffic scenario has a maximum number of 8 aircraft at one time and an incoming feed rate of 70s per aircraft. All aircraft have been arranged to fly randomly into the sector from either EMRAN or IGOGU. The experiment was conducted using a customized surveillance display from Matlab® together with either Procedural Control Bay or Electronic Flight Strip Bay. The experiment for all subjects was arranged as shown in Table 1.

|       | 1       | 2       | 3       | 4       |
|-------|---------|---------|---------|---------|
| Traffic Control Panel | Traffic Control Panel | Traffic Control Panel | Traffic Control Panel |
| 1     | High PCB | High EFSB | High PCB | High EFSB |
| 2     | Low PCB  | Low EFSB  | Low PCB  | Low EFSB  |
| 3     | Low EFSB | Low PCB  | Low EFSB | Low PCB  |
| 4     | High EFSB | High PCB  | High EFSB | High PCB  |

PCB: Procedural Control Bay
EFS: Electronic Flight Strip Bay

Figure 3 and 4 illustrate a complete setup for the HITL experiment. During the experiment, subject was placed in the Controller Station, while 3 pseudo-pilots were placed in the Pseudo-Pilot Station. They were separated by 15 meters between them in order to simulate the long-range communication between controller and pilot.

(a) (b)

**Figure 3.** Control panel options: (a) Procedural control bay, (b) flight strip manager software
Figure 4. Illustration of equipment setup

3. Results and discussion
The evaluation of controller situation awareness and response behavior was measured using a heart rate sensor device, whilst the evaluation of ATCo subjective ratings was made using ISA workload rating together with questionnaire tool from NASA TLX. The experiment also looked into the resulting traffic pattern, especially occurrences of minimum separation infringement or referred to as conflict hereafter. The minimum separation between aircraft was set at 5 nautical miles and any aircraft that fly within the separation limit will be regarded as conflicting traffic.

3.1. Expert subject
Figures 5 and 6 show heart rate readings together with ISA workload rating for both high and low traffic, respectively, for Subject 1 (expert) while using the Procedural Control Bay. Based on the response from Subject 1, the conflicts in Figure 5 occurred because of the same level assignment of aircraft based from the scenario given. In common practice, if this scenario happened, ATCo will reassign a new cruising altitude for the aircraft in order to maintain separation between intercepting traffic. However, this was not possible for the scenario given as the subjects were only allowed to give flight speed and heading changes in order to ensure safe separation between aircraft. For conflict point number 2, the heart rate reading is seen to increase drastically as the subject encountered conflict situation upon hand-over to the neighboring sector (Figure 7(b)). The increase in workload is also confirmed through the subject’s ISA workload rating given during the conflict period.

Figure 5. High traffic for Subject 1 using Procedural Control Bay
Furthermore, Subject 1 highlighted that the high traffic feed setting that has a maximum number of aircraft of 10 was giving a higher than expected demand to the subject without leaving much parameter to control the traffic since he was only allowed to use flight speed and heading. However, in low traffic feed scenario, the subject was able to control the traffic while having zero conflict with a consistently low workload rating throughout the 15 minutes-scenario. Having said that, it should be made aware that the use of heading command is not a common standard procedure during procedural control at Lumpur Sector 4. With both expert subjects from KLATCC who are an area procedural and surveillance rated ATCo, they were already briefed and were clear on the control options available during the experiment.

Ideally, participants are required to provide a separation between the aircraft from both airways by controlling their time of arrival at merging waypoint. However, during the exercise when subjects were unable to control the situation and the method of controlling aircraft time of arrival at merging point was not feasible, for traffic from MEKAR eastward, participants were allowed to use surveillance control methods whereby they were allowed to change the aircraft’s flight path by assigning heading in order to maintain adequate separation before handing over to the next sector, which is on surveillance control environment.

For simulation using Electronic Flight Strip Bay, conflicts only occurred during high-load condition as shown on Figure 8. From the graph, conflict occurrences are represented by the three diamond points, which indicate three conflicts occurrences for Subject 1. The red colored aircraft on the radar screen in Figure 9 represents conflict detection while the green colored aircraft represents aircraft that has been hand over to the other sector. The first and third conflict occurred between minutes 5 to 6 and 11 to 12. During these instances, the conflict occurred when Subject 1 already transferred the aircraft to the other sector (Figure 9 (a)). Therefore, the heart rate reading of Subject 1 is not in accordance to the reported workload rating. Meanwhile, when the second conflict occurred between minutes 9 to 10, the heart rate of Subject 1 had suddenly increased due to the conflict that occurred near the intercepting point (Figure 9 (b)).
Figure 8. High traffic for Subject 1 using Electronic Flight Strip Bay

(a) Conflict 1
(b) Conflict 2

Figure 9. Conflicts from Subject 1 using Electronic Flight Strip Bay

In ATC, the strategies selection and execution have a big influence on the performance of an ATCo. Strategies used depend on individual skills and experiences. Based on Figure 10 (a), Subject 1 was not actively using the Procedural Control Bay as one of the tools to control air traffic during the experiment. Hence the subject was unable to perform very well without causing any conflicts during the experiment. The subject needs to invest more time to track the correct strip for the aircraft in the radar during his experiment session. As a result, Subject 1 recorded a total of three conflicts during high traffic scenario as shown previously in Figure 5. Figure 10 (b) shows a better strategy practiced by the Subject 2. He used Procedural Control Bay to arrange and manage the flight strips efficiently. Subject 2 only recorded one conflict in high traffic scenario.

Figure 10. Subject strategy during control: (a) Subject 1, (b) Subject 2
3.2. Trained subject
For the trained subject, based on the result as shown in Figures 11 and 12, it can be seen that Subject 3 (trained subject) recorded the highest number of conflict during the whole scenario. However, for low traffic, the subject was able to reduce the conflict to zero (Figure 12). Most of the conflicts were due to the intercepting route, which merges the aircraft into one route.

![Figure 11. High traffic for Subject 3 using Procedural Control Bay](image)

![Figure 12. Low traffic for Subject 3 using Procedural Control Bay](image)

The average rating of workload prompted by Subject 3 (trained subject) was higher than the Subject 1 (expert subject) for both high and low traffic. The most obvious difference between trained and expert subjects is the heart rate reading of trained subject increase during conflict occurrence regardless of their workload. This is due to the big gap of knowledge, experiences and skills of managing air traffic between the expert and trained subject. Two conflicts taken from the Subject 3 were shown in Figure 13.

![Figure 13. Conflicts from Subject 3 using Procedural Control Bay](image)
For control activities using Electronic Flight Strip Bay, it is observed that Subject 3 has also resulted in five conflict situations as shown in Figure 14. The diamond point in the graph shows the time when the conflict occurred. It clearly shows that there is a positive association between workload rating and the heart rate of the trained subject at this particular time. The result in Figure 14 shows that the point of conflict is the same with the peak of the heart rate and the workload rating. Only one conflict point that resulted in no peak in the workload rating, which is conflict point 2. This is because the conflicting aircraft has already been handed over to other sector and the conflict was being totally neglected by the Subject 3 (Figure 15).

![Figure 14. High traffic for Subject 3 using Electronic Flight Strip Bay](image1)

3.3. Subjective workload measure (NASA TLX)

The NASA TLX score results after using the Procedural Control Bay show that the overall NASA TLX score for Subject 1 is 65.3, which was much higher than the overall NASA TLX score for Subject 2 (Figure 16). It was clear that Subject 1 faced difficulty or felt more pressured during the experiment than Subject 2. Subject 2, on the other hand, reported a low rating for mental, physical and temporal demand as in the NASA TLX score in Figure 16 (b). It is observed that Subject 2 have a more organized working method where he took out the strip from the bay once the aircraft was being handed over to the next sector, thus avoiding clutter on his Procedural Control Bay.

The same situation can be observed while using the Electronic Flight Strip Bay. Based on Figure 17, the overall NASA-TLX rating was significantly higher for Subject 1. His rating shows that the mental demand, physical demand and temporal demand was the highest rating compared to performance, effort
and frustration. Based on Figure 17, the overall NASA TLX score for Subject 1 is 64.7 whereas Subject 2 reported a NASA TLX score of 24.3. This is in accordance to the NASA TLX score given during the Procedural Control activities.

### Figure 16. NASA TLX results using Procedural Control Bay for: (a) Subject 1, (b) Subject 2

| Rating Tally Weight | Rating Tally Weight |
|---------------------|---------------------|
| Mental Demand       | Mental Demand       |
| Physical Demand     | Physical Demand     |
| Temporal Demand     | Temporal Demand     |
| Performance         | Performance         |
| Effort              | Effort              |
| Frustration         | Frustration         |
| Overall = 65.33333  | Overall = 26        |

### Figure 17. NASA TLX rating using Electronic Flight Strip Bay for: (a) Subject 1, (b) Subject 2

| Rating Tally Weight | Rating Tally Weight |
|---------------------|---------------------|
| Mental Demand       | Mental Demand       |
| Physical Demand     | Physical Demand     |
| Temporal Demand     | Temporal Demand     |
| Performance         | Performance         |
| Effort              | Effort              |
| Frustration         | Frustration         |
| Overall = 64.66666  | Overall = 24.33333  |

4. Conclusion and recommendation

This study was aimed on assessing the response behaviour of the use of the Procedural Control Bay as well as Electronic Flight Strip Bay with the assistance of radar information on controller through HITL experiment. The method of assessment for controller response behaviour was measured through heart rate readings, workload rating and also questionnaires from NASA-TLX. The HITL experiment were subjected to two experts and two trained subjects through scenarios of high and low traffic feeds. Based on the results, high traffic scenario was observed to result in a higher heart rate peak together with a higher workload rating. Meanwhile, for the low traffic scenario, it was observed that a lower workload rating was consistently prompted by the subjects along with a more stable heart rate readings. The results were observed to be consistent for both Procedural Control Bay as well as Electronic Flight Strip Bay. The promising outcome of this initial study suggests that heart rate monitoring device may be suitable in workload monitoring of ATCo. However, a more comprehensive study needs to be conducted with a greater number of participants, especially from the expert subjects group. It is also recommended that the HITL experiment is conducted on-site as to properly investigate the suitability of the device to be used in real condition.

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