Workload and Fatigue Assessment on Air Traffic Controller

V Triyanti 1,2, H A Azis 1, H Iridiastadi 1 and Yassierli 1

1 Institut Teknologi Bandung, Jl. Ganesa 10, Bandung, Indonesia
2 Atma Jaya Catholic University of Indonesia, Jl. Jend Sudirman 51, Jakarta, Indonesia
vivi.triyanti@atmajaya.ac.id

Abstract. Workload experienced during certain work periods may cause fatigue. In Air Traffic Control work, a high air traffic rate may increase the workload and fatigue, especially during rush hour and may lead to risky situations. This study intended to estimate the value of the mental workload and fatigue of an Air Traffic Controller (ATCo) in airport X during their work period. The NASA-TLX and Samn Perelli Scale were used to quantify mental workload and fatigue. The questionnaires were distributed to ATCo and 257 questionnaires were obtained. Results showed the value of the mental load at airport X tended to be higher than other airports (average 66.53), especially for mental demand, time pressure, and effort. The value of fatigue before and after work also increased (average 1,749 to 3,506) included in the safe category. However, there was no convincing evidence that differences in mental load values affect the value of fatigue. These results indicated that although the workload of ATCO was relatively high, the ATCo in Airport X still can handle it and did not cause excessive fatigue.

Keywords: Air Traffic Controller, fatigue, workload, Samn Perelli scale, NASA-TLX

1. Introduction

Task demands related to cognitive work will lead to complexity in thinking systems. The accumulation of all task demands and complexities that occurred in the human thinking system may cause workload [1], especially mental workload. Mental workload is the amount of attention allocated to carry out an activity [2]. The impact of high mental workloads (or even moderate) experienced in a long duration was the occurrence of fatigue, especially mental fatigue [3,4,5]. Researches showed that the main trigger for mental fatigue was time-on-task (TOT) [5,6,7]. For example, mental demands experienced for 2 hours continuously will cause mental fatigue and potentially slow down the work (increase reaction time) [6].

Mental fatigue will cause several negative impacts on one's performance and motivation. The fatigue can reduce the level of alertness, concentration, speed, and accuracy in doing work [3, 4]. Mental fatigue was worsened when someone also experiences drowsiness [8]. A person who experienced fatigue due to lack of sleep will experience decreased ability in information processing, memory, problem-solving, and decision making [9]. The potency for mental fatigue increased when work involved stress, such as time pressure [10] or pressure due to high work risks [11].

Air Traffic Control is a service task whose duty is to prevent conflicts between aircraft. Its main tasks are to regulate air traffic and to provide information and support for pilots [12]. To prevent collisions, continuous vigilance is needed [1]. Constant vigilance is needed to ensure that all aircraft in the jurisdiction are always safe. The safe criteria are when aircraft separated at a safe distance and can reach their destination safely, according to the International Civil Aviation Organization (ICAO) rules [13].

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The task demands related to the complexity of air traffic, airspace, and operational traffic conditions [14] cause mental workload on ATC officers.

Some previous studies have estimated the amount of mental workload on ATCo [2, 12, 14]. However, those studies had not yet explained the relationship of the workload with fatigue experienced by the ATCo. Besides, these studies have not determined whether the workload experienced by ATC officers at the airport was classified as high or not, compared to the mental workload experienced by similar professions (ATC) at other airports.

This study was aimed to estimate the mental workload and fatigue conditions of ATC officers in a real work system. The ATC work was chosen because it has a combination of three things, namely the potential to experience a high mental workload, the need for constant vigilance, and high work risks. High task demands have the potential to cause mental workloads and fatigue at ATC officers, which in turn can reduce performance and cause the risk of aircraft-related accidents [5].

By using ATC as the object of study, the objective of this study was to estimate the value of mental load and fatigue for ATC officers. Through this study, the expected output was the estimation of mental load and fatigue conditions in real work situations in ATC. Based on this goal, the hypotheses developed were 1) ATC is a job with a high mental workload and 2) There is an increase in fatigue after carrying out their duties. A field survey was conducted on the ATCo to collect data related to this hypothesis, on the actual ATC working conditions. The survey focused on values and factors that influence mental workload and fatigue. This survey did not discuss performance and its relation to mental workloads and fatigue.

2. Methods

2.1. Participant and Apparatus

The survey was conducted in May 2019. There are two ATC units were examined, namely ACC and APP. In one shift, numbers of questionnaires were randomly distributed to officers in both units with the help of supervisors. If there were difficulties, the researcher assisted the ATCo in filling them. After the questionnaire was filled in, the researcher ensured that all questions have been filled out completely and following the provisions before the questionnaire was collected. During each shift, the assessment of workload was conducted only one time. However, controllers must assess the level of fatigue they experienced two times, which were before and after doing work. From 3 days of research, 263 questionnaires had been collected, but only 257 data can be processed. The six questionnaires were disused because they were filled out by supervisors or field managers. Supervisors or managers should not fill the questionnaires because they were not directly in charge of managing the traffic, but only supervised the work of ATCo. This research used a simple random sampling design. Samples are taken randomly, without regard to differences in conditions that exist in the population [15].

2.2. Workload Assessment

In this study, the unweighted NASA-TLX approach was used to estimate the workload. NASA TLX is a multi-aspect approach that can also be used to estimate the value of mental demand and physical demand. The approach was chosen because it proved to be closely correlated with several other subjective load assessment methods, such as SWAT and WP [16]. NASA – TLX also has relatively good validity, reliability, and sensitivity values [17]. Also, this scale was widely used to assess mental workloads in the field of Aviation [9].

NASA-TLX consists of 6 subscales: Mental Demand (MD), Physical Demand (PD), Time Pressure (Temporal Demand / TD), Frustration (Frustration), Effort (Effort / EF), and Performance (PE). Twenty equal intervals - marked between labels at each end from 'low' to 'high' or 'good' to 'bad' - were used to rank on these dimensions, producing a score between 0 and 100. An average of the six-dimensional workloads represented the overall workload.
2.3 Fatigue Assessment

The Samn-Perelli Crew Status Check (referred to as Samn-Perelli scale) was a method for measuring mental fatigue that was originally developed for military air transport operations [18]. It had been widely used in flight studies [9,19]. Consistent with the definition of ICAO fatigue [13], this scale ranking was directly related to the likelihood of performance degradation on a scale of 1 to 7. For interpretation of this score, categorization can be used [20]. This criterion was based on operational experience in military airlift operations.

| Table 1 Interpretation of scores from the Samn-Perelli Scale [20] |
|---------------------|----------------------------------|
| Score | Interpretation |
| 1-3 | There is likely no performance decrease related to fatigue that was expected |
| 4 | Performance degradation is possible but not a significant factor |
| 5 | Moderate fatigue. Decreased performance related to fatigue may occur. Execution of tasks is permitted but not recommended unless urgent |
| 6 | Severe fatigue. Decreased performance related to fatigue may occur. The execution of tasks was not recommended. |
| 7 | Severe fatigue. Performance must be disrupted. The execution of tasks was not recommended. Flight safety is in danger |

3. Result and Discussion

The results are presented sequentially for each hypothesis.

3.1. Hypothesis 1: ATC is a work with a high mental workload

The mental workload was calculated using the unweighted NASA-TLX approach on a scale of 1-100. To estimate the category of mental workloads, a percentile approach was used. Twenty-four studies had been conducted on ATCo to determine the percentile limit of mental load [21] (Table 2). This value was then compared to the data collected in the current study. It appears that the 25th, 50th, and 75th percentiles of this study are far greater than those produced in the 24 ATC studies. This result can also be interpreted that the mental workload felt by the ATCo at the study site was classified as high.

| Table 2 Percentile of ATCo’s workload value of this research compared to literature [21] |
|---------------------|----------|----------|----------|
| Percentile | Average of 24 ATC | Rounded | This research |
| P-25% | 42.81 | 43 | 55 |
| P-50% | 52.44 | 52 | 65 |
| P-75% | 68.32 | 68 | 74 |

Research from [22] was used to interpret each mental load value in this study. The research suggested that mental load with values <50 means "acceptable", 50-70 means "within limits", and mental load > 70 as "sometimes acceptable in certain situations." Based on the previous studies, a justification for mental load categories for ATC tasks was carried out in the medium, high and very high categories (Table 3).

| Table 3 Categorization of NASA-TLX value of ATCo |
|---------------------|----------|----------|
| Justification | Category | Interpretation |
| < 43 – 52 | Medium | Acceptable |
| 52 – 68 | High | On borderline |
| > 68 | Very high | Only can be accepted in a certain situation |
With justification in Table 3, values 52 - 68 indicated a high mental workload. Based on the assessment of mental load, the total score of mental workloads was 66.53, which was included in the high category. Mental demands, physical demands, and time pressure are aspects of workload that are directly felt by workers. On the other hand, performance, effort, and feeling of frustration are aspects of workload that are felt as impacts [16]. From the scores in Table 4, it is shown that the highest workload value is Effort. However, all aspects of workload cause a relatively high workload, especially in aspects of mental demands and time pressure. However, with the very high value of mental demands, time pressure, and effort, the ATCo felt that they had done the job with good performance, so the feeling of frustration felt was also relatively lower.

### Table 4 NASA-TLX Workload assessment of ATCo

| Aspects          | Score | SD   | Category   |
|------------------|-------|------|------------|
| Mental demand    | 75    | 3.99 | Very high  |
| Physical demand  | 66    | 4.50 | High       |
| Time pressure    | 74    | 3.85 | Very high  |
| Performance      | 53    | 3.30 | High       |
| Effort           | 81    | 3.58 | Very high  |
| Frustation       | 50    | 5.69 | Medium     |
| **Average**      | 66.53 | 2.90 | High       |

3.2. **Hypothesis 2.1: There is an increase in fatigue during his work period**

Mental fatigue was assessed using the Samn-Perelli scale with a value of 1-7; the higher means more tired [13]. From Table 5, it can be seen that the average value of fatigue before work is 1.749, which is included in the category "Very excited, responsive, but not at its peak." Values below 3 indicate that the officer is relatively tired. A value of 4 indicates slight fatigue [20]. The value of fatigue after work, on average, is 3.506, which belongs to the category "A little tired, less than fresh". For a score of 4, a decrease in performance may occur but not a significant factor [20]. This value condition indicates that the maximum working time setting of 2 hours as implemented by the ATC organizer has been effective enough to prevent excessive fatigue.

Based on data processing, it is known that the potential for fatigue continues to occur because all data showed an increase in the value of fatigue before and after work. With a paired t-test with a significance level of 0.05, it was concluded that fatigue before and after work was significantly different (\( p \)-value = 0.0000 and \( T \) value = 23.22), with a higher level of fatigue after work (average difference of 1.7569). However, the average value of fatigue both before and after work is still at a reasonable level, because it is only still slightly above 3 with a relatively small standard deviation.

### Table 5 Fatigue value before and after work

| Group         | Average | Variance | SD  |
|---------------|---------|----------|-----|
| Before work   | 1.749   | 0.874    | 0.935|
| After work    | 3.506   | 1.330    | 1.153|

3.3. **Discussion**

The main objective of this study was to assess workload and fatigue experienced by Air Traffic Controller. The overall results of the study indicate that officers at Airport X ATC have a tendency to have a high workload during their work shifts. When viewed from the traffic rate, the actual average traffic during 2019 decreased considerably compared to the previous year (Figure 1). In 2018, the average number of flights per month is relatively higher because at that time flight fares have not been
adjusted. In 2019 there was an increase in flight rates [23,24], which caused a decrease in the number of passengers and the number of flights. Referring to this data, there are two possibilities for the data obtained. The first possibility, the officer still does not feel a reduction in workload associated with a reduction in traffic. This is possible if there is an adjustment in the number or extent of sectors that must be handled by an officer. This adjustment could cause the mental burden felt by officers to remain the same, despite the reduction in air traffic. The second possibility is that the workload in the previous conditions is very high.

![Figure 1. Average Number of flights per shift per month](image)

The second possibility is that the workload in the previous condition is indeed higher. This is indicated by the average number of flights per hour which is close to the maximum value, which is 80 aircraft per hour [25]. This value mainly occurs in the morning shift. From this data, it can also be seen that high traffic occurs in the morning shift (06.00-12.00) and night (20.00-10.00). These two shifts are likely the second most optimal time as departure and return times from business destinations.

Based on the results, we may also analyze the relationship between the mental workload and fatigue. There is a possibility that a higher workload may cause a higher level of fatigue. The mental load perceived by ATCo was classified into the medium, high and very high, according to Table 3. Based on these categories, the level of fatigue was compared for each pair. By using two independent sample T-tests, it is concluded that there was no strong evidence that differences in mental workload level have a significant effect on fatigue value (Table 6). However, if examined further, we can see in all workload conditions, the fatigue tend to increase after work. The increasing value tends to be higher in higher workload. It means that higher workload tends to cause a higher level of fatigue, although the increase is not significant.

Although we can have explanations of workload conditions in Airport X, the research still has many limitations. There are a lot of factors that can both workload and fatigue that have not been explored yet in this manuscript. The first factor is the ATC work schedule. ATC is a job that must be run by 24 hours continuously without stopping. Work shift and amount of work time can have an impact on the risk of fatigue. For example, working when workers are biologically programmed to sleep (which can interfere with the worker's body clock) and working for long periods can cause fatigue. In addition to work-related factors, individual and environmental factors that are not related to work can also affect fatigue. The quantity and quality of sleep, health, age, sex, emotions, and social conditions are one example of this factor. Analyzing all these factors. The analysis of factors that can influence the mental burden and fatigue of ATC officers can be an interesting discussion for future research.
Table 6 Output two samples independent t-test of workload (low, medium, high) to fatigue difference

| Hari          | Count | Mental fatigue |     |     |
|---------------|-------|----------------|-----|-----|
|               |       | Average        | SD  |     |
| Medium        | 34    | 1.676          | 1.389 |     |
| High          | 102   | 1.765          | 0.913 |     |
| Very high     | 121   | 1.793          | 1.715 |     |

| Comparison    | p-value | T-value |
|---------------|---------|---------|
| Medium – High | 0.662   | 0.438   |
| Medium – very high | 0.778 | 0.282 |
| High – Very high | 0.393   | 0.856   |

4. Conclusion
Air Traffic Control is a job that requires the ability to remain vigilant and make decisions continuously throughout its working period. These task demands cause relatively high workloads. At Airport X, the workload felt by officers was also relatively high, especially in aspects of effort load, mental demand, and frustration. The total workload value is even higher than the average ATC work at other airports. However, the high workload does not cause excessive fatigue in ATCo. Fatigue before and after work significantly increased, but still within the limits of reasonableness. Furthermore, this increase in fatigue is related to an increase in mental load, but no evidence proved that the relationship is significant. For further research, it is advisable to investigate further the factors associated with mental burden and fatigue, both factors related to or not related to work.

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