A Preliminary Field Study of Air Traffic Controllers' Fatigue for Interface Design

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Abstract. Air traffic controllers' fatigue on duty affect their performance and even threaten aviation safety. But the design and promotion of air traffic management systems seldom consider dynamic changes of fatigue for controllers on duty. The aim of this study was to detect changes of fatigue for controllers on duty along with different task loads and working schedules. Fatigue influence sleep, mood and perception of controllers, and the three kinds of index employed to characterize their fatigue. A field investigation with 3 × 4 levels of two factors including task load and working schedule was carried out at one busy area control unit in China. 156 effective questionnaires (52 person times) were collected and analyzed with statistical methods. Primary results of repeated measure variance analysis showed that the accumulation of task load resulted in their sleep subscale scores increased very significantly, mood subscale scores and perception subscale scores decreased very significantly. Results of independent measure variance analysis showed that the influence of working schedule was also very significant to their sleep subscale, mood subscale and perception subscale scores. And the results of multiple factors covariance analysis showed that the interaction of task load and working schedule was significant. These primary results need to verify with large number of samples. These results clearly indicated that air traffic controllers' fatigue dynamically changed on duty. And the results will promote the design of new smart and adaptive air traffic management system which should take the dynamical change of controllers' fatigue and even capacity in to account.

Keywords: Air traffic controller · Fatigue · Task Load · Working schedule

1 Introduction

The rapid growth in commercial air travel, both in China and worldwide, is putting immense pressure on air traffic management (ATM). Consequently, ATM technological systems keep iteration and updating in order to meet the demands for enhanced capacity,

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efficiency, and safety [1, 2]. And air traffic controllers (ATCOs) tend to work with more and more complex and powerful ATM systems, in which a proficient interaction between humans and computer systems is crucial to provide a safe and efficient service. Therefore, it has reached a consensus that the design of ATM systems needs to fit ATCOs ability demand [3]. For example, Brink, et al. established a new interface prototype that enables controllers to manipulate multiple flows of traffic by facilitating interaction with a path-planning algorithm [4]. IJtsma, et al. proposed to design an adaptive automation system to balance air traffic controller workload between underload and overload [5]. Borst, et al. put forward a prototype ecological interface for tactical conflict detection and resolution in the horizontal plane to assist ATCOs in fault diagnosis of automated advice [6]. Most of these studies regard ATCOs' ability and performance during operational duty as static stability. However, is the ATCOs' capacity to perform their duties stable during operational duty although they have got training and hold certifications?

The responsibility of ATCOs work is to avoid collisions of aircrafts with barriers on the ground, and with other aircrafts, and to guide aircrafts orderly and efficiently flow [7]. Therefore, ATCO has to monitor the aircraft assumed in the air-sector, and command the pilots for safe, efficient and smooth navigation, intervening in case of risk of infringing the prescribed safety separations between aircrafts. They tend to suffer fatigue during operational duty under such a multitask mode and stressful work environment [8, 9]. Recent years, along with the rapid increasement of flights in China, ATCOs' task loads increase quickly and their safe pressure increases fast in their daily work. For example, In July 2014, ATCO at Tianhe Airport, Wuhan slept on duty [10]. Obviously, fatigue is able to reduce ATCOs' capacity to perform their duties [8, 9]. What's more, fatigue results in human body biochemical metabolic changes [11, 12], makes his mood worse to cause aggressive behavior, and brings about perceptive ability decreased [13, 14]. Bad mood and reduced perception affect ATCOs' capacity to perform their duties very possibly. All this means that the state of ATCOs' ability during operational duty is dynamically changing. In this paper, we examined the changes of ATCOs' fatigue characterized as sleep, mood and perception three aspects during operational duty with a cross sectional field investigation in order to provide the trend information on dynamical changes of ATCOs for the design of smart and adaptive ATM systems.

2 Experiment

2.1 Study Design

ATCOs' task load and working schedule were designed as two independent variables in this study. A two factors mixed experimental design with 3 × 4 levels showed in Table 1. The 3 levels for task load set as 0 for rest, 0.5 for working in the middle of a shift, and 1.0 for complete working of a shift. The 4 levels for working schedule set as shift I (morning, 8:00–12:00), shift II (afternoon, 12:00–18:00), shift III (evening, 18:00–24:00), shift IV (deep night, 24:00–6:00).

2.2 Participants and Questionnaire Survey

ATCOs were recruited as volunteers in this study, who worked at one busy area control unit in China where the number of controlling flights was nearly 4000 a day during our

Table 1. Two factors mixed experimental design with 3 × 4.

Factor	Task load	Working schedule
Levels	0	Shift I
	0.5	Shift II
	1.0	Shift III
		Shift IV

survey period (from 26 to 28 Aug. 2019). They were regularly assigned to work for continuous two days and rest next continuous two days. All of them got quite enough rest before work. All the ATCO volunteers participating in the survey held certificates of competency. The general information of ATCO volunteers showed in Table 2.

Table 2. General information of ATCO volunteers in the study.

Age	Gender	People number	Shift I	Shift II	Shift III	Shift IV
23–42	Male	52	15	15	15	7
Mean 29.6						

On the premise to limit disturbance to minimum possible to ATCOs' work, we selected one scale developed in our previous work as the fatigue questionnaire which was simple and easy to understand. And the reliability and validity of the scale was verified with ATCOs during operational duty in the previous work [15]. The scale contains 7-item as sleepy, anxious, feel confident, irritable, able to concentrate, energetic, and slow degree of nerve, respectively. There are 10 degrees from 10 to 100 for each item, 10 represented the lowest degree, and 100 represented the highest degree. After reading the instructions on the scale, the volunteers were asked to select the value of each item to indicate how they currently feel.

The ATCO volunteers were required to fill out the questionnaire just before, in the middle, and just after their duties. Sixty ATCOs were recruited and fifty-eight ACTOs completed the scale three times as before, in the middle and after their duties.

The study protocol was approved by the Ethics Committee of the Second Research Institute of Civil Aviation Administration of China. All ATCOs participating in the experiment were provided with and signed an informed consent form. All relevant ethical safeguards have been met with regard to subject protection.

2.3 Statistical Analysis

Collected questionnaires were analyzed with statistic methods mainly including repeated measure variance analysis, independent variance analysis, multiple factors covariance analysis, and so on. In order to conveniently analyze and easily understand the results, 7-item of the scale was divided into three subscales as sleep subscale (SS) including sleepy, mood subscale (MS) including anxious, feel confident and irritable, and perception subscale (PS) including able to concentrate, energetic and slow degree of nerve.

3 Results and Discussion

156 questionnaires (as 52 persons) past the box plot test and applied to statistical analysis. The reliability of the questionnaires was very high (Cronbach's α, 0.85).

3.1 Influence of Task Load

Firstly, we investigated the influence of task load to ATCOs' fatigue with three aspects including sleep, mood and perception, respectively. Before ATCOs' duty, their task loads set as 0. In the middle of ATCOs' duty, their task loads set as 0.5 considering that there are regulations on balance of task loads by opening or closing sectors for very high or very low task loads in the 'Air traffic control rules for civil aviation' in China. And after ATCOs' duty, their task loads set as 1.0. The scores of ATCOs' SS, MS, and PS before, in the middle, and after duty showed in Fig. 1.

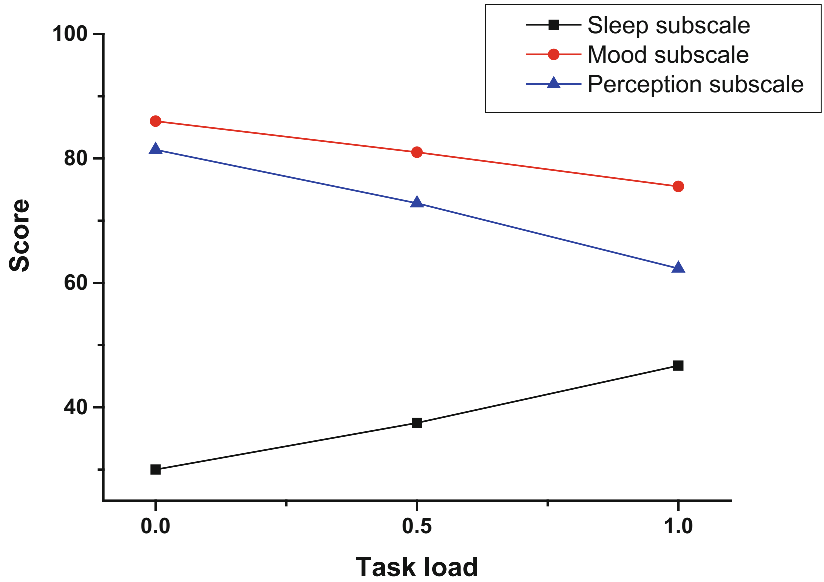

Fig. 1. Changes of ATCOs' fatigue with their task loads. (Color figure online)

Repeated measure variance analysis employed to the collected effective questionnaires to investigate the influence of task load to ATCOs' sleep, mood and perception, respectively. Results of ATCOs' SS showed that the influence of task load was very significant ($P < 0.001$, Fig. 1, black line). Multiple comparison analysis of the repeated measure data discovered that the SS scores in the middle of duty (mean 37.5) and after duty (mean 46.7) were very significant increased compared with that before duty (mean 30.0), respectively ($P = 0.006$, $P < 0.001$), and the SS scores after duty (mean 46.7) increased very significantly compared with that in the middle of duty (mean 37.5) ($P < 0.001$). These results indicated that the ATCOs' task loads resulted in their SS scores rapid increasing, and they kept to increase rapidly along with work time extension as task load accumulation. It was worth to notice that in the middle of duty, ATCOs' sleep changed very significantly compared with that before duty when they had performed duty only for 2 or 3 h. Therefore, it's a legitimate implication that ATCOs' sleep was a dynamical change process during they performed operational duty.

Then, for ATCOs' MS, results showed that the influence of task load was very significant ($P < 0.001$, Fig. 1, red line). Multiple comparison analysis of the repeated measure data discovered that the MS scores in the middle of duty (mean 81.0) and after duty (mean 75.5) were significant and very significant decreased compared with that before duty (mean 86.0), respectively ($P = 0.016$, $P < 0.001$), and the MS scores after duty (mean 75.5) decreased very significantly compared with that in the middle of duty (mean 81.0) ($P < 0.001$). These results indicated that the ATCOs' task loads resulted in their MS scores rapid decreasing, and they kept to decrease rapidly along with work time extension as task load accumulation. The results were similar with that of another survey for military drivers on their mood in China [14]. It's important to notice that in the middle of duty, ATCOs' mood changed significantly compared with that before duty when they had performed duty only for 2 or 3 h. It's reasonable to speculate that ATCOs' mood was a dynamical change process during they performed operational duty.

At last, for ATCOs' PS, the results, similar to that of MS, showed that the influence of task load was very significant ($P < 0.001$, Fig. 1, blue line). Multiple comparison analysis of the repeated measure data discovered that the PS scores in the middle of duty (mean 72.8) and after duty (mean 62.3) were significant and very significant decreased compared with that before duty (mean 81.4), respectively ($P = 0.011$, $P < 0.001$), and the PS scores after duty (mean 62.3) decreased very significantly compared with that in the middle of duty (mean 72.8) ($P < 0.001$). These results indicated that the ATCOs' task loads resulted in their PS scores rapid decreasing, and they kept to decrease rapidly along with work time extension as task load accumulation. The results were in accord with that of the survey for Chinese military drivers on their perception [14]. Similar to the mood, in the middle of duty, ATCOs' perception changed significantly compared with that before duty when they had performed duty only for 2 or 3 h. It's reasonable to speculate that ATCOs' perception was a dynamical change process during they performed operational duty.

The above results showed that ATCOs' fatigue characterized as sleep, mood and perception were influent significantly by task load. And the increasement of their fatigue presents as SS scores increasing, MS and PS scores decreasing. It's a legitimate implication that ATCOs' fatigue was a dynamical increase process during they performed operational duty. The results were consistent with that of another research for the fatigue of ATCOs at one terminal unit in China using the Stanford Sleeping Scale [16].

3.2 Influence of Working Schedule

Secondly, we investigated the influence of working schedule to ATCOs' sleep, mood and perception, respectively. In order to provide 24-h continuous air traffic management service, there were many working schedules at the area control units. We selected four typical working schedules as morning, afternoon, evening, and deep night as shift I, II, III, and IV for this study. The scores of ATCOs' SS, MS, and PS on the four shifts before duty showed in Fig. 2.

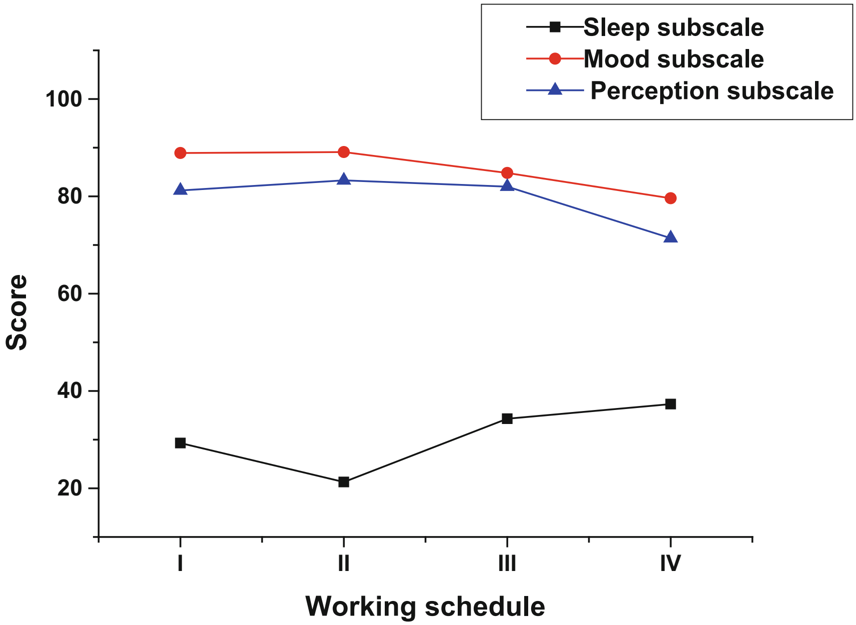

Fig. 2. Changes of ATCOs' fatigue along with their working schedules before duty. (Color figure online)

Independent measure variance analysis employed to the questionnaires before duty to investigate the influence of working schedule to ATCOs' sleep, mood and perception, respectively. The changes of ATCOs' three parameters before duty caused mainly from their basic factors such as circadian rhythm, age, and so on, without disturbance from task load considering they got enough rest before duty. And these basic factors reflected in the working schedule. For ATCOs' sleep (Fig. 2, black line), the variance analysis of independent measurement in the four shifts discovered that SS scores in shift IV increased significantly compared with that in shift I ($P = 0.030$), II ($P = 0.027$), and increased very significantly compared with that in shift III ($P = 0.006$), respectively. And there was no significant difference appeared for the SS scores among shift I, II and III. For ATCOs' mood (Fig. 2, red line), the statistical results showed that MS scores in shift IV decreased significantly compared with that in shift I ($P = 0.027$), II ($P = 0.035$), and III ($P = 0.041$), respectively. And there was no significant difference appeared for the MS scores among shift I, II and III, either. For ATCOs' perception (Fig. 2, blue line), the statistical results, similar to mood, PS scores decreased very significantly compared with that in shift I ($P < 0.001$), II ($P = 0.002$), and III ($P = 0.001$), respectively. And there was no significant difference appeared for the PS scores among shift I, II and III, either.

These results were consistent with the change of the circadian rhythm. In the day time, people remain clear-headed to work in accordance with shift I to III. And at night, people become fatigue and sleep to gather strength in accordance with shift IV [17, 18]. The above results also agreed with that of ATCOs at the terminal control unit in China [16].

3.3 Influence of Interaction Between Task Load and Working Schedule

Then, we investigated the interaction influence between task load and working schedule to ATCOs' sleep, mood and perception, respectively. Multiple factor covariance analysis employed to examine the interaction influence.

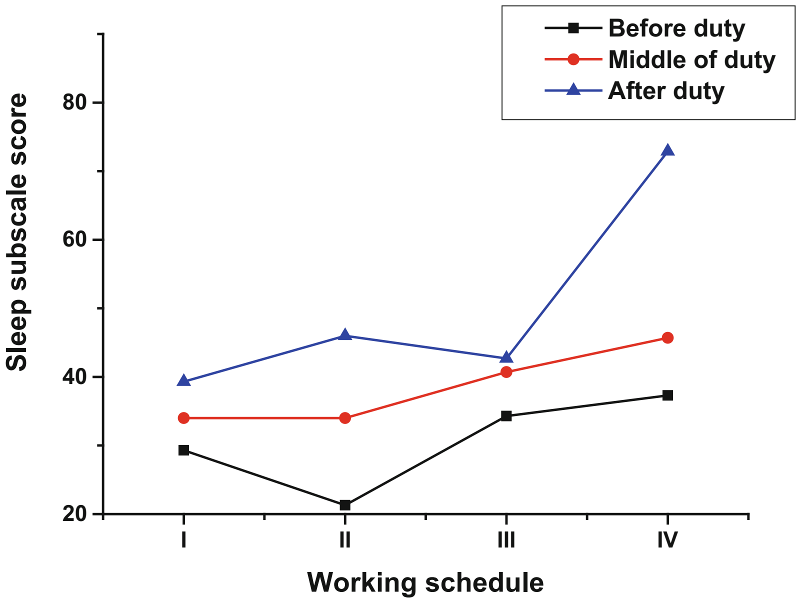

Fig. 3. Changes of ATCOs' sleep along with their task loads and working schedules

For ATCOs' sleep during operational duty, the changes of SS scores with different working schedule showed in Fig. 3. Results of covariance analysis showed that the interaction influence of task load and working schedule was very significant for ATCOs' sleep ($P = 0.007$). And the interaction influences enhanced ATCOs sleep. Therefore, this process is a dynamically changing course and is worth to pay attention in the design of new air traffic management systems.

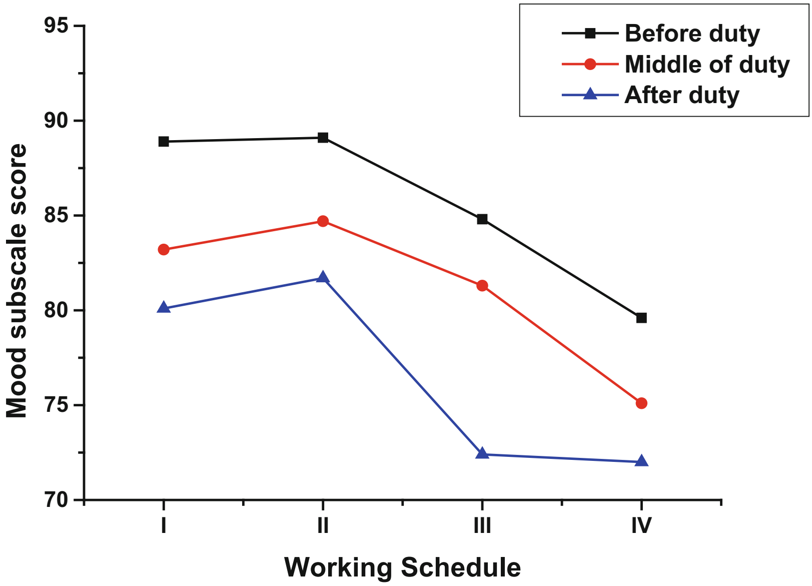

Fig. 4. Changes of ATCOs' mood along with their task loads and working schedules.

For ATCOs' mood during operational duty, the changes of MS scores with different working schedule showed in Fig. 4. Results of covariance analysis showed that the interaction influence of task load and working schedule was significant for ATCOs' mood ($P = 0.046$). To our knowledge, for the first time, we preliminarily demonstrated the interaction influence of task load and working schedule in ATCOs' mood with the questionnaire survey. Moreover, the interaction influence needs a greater number of samples to verify. The interaction influences reduced ATCOs mood and made their temperature more awful. And the process of ATCOs' bad mood is a dynamically changing course.

For ATCOs' perception during operational duty, the changes of PS scores with different working schedule showed in Fig. 5. Results of covariance analysis showed that the interaction influence of task load and working schedule was significant for ATCOs' perception ($P = 0.031$). And the interaction influences reduced ATCOs perception. To our knowledge, for the first time, we preliminarily demonstrated the interaction influence of task load and working schedule in ATCOs' perception with the questionnaire survey. Obviously, the reduced perception leads to lessen the capacity of ATCOs to perform their duties. Similarly, the process of ATCOs' perception decreasing is a dynamically changing course and worth to consider in the design of new ATM systems.

These results were also consistent to the result of the investigation for ATCOs at one terminal control unit in China in another work [16]. Those results indicated that ATCOs fatigue was a dynamically increasing process along with the accumulation of task loads and work at night shift. And fatigue is able to reduce the ATCOs' ability to conduct their duties [8, 9]. Therefore, this process is worth to pay attention in the design of new air traffic management systems.

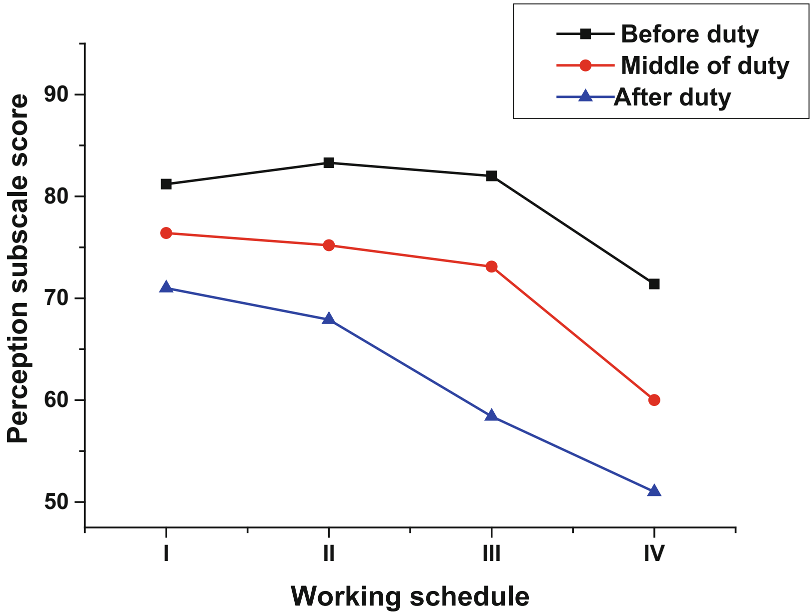

Fig. 5. Changes of ATCOs' perception along with their task loads and working schedules.

In brief, the primary results of this cross section field investigation clearly showed that during operational duty, ATCOs' fatigue dynamically changed. What's more, even they performed duty only for 2 or 3 h the three parameters changed significantly. These results full demonstrate that the dynamical process of the three parameters for ATCOs is not neglectable and is able to influence their capacity of duty. Therefore, the dynamical process is worth to pay special attention in the design of new ATM systems, otherwise, the new designed system will most likely not able to achieve desired results. Brink et al. applied their designed interface prototype to test with human participation, the sector robustness and efficiency did not improve the solution as compared the previously designed interface [4]. As for IJtsma's adaptive automation system, lower triggering thresholds increased the frustration level of participants and decreased acceptance of the support [5]. It may be a practical good try to take the dynamic process of ATCOs' fatigue into account for improvements of these designed systems. For example, it may decrease the frustration level of participants and increase acceptance of the support to set higher triggering thresholds at the onset of ATCOs' duty and then to decrease thresholds gradually for the adaptive automation system of IJtsma et al., considering their fatigue gradually increasing during operational duty.

4 Conclusion

In conclusion, the continuous increasing commercial flights require to improve the smart adaptive new ATM systems. The design of the systems seldom pay attention to the dynamical change of ATCOs fatigue to perform their duty during operational duty. In this paper, we primarily demonstrated that ATCOs' fatigue changed dynamically during they performed operational duty with a cross sectional field investigation. In particular, their sleep was tended to increase, their mood and their perception were tended to decrease on duty. Task load and working schedule as two main influent factors for the sleep, mood and perception of ATCOs were investigated. The results showed that the influence of task load was very significant to ATCOs' sleep resulted in it increased, and was also very significant to ATCOs' mood and perception resulted in them decreased. The results indicated that the influence of working schedule was very significant to ATCOs' sleep caused it increased at night, and was very significant to ATCOs' mood and perception resulted in them decreased at night. What's more, the results, for the first time, primarily discovered that the interaction influence between task load and working schedule exited indeed to ATCOs' fatigue. The results of the study were just primary results and needed a great number of samples confirm.

All these results demonstrated that on duty ATCOs' fatigue was dynamically changed with task load and working schedule. And the changes of their fatigue necessarily result in the changes of their capacity for work. Therefore, the design of new ATM systems should take the dynamical change of ATCOs' capacity into account. It means that the parameters for the design of systems include ATCOs' dynamical state as a variable in place of a constant. The expression or the change rule of the variable needs to further research.

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