Factors Influencing Cargo Pilots' Fatigue

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Abstract. In recent years, cargo pilots' training and reserves in China have been unable to meet the needs of the development of cargo aviation, due to the rapid development of the country's cargo aviation and the continuing increase in air traffic. Frequent night and cross-time-zone flights in particular worsen the severity of pilots' fatigue situation. At present, cargo pilots' fatigue is a key problem that affects the development of China's cargo aviation. In this study, a survey was carried out with Cargo Pilot's Fatigue Survey Scale, and the factors influencing cargo pilots' fatigue were analyzed and compared with the fatigue of the airline pilots. The results indicated that: compared with the airline pilots, cargo pilots have a higher degree of fatigue and are more likely to be conscientious and open; we also determined that number of night flights, workload, and health history are highly correlated with pilots' degree with fatigue. Nevertheless, no significant difference in workload, age, or sleep quality was noted between cargo pilots' and airline pilots' fatigue.

Keywords: Cargo pilots · Fatigue · Pilot fatigue survey scale · Grey correlation

1 Introduction

On August 14, 2013 at 5:00 am, an A300-600 cargo plane belonging to the United Parcel Service crashed near Birmingham International Airport in Birmingham, Alabama, killing two pilots. The National Transportation Safety Board released the accident investigation report on September 9, 2014, which pointed out that pilot's errors and fatigued piloting were the main causes of the accident. Notably, pilot fatigue has become one of the main risk factors affecting flight safety. A survey on the flight time limits conducted by the British Air Line Pilots Association, showed that 56% of pilots reported falling asleep at the cockpit and 29% recalled waking up to find another pilot asleep [1].

Several scholars have conducted in-depth research on the causes of flight fatigue. For example, Rosekind [2] investigated the impact of flight missions on pilots' sleep quality, circadian clock changes, and subjective feelings about fatigue, and determined that the main causes of fatigue were sleep deprivation and circadian rhythm changes. Similarly, Blakey [3] pointed out that pilot fatigue is the main causes of airplane crashes; in addition to work load, this fatigue results from lack of sleep, individual physiological clock disruption, abnormal scheduling, poor sleep quality, and drug use. Blakey added that people in a state of fatigue increase the risks associated with the task they are performing; therefore, crew fatigue conditions should be confirmed before a

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flight to determine the ability of the individuals to complete flight tasks. Moreover, Caldwell [4, 5] suggested that long and short route pilots commonly attribute fatigue to overnight flights, jet lag, early wake-up times, time pressure, multiple flights, and long shifts. The most common causes of fatigue are lack of sleep, diurnal rhythm changes, poor sleep quality, stress, and excessive workload. SAFO [6] indicated that sleep deprivation and a heavy workload can trigger short-range pilots' fatigue; by contrast, long-range pilots' fatigue is attributable to a lack of sleep and the circadian rhythm disruption caused by cross-time-zone flights. Han [7] argued that amount of sleep, work load, and mood contribute to flight fatigue, and Ge [8] explored the relationship between flight fatigue and age in pilots who work long-haul flights. Li [9] suggested that a lack of sleep and changes in circadian rhythm are directly related to fatigue; he added that late work hours and monotonous tasks also lead to fatigue, while a lack of sleep can produce physiological and psychological decline and subsequent decline in work efficiency. He concluded that a decreased efficiency in flight tasks was likely to produce human error, and thus lead to accidents.

The CCAR-121 clearly stipulates that all-cargo transport aircraft (which can operate with a maximum load of more than 3400 kg), including large public air transport carriers, must comply with the provisions of Chapter P, which discuss pilot crew duties related to period limitations, flight time restrictions, and rest requirements. Although China's rules for pilot rest do not differentiate between airline and cargo pilots, Chinese pilot fatigue management only considers the lengths of time for work and rest periods; current Chinese rules do not effectively consider the question of cargo pilots' night flights.

In short, fatigue is a critical factor affecting the safety of cargo flights. Pilot fatigue can lead to a decline in operative capabilities, ability to judge errors, and hallucinations during flight, and can lead to serious and tragic flight accidents. Therefore, in this study we conducted a survey to analyze cargo pilot fatigue in a Chinese cargo airline. Based on the collected data, the grey correlation method was used to identify the factors that influence pilot fatigue.

2 Cargo Pilot Fatigue Questionnaire and the Grey Correlation Analysis Method

2.1 Cargo Pilot Fatigue Questionnaire

The questionnaire comprised six separate surveys: personal information survey, fatigue perception survey, work-related factors survey, sleep quality survey, life event factors survey, and personality characteristics survey. The six sections were later combined to investigate the overall fatigue statuses of pilots.

(1) Personal Information Survey

The first survey collected pilots' basic personal information, and consisted of three parts: basic information, family status, and health status. Basic information included age, total flight hours logged, typical route types and crew position; family status included marital status and number of children; and health status included dietary habits, exercise routines, prescribed medications, and the presence or absence of any chronic disease.

(2) Fatigue Perception Survey

The second survey was based on the Fatigue Self-Rating Survey Scale developed by Prof. Tianfang Wang [10] and the MFI-20 Scale [11] developed by the psychology department at the University of Strand. By combining these surveys with questions that targeted the specific circumstances of China's cargo pilots, a new fatigue rating scale (MFI-16) suitable for pilots was developed. There are four dimensions to the survey, namely general fatigue, physical fatigue, mental fatigue, and reduced motivation, comprising a total of 16 items. The score for each dimension ranged from 4 to 20 points; all four dimensions had a total score of 16–80 points, with higher scores indicating a greater perceived degree of fatigue. This survey determined the fatigue statuses of the pilots over the course of 1 month, and demonstrated good reliability and validity.

(3) Work-Related Factors Survey

The work-related factors survey consisted of 19 items organized into four dimensions: scheduling factors, work load, work environment, and other factors.

(4) Sleep Quality Survey

The sleep quality survey adopted the content of the Pittsburgh Sleep Quality Index [12]. The scale was developed by a sleep specialist, Buysse Dj, in 1993 while he worked for the Center for Sleep and Biorhythmics at the University of Pittsburgh Medical Center to assess subjects' subjective perceptions of sleep quality over a period of 1 month. The reliability and validity of this scale have been verified by Xianchen Liu in China. Thus, it has become a common scale for studying sleep disorders and clinical evaluation.

(5) Life Event Factors Survey

The life events factor survey reviewed 17 common life events, which were organized into the following seven dimensions: workload, career development, interpersonal relationships, marriage and family, property economy, physiological status, and institutional pressure. Notably, this survey not only explored general life events that can produce considerable fluctuations in human emotions, but also occupation-related special events specific to pilots.

(6) Personality Characteristics Survey

The personality trait theory defines a "trait" as a basic characteristic of individual behavior and the effective unit of personality; it is generally agreed that people can be described by a limited number of traits. Although the range and specificity of traits are unique to each person, the conceptualization of "traits" is consistent and reflects regular individual behavior and features [13]. This final survey explored personality within five dimensions: extroversion, amenability, conscientiousness, neuroticism, and openness. The score for each dimension ranged between 5 and 30, with higher scores indicating that a person was more likely to be defined by that feature.

2.2 Grey Correlation Analysis Method

The grey correlation analysis is a quantitative description method that examines trends in the development of and changes in a system. The results reveal whether a connection is close by comparing the similarity between the reference data column and the geometry of the data column, which reflects the degree of correlation between curves.

Steps for grey correlation analysis:

(1) Determine the analysis sequence

The reference sequence reflects the behavioral characteristics of a system, and is used to determine the comparison sequences that affect the behavior of that system. The data sequence that reflects the behavior of the system is known as the reference sequence, whereas the data sequence that affects the behavior of the system is called the comparison sequence.

Assuming that the reference sequence is $\mathrm{Y} = \{Y(k)|k = 1, 2, \wedge, n\}$; The comparative sequence can be assumed to be $X_i = \{X_i(k)|k = 1, 2, \wedge, n\}, i = 1, 2, \wedge, m$.

(2) Determine the nondimensional variables

Because the data dimension of each factor is different, it is difficult to obtain a valid conclusion. Therefore, in our analysis of grey correlation degree, it was necessary to perform a dimensionless processing of the data. At present, the common nondimensional processing methods are extreme value, standardized, mean, and standard deviation, with the standardized method being the most common. However, if the indicators' means are all 0 and the standard deviations are all 1 when the indicators are obtained through standardized method, the results can only demonstrate the interaction between the indicators; by contrast, dimensionlessness equalizes the degrees of variation of the indicators, therefore, the standardization method does not apply to the comprehensive evaluation of multiple indicators. The covariance matrix of the data processed by the mean method can reflect the variance of each index in the original data, as well as information regarding the differences between each degree of influence of each index. Therefore, the mean method was adopted in this study.

$$x_i(k) = \frac{X_i(k)}{X_i(l)},\ k = 1, 2 \ldots n;\ i = 1, 2 \ldots m$$

$X_i(l)$ represents the mean of the column i.

(3) Calculate the correlation coefficient

The correlation coefficient between $x_o(k)$ and $x_i(k)$

$$\delta_i(k) = \frac{\min\limits_i \min\limits_k |y(k) - x_i(k)| + \rho \max\limits_i \max\limits_k |y(k) - x_i(k)|}{|y(k) - x_i(k)| + \rho \max\limits_i \max\limits_k |y(k) - x_i(k)|}$$

$\rho \in (0, \infty)$, is called the resolution coefficient. We usually take $\rho = 0.5$.

(4) Calculate the correlation degree

Because the correlation coefficient is the value of the correlation degree between the comparison sequence and the reference sequence at each moment (i.e., each point on the curve), the correlation coefficient has more than one value (it has a distinct value at each point on the curve); thus the information is too scattered to facilitate an overall comparison. Therefore, it is necessary to collect the correlation degree at each moment as a numerical value, and determine the mean value as a value of the correlation degree between the comparison and reference sequences. The correlation formula is as follows:

$$r_i = \frac{1}{n}\sum_{k=1}^{n}\delta_i(k), k = 1, 2, \wedge, n$$

(5) Rank correlation degrees

The correlation degree is sorted by size, and if $r_1 < r_2$, the reference sequence y is more similar to the comparison sequence x_2.

After calculating the correlation coefficient between $X_i(k)$ sequence and Y(k) sequence, calculated the mean value of each kind of correlation coefficient. The average value r_i is called the correlation degree between Y(k) and $X_i(k)$.

3 Analysis of the Results

Questionnaires were distributed to China Postal Airlines crew members, and were completed by people in various crew positions, including flight inspectors, teachers, pilots, and copilots. A total of 100 questionnaires were distributed; both the recycling and recovery rates were 50%, the overall efficiency was 100%.

3.1 Results of the Cargo Pilots Fatigue Survey

(1) Personal Information Survey

Of the cargo pilots who participated in this study, the age range was from 23 to 55 years; the average age was 32 years, the average work history was 8 years, and the average number of flight hours logged was 4385 h. Moreover, the percentage of the pilots who flew international routes, local routes, trunk routes, and feeder routes, respectively, was 23.4%, 29.9%, 36.4%, and 10.4%. In total, 53.1% of the pilots noted that their diet habits were regular, 49.0% did not drink, 61.7% did not smoke, and 87.8% identified a weekly exercise routine. Finally, the percentage of the pilots who believed that their health was in good, general, and poor condition, respectively, was 28.6% and 14.3%.

(2) Perceived Fatigue Survey

Perceived fatigue was divided into five levels: none, mild, moderate, severe, and extreme. According to the total scores, the following percentages indicate the distribution of fatigue among the pilots: 8% perceived no fatigue, 23% perceived mild fatigue, 47% perceived moderate fatigue, 20% perceived severe fatigue, and 2% perceived extreme fatigue.

Fatigue was then divided into our set of dimensions, comprising general fatigue, physical fatigue, mental fatigue, and diminished motivation. The statistical distribution of the scores between the two sets of dimensions is presented in Table 1.

Table 1. Distribution of fatigue on different dimensions

Degree four dimensions	Free	Mild	Moderate	Severe	Extreme
General fatigue	2%	13%	33%	42%	9%
Physical fatigue	4%	14%	49%	22%	10%
Mental fatigue	4%	14%	43%	31%	8%
Reduced motivation	0%	16%	65%	14%	4%

After adding the second set of dimensions, it was determined that 51% of cargo pilots considered themselves to be severely fatigued, 32% considered themselves to be seriously physically fatigued, 39% considered themselves to be seriously mentally fatigued, and 18% considered their work motivation to be low.

A comparative investigation of the fatigue conditions of commercial pilots in China revealed that 6% of commercial pilots considered themselves to be severely and extremely fatigued, 16% considered themselves to be severely fatigued, 12% considered themselves to be physically fatigued, 18% considered themselves to be mentally fatigued, and 15% considered their work motivation to be very low. Therefore, in contrast to the commercial pilots, cargo pilots experienced more serious general, physical, and mental fatigue, and had lower work motivation.

(3) Work-Related Factors Survey

On the dimension of scheduling factors, we found that 55% of staff involved in flight investigations have adapted to their currently scheduled shifts and 45% have not adapted. Additionally, more than 90% of the pilots who identified as severely and extremely fatigued noted that their sleep habits were not compatible with their currently scheduled shifts. By contrast, 55% of the pilots overall felt fully rested after a night shift, of whom 77% were accustomed to their current shifts, whereas 45% of the pilots were unable to get adequate rest, of whom 78% were not accustomed to their current shifts. This analysis suggests that inadequate rest is a primary factor preventing pilots from adapting to their scheduled shifts; pilots who cannot adequately rest tend to perceive their workload as heavy.

On the dimension of workload factors, the statistical results showed that 55% of cargo pilots believed that they had heavy workloads. In total, 88% of the cargo pilots worked 4.2 days a week on average, and 61% worked 20 days each month and flew for more than 6 h over three segments per day. Moreover, 80% of cargo pilots suggested that night duty had a substantial influence on their fatigue, compared with only 4% of cargo pilots who believed that night duty had no effect or a minimal effect on their fatigue; thus, night duty was a key factor affecting the cargo pilot fatigue. Among the

68% of cargo pilots who were on duty for 4 or 5 days a week around the clock (i.e., before 12:00 am and after 4:00 am), cross-day work was more common.

On the dimension of working environment, we noted that people who work in a noisy environment, which is characterized by continuous background murmuring, are easily fatigued. Although new employees in such an environment can initially feel uncomfortable, they eventually adapt to this noise over time; this auditory noise eventually overstimulates the brain when a person's auditory threshold has risen sufficiently, which causes people to move slowly, think unclearly, and can lead directly to sleep [14]. Our survey results were consistent with these ideas. For example, we found that a plane's cabin environment impacts fatigue based on the conditions of noise, vibration, odor, temperature, and lighting, at rates of 89.8%, 53.1%, 53.1%, 40.8%, and 32.7%, respectively. To reduce cabin-environment-related fatigue, we suggest first addressing the distractions that are produced by noise, vibration, and odor, to obtain a multiplier effect. Our survey also revealed that 63% of cargo pilots flying at night tended to experience a strong sense of loneliness or depression.

On the dimension of other factors, our survey demonstrated that seasons are an important factor affecting fatigue, with 71% of cargo pilots noting that their fatigue levels were impacted by the season. In particular, 75% of the pilots revealed that their fatigue worsened in the summer, because summer flights need to avoid thunderstorms and thus the pilots faced larger workloads.

(4) Sleep Quality Survey

Sleep quality is also a crucial indicator of fatigue, and a lack of sleep is one of the main reasons that flight crews experience fatigue. In particular, cargo pilots who begin work early in the morning and work long hours experience increased degrees of fatigue. Notably, long-term sleep deprivation or poor sleep quality can lead to chronic fatigue, which not only impacts people's work but poses a marked threat to health. Table 2 shows the results of the sleep quality survey.

Table 2. Results of the sleep quality survey

Sleep conditions	The proportion
Sleep quality is very good	14%
Sleep quality is okay	50%
Sleep quality is mediocre	34%
Sleep quality is poor	2%

Specifically, the survey revealed that "mediocre" and "poor" sleep quality together accounted for 36%; only 14% of the pilots indicated that they had "very good" sleep quality.

Sleep quality was also assessed according to five dimensions of sleep status, namely sleep duration, sleep efficiency, sleep disorders, sleep medication use, and daytime dysfunction (see Tables 3, 4, 5, 6 and 7).

Table 3. Cargo pilots' sleep duration

The sleep time	The proportion
Less than 5 h	34%
5–6 h	12%
6–7 h	16%
More than 7 h	34%

Table 4. Cargo pilots' sleep efficiency

The sleep efficiency	The proportion
65%	38%
65%–74%	10%
75%–84%	16%
85%	36%

Table 5. Cargo pilots' night sleep disorders

Sleep disorders	The proportion
No	8%
Minor	54%
Larger	34%
Very difficult	4%

Table 6. Cargo pilots' daytime dysfunction

Daytime dysfunction	The proportion
No	6%
Minor	34%
Larger	34%
Very difficult	26%

Table 7. Cargo pilots who use sleep medicine

Using sleep medicine	The proportion
No	96%
Average 1–2 nights per week	2%
An average of more than 3 nights a week	2%

The statistical results indicated that 62% of the cargo pilots had an average sleep duration of less than 7 h per night. The percentage of pilots who slept nocturnally without disorders was 8%, while 6% slept during the day. 38% of the cargo pilots had sleep quality percentages that were less than 65%. However, only 4% of the pilots used drugs to facilitate sleep. Overall, the data show that cargo plane pilots generally had poor sleep quality, which at least partially explains their high degrees of fatigue.

(5) Life Event Factors Survey

The life events analysis method provides a life cycle calculation period that covers 18 months, and accumulates the values of life changes that correspond to notable events that occurred during the cycle. The calculation of the total value of life changes is used as a statistical index; the higher the score is, the greater the degree of influence an event posed. The life events impact scores of the cargo pilots involved in this study are listed in Table 8.

Table 8. Scores from the life event factors survey

Scores	The proportion
0	50.0%
$0 < \text{score} \ll 50$	46.0%
score > 50	4.0%

Notably, life events had no effect on 50% of the cargo pilots, a light impact on 46% of the pilots, and a substantial impact 4% of the pilots. Thus, the statistical data suggest that life events impact fatigue only to a limited extent.

(6) Personality Characteristics Survey

Different personalities tend to mitigate the stresses of life and work by different methods. Pilots' sensitivity levels to the impact of fatigue may also reflect their personality characteristics. The statistical results of the personality characteristics survey adopted in this study are presented in Table 9.

Table 9. Results of the personality characteristics survey

Score / personality characteristics	6-14	15-22	23-30
Extroversion	15.6%	80.0%	4.4%
accommodating	4.3%	78.3%	17.4%
conscientiousness	0.0%	57.8%	42.2%
neuroticism	31.1%	68.9%	0.0%
openness	2.2%	75.6%	22.2%

Specifically, we determined that the cargo pilots of freighter planes are more conscientious and open. Moreover, none of the cargo pilots had neurotic characteristics, indicating that they were interpersonally engaged, self-controlled, and emotionally stable.

3.2 Factors Affecting Cargo Pilots' Fatigue

According to the survey results, we determined that the following factors most crucially influenced cargo pilots' fatigue: age, total flight hours logged, total number of years as a pilot, diet, alcohol consumption, smoking, exercise routine, overall health status, sleep quality, adaptability to varying work shifts, workload self-assessment, number of working days per week, engagement in overnight flights, number of weekly flight hours, and the number of days of flight that spanned a day and night. The correlation coefficients of each variable, along with the degree of fatigue, were calculated using grey relational analysis. The results are listed in Table 10.

Table 10. Ranking of factors that affect fatigue

Influencing factors	Correlation degree	Ranking
Night flight	0.911	1
Workload	0.909	2
Health status	0.905	3
Number of working days per week	0.903	4
Whether sleep habits adapt to shifts	0.895	5
Exercise	0.892	6
Weekly flight hours	0.889	7
Age	0.878	8
The number of days of flight across the day and night	0.872	9
Regular diet or not	0.862	10
Sleep quality	0.860	11
Alcohol consumption	0.860	12
Smoking	0.856	13
Total flight years	0.794	14
Total flight hours	0.756	15

Subsequently, the results revealed that the factors associated with fatigue of airline pilots, in decreasing order, are: engagement in overnight flights, workload self-assessment, overall health status, number of working days per week, adaptability to varying work shifts, exercise routine, number of weekly flight hours, age, the number of flight days that spanned a day and night, diet, sleep quality, alcohol consumption, smoking, total number of years as a pilot, and total flight hours logged.

3.3 Comparative Analysis of Factors Affecting Fatigue Between Cargo and Airline Pilots

Eight of the factors that affect the fatigue of cargo pilots were also found to affect airline pilots, namely age, overall health status, workload self-assessment, sleep quality, total flying hours logged, number of working days per week, number of weekly flight hours, and total number of years as a pilot. The correlation coefficient along with

Table 11. Factors affecting the fatigue of airline pilots

Influencing factors	Correlation degree	Ranking
Work load	0.914	1
Health status	0.886	2
Age	0.881	3
Sleep quality	0.877	4
Number of working days per week	0.859	5
Weekly flight hours	0.841	6
Total flight hours	0.649	7
Total flight years	0.635	8

degree of fatigue, were calculated using the grey correlation method, and the results are shown in Table 11.

The analytical results revealed that the factors associated with fatigue in airline pilots, in decreasing order, are workload self-assessment, overall health status, age, sleep quality, number of working days per week, number of weekly flight hours, total flying hours logged, and total number of years as a pilot.

As revealed in Table 12, the effect of workload self-assessment, age, and sleep quality factors on fatigue does not significantly differ between airline and cargo pilots.

Table 12. Correlation coefficient comparison

Influencing factors	Airline pilots fatigue correlation degree	Cargo pilots fatigue correlation degree
Work load	0.914	0.909
Health status	0.886	0.905
Age	0.881	0.878
Sleep quality	0.877	0.860
Number of working days per week	0.859	0.903
Weekly flight hours	0.841	0.889
Total flying hours	0.649	0.756
Total flight years	0.635	0.794

In short, our comparative analysis indicated that workload self-assessment is the primary factor affecting airline pilots' fatigue, whereas overnight flights are the primary factor affecting cargo pilots' fatigue. However, the correlational degree ranking of overnight flights was higher than the workload self-assessment overall, indicating that overnight flights were more likely to make pilots feel fatigued than their workload self-assessment. Additionally, the number of working days per week and number of weekly flight hours were shown to have a greater effect on cargo pilots' fatigue than on airline pilots' fatigue, which may be related to the distinct work cycles of cargo and airline pilots. Specifically, most airline pilots are on duty during the day, whereas cargo

Table 13. Ranking comparison of the fatigue-influencing factors

Affecting factors of airplane pilots fatigue	Correlation degree ranking	Affecting factors of cargo pilots fatigue
Work load	1	Night flight
Health status	2	Workload
Age	3	Health status
Sleep quality	4	Number of working days per week
Number of working days per week	5	Whether sleep habits adapt to shifts
Weekly flight hours	6	Exercise
Total flying hours	7	Weekly flight hours
Total flight years	8	Age

pilots are mostly on duty at night; therefore, the effect of overnight flights on pilot fatigue is essential problem that must be addressed (Table 13).

4 Conclusion

1. Compared with commercial airplane pilots, the overall degree of fatigue experienced by cargo pilots is higher; additionally, the degree of both mental and physical fatigue is more serious among cargo pilots, with 51% of the pilots in this study self-identifying as severely and extremely fatigued.
2. The main reason pilots are unable to adapt to their scheduled shifts is that they do not get enough rest, which results in the perception of a heavier workload.
3. Noise and vibrations in the cabin environment have the greatest impact on fatigue. Pilots are also more likely to feel fatigued in the summer, and to feel lonely or depressed when flying at night.
4. The more prominent personality characteristics among cargo pilots are conscientiousness and openness, affinity for interacting with others, strong self-control, emotional adaptability, and emotional stability.
5. Night flights, a heavy workload, and overall health status are the three most critical factors associated with cargo pilots' fatigue; this knowledge can be used to effectively manage the problem of pilot fatigue.
6. No significant difference in workload self-assessment, age, or sleep quality is shown by the correlation degrees of cargo pilots' and airline pilots' fatigue. Thus, these three fatigue factors are considered to have a similar effect on fatigue, regardless of the type of pilot.

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