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Air Traffic Volume and Air Traffic Control Human Errors

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Abstract

Navigable airspaces are becoming more crowded with increasing air traffic, and the number of accidents caused by human errors is increasing. The main objective of this paper is to evaluate the relationship between air traffic volume and human error in air traffic control (ATC). First, the paper identifies categories and elements of ATC human error through a review of existing literature, and a study through interviews and surveys of ATC safety experts. And then the paper presents the results of an experiment conducted on 52 air traffic controllers sampled from the Korean ATC organization to find out if there is any relationship between traffic volume and air traffic controller human errors. An analysis of the experiment clearly showed that several types of ATC human error are influenced by traffic volume. We hope that the paper will make its contribution to aviation safety by providing a realistic basis for securing proper manpower and facility in accordance with the level of air traffic volume.

Keywords: ATC, Human Error, Air traffic volume, Workload

1. Introduction

The objectives of the air traffic services shall be to prevent collisions between aircraft, prevent collisions between aircraft on the manoeuvring area and obstructions on that area, expedite and maintain an orderly flow of air traffic, provide advice and information useful for safe and efficient conduct of flights, notify appropriate organizations regarding aircraft in need of search and rescue aid, and assist such organizations as required [1]. In order to achieve this purpose, air traffic controllers should be especially apt to deal with the interaction between humans and mechanical devices while they provide directions or advices to pilots to maintain vertical and horizontal separations between aircrafts and avoid aircraft collision. Accordingly, the air traffic controllers need to conduct multiple functions at the same time, such as thinking, listening and speaking. Considering the complicated nature of this task, one would wonder whether there is a higher probability for an air traffic controller to make mistakes when traffic is heavier. The objective of this paper is to investigate if air traffic control (ATC) human error is influenced by the size of traffic volume.

First, categories and elements of ATC human error was studied through existing literature, and interviews and surveys of ATC safety experts. And then the paper presents the results of an experiment conducted on 52 air traffic controllers sampled from the Korean ATC organization, to find out if there is a relationship between traffic volume and air traffic controller human error. It should also be noted that we used an ATC simulator invented by the Korean Government for this experiment.

2. ATC Human Error and Air Traffic Volume

It is known that a lot of aircraft accidents are caused both directly and indirectly by human factors. Considering that human factor involves all aeronautical personnel who are related to aircraft operations, it is critical to do an in-depth research on the human factors of pilots and air traffic controllers who take the most crucial roles in aircraft operations. As for pilots, there are various studies and solutions that deal with issues such as the Cockpit Resource Management (CRM) and incorporation of a human resource management system into the Line Oriented Flight Training (LOFT). However, researches on the ATC human factor have been relatively inactive.

According to the Boeing Company, it turned out that of the commercial aircraft accidents for the past 10 years, 55% were caused by pilot error, 17% by aircraft defect, 13% by weather condition, 5% by airport and ATC, 3% by maintenance and 7% by miscellaneous matters [2]. Although ATC accounted for only 5% of commercial aircraft accidents, which is comparatively lower than other factors, it should not be overlooked that the 55% portion for which pilot error accounts, either directly or indirectly involves ATC because the cooperation between a pilot and an air traffic controller composes a significant part of aircraft operation.

Inspired by the current CRM program originally designed for the airline cockpit crew, EUROCONTROL has developed Team Resources Management (TRM) in order to research human factors in air traffic controllers [3]. FAA has also created a new area called "ATC-CRM" for the study of controllers' errors [4].

The definition of air traffic volume used for ATC purposes is the maximum number of aircraft entering a sector in a given length of time. It is generally accepted that heavy traffic volume may present an excessively heavy workload to ATC personnel [5] and may thus result in a higher probability of error [6]. So, it is also necessary to examine workload increase according to traffic volume increase. US Federal Aviation Administration (FAA) has reported that supplementary manpower in ATC is not provided in a timely manner, which consequently causes a heavy workload and finally leads to more accidents [7]. The ATC workload standard of EUROCONTROL is as described in the following table [8].

As ATC control sectors become more complicating because of the increase in air traffic volume worldwide, there have been efforts to rearrange sector structures and introduce more enhanced and automated ATC systems all around the world. However, due to the increase of information as well as air traffic volume, air traffic controllers are exposed to problems and situations that they have never experienced before, consequently increasing workload which is the cause of human errors [9]. The following two accidents are example cases of air collision in which human errors occurred directly or indirectly because of heavy workload due to high air traffic volume, and lack of ATC facility and manpower.

Table 1. Sector hourly capacity.

Threshold (%)	Interpretation	Recorded Working time during 1 hour
70 or above	Overload	42 minutes and more
54 - 69	Heavy Load	32 - 41 min
30 - 53	Medium Load	18 - 31 min
18 - 29	Light Load	11 - 17 min
0 - 17	Very Light Load	0 - 10 min

Source: EUROCONTROL, Pessimistic Sector Capacity Estimation, 2003.

Table 2. Major airplane accidents related to ATC human factor.

Date	Aircraft and accident outline	Major cause
1956.6	In the airspace over Grand Canyon, the U.S, DC-7 aircraft of UAL and L-1049 aircraft of TWA (both flying under IFR) had a mid-air collision at 20,000 feet, causing death of all 128 passengers.	Air traffic congestion Shortage of controlling facility Shortage of ATC manpower Insufficient delivery of Traffic information
2002.7	While controlled by the ACC of Zurich, Switzerland, TU-154 aircraft of Russian Bashkirian Airlines and B757 cargo aircraft of the U.S. DHL were flying on a collision course at the same altitude (FL360). Both airplanes descended to avoid each other, then the Bashkirian aircraft collided at a right angle with the Boeing cargo aircraft at FL354, killing all 71 passengers.	ATC instruction error RADAR malfunction (Short Term Conflict Alert) Route congestion Shortage of ATC manpower

3. Structure of ATC Error Elements

Based on a literature review [10], and interviews and surveys of ATC safety experts, the study categorized the ATC error into three categories; communication error, procedure error, and instruction error. The definition of each error category is as follows:

• **Communication error** refers to errors during radio communication. Communication error in ATC is divided into the two categories of errors that occur between a pilot and an air traffic controller, and the errors that occur between air traffic controllers. For instance, there are errors such as not challenging incorrect readback, using wrong call-signs, using non-standard phraseology, and missing and clipping the call sign.

• **Procedure error** involves incompliance with ATC procedures; for instance, failure to respond to an unanswered call, not responding to alarm, not identifying aircraft, failure to terminate radar services, not issuing approach clearance, not giving reasons for vectoring information, failure to deliver information to aircraft, etc.

• **Instruction error** occurs while conducting control procedures and communications. Specifically, there are errors such as delivery of incorrect information, issuing descent instruction late, issuing flight phase change instruction late, direction instruction error, clearance instruction error, etc.

This research also tried to define major error elements, which are components of each ATC human error cate gory, by the analysis of the data on ATC error items. These data are obtained from the interviews and surveys

Table 3. Structure of ATC human error elements.

Category	Explanation	Elements	Operational definition
Communication error	Difficulties in communicative interaction or aeronautical operations	C1	Incorrect Readback Not challenged
		C2	Wrong callsign Used
		C3	Non-standard Phraseology
		C4	Missed call
		C5	Callsign Omission/Truncation
		C6	Clipped call
Procedure error	Errors such as difficulties in following checklists	P1	Failure to respond to unanswered call
		P2	No/late response to alarm
		P3	No level verification
		P4	No Identification of aircraft
		P5	Radar service not terminated
		P6	Late/No Issuance of landing clearance
		P7	Reasons for Vectoring not Given
Instruction error	Errors such as giving incorrect instructions	I1	Incorrect information passed to aircraft
		I2	Late descent
		I3	Late change
		I4	Altitude Instruction Error
		I5	Heading Instruction Error
		I6	Clearance Instruction Error

of profoundly experienced ATC practitioners who participated to provide their opinions on ATC human error elements. Finally, we constructed a structure of error elements as shown in the following table.

4. Empirical Analysis on Level of Influence on ATC Human Errors according to Air Traffic Volume

4.1. Preparation for Experiment

This study conducted experiments on ATC duty performance and human error during duty with sampled air traffic controllers utilizing simulated approach control lab. The ATC task is generally divided into 4 major parts: area control, approach control, aerodrome control and ramp control. According to the Korean Government's data (2008), there are about 300 air traffic controllers who perform this duty. The sample group for this research was air traffic controllers who are currently or were previously in charge of ATC aerodrome control and approach control at international airports in Korea. The characteristics of this 52 sample group are as described in the following table.

Table 4. Demographic distribution of sample group.

Category	Category	Number of sample	Percentage (%)
Gender	male	46	88.5
	female	6	11.5
Age	In 20s	15	28.8
	In 30s	34	65.4
	In 40s	3	5.8
Duty	ATC	33	36.5
	Non-ATC	19	63.5
Work experience	5 years or less	12	23.1
	6 - 10 years	22	42.3
	11 - 20 years	16	30.8
	21 years and more	2	3.8

The ATC simulation equipment utilized for this research is a kind of training device for air traffic controllers, developed by the Ministry of Land Transportation and Maritime (MLTM) of Korea in 2007. This device can simulate various flight situations that may occur during air traffic control duty. It has basic functions that give various control instructions related to flight maneuver such as climb, cruise, descent, and speed control of an airplane. It enables trainees to experience situations close to ones that occur during the actual duty of ATC by simulating situations and conditions such as the approach course diagram, initial take-off direction, instrument landing approach path, various weather conditions, etc.

4.2. Conducting the Experiment

In order to carry out the experiment, the above mentioned ATC simulator was installed and the training program was adjusted so that it could produce the data appropriate for the purpose of this research. There were 3 computers, 4 monitors, 5 radio communication devices and 2 speakers provided for the participant group consisting of 1 air traffic controller and 3 pilots. The seats for the pilots and controller is separated by more than 5 meters with a partition, so that verbal communication between the air traffic controller and pilot can be conducted in a situation similar to that of the actual radio communication between pilots and the controller.

The spatial background of the experimental scenario is the terminal management areas of two large international airports in Korea, Jeju International Airport and Gimhae International Airport. We conducted the experiment twice spending four months in total. The first period of experiment was from January 15, 2009 to March 15, 2009,

Table 5. Definition of traffic volume level.

	Level of Traffic Volume	Number of Aircraft Controlled during 15 minutes
Experiment 1	V1	10
	V2	20
	V3	30
Experiment 2	L1	2.5
	L2	5
	L3	7.5
	L4	10
	L5	12.5
	L6	15
	L7	17.5
	L8	20
	L9	22.5
	L10	25
	L11	27.5
	L12	30

and the second one was from July 1, 2009 to August 31, 2009. Each sampled air traffic controller was asked to perform air traffic control duty for 15 minutes with varied levels of air traffic volume. They were required to try out transfer of control, issuance of traffic information, and aircraft separation. In the first period there were three levels of traffic volume, designated as V1, V2 and V3. The second period experimented with twelve levels of traffic volume, designated as L1, L2, L3, L4, L5, L6, L7, L8, L9, L10, L11 and L12 (refer to **Table 5**). This volume spectrum is defined to accommodate the entire range of possible situations, from a very low level to an extremely high level of traffic volume. As one can see at **Table 5**, the level of traffic volume is defined by the number of aircraft controlled by each sampled controller during the 15 minute experimental session. The number of errors made by each sampled controller was counted utilizing the records of ATC duty during his/her experimental session.

4.3. Analyses

This study established four hypotheses, in order to discuss the relationship between air traffic volume and frequency of error occurrence:

Hypothesis 1: Overall ATC Error will increase as air traffic volume increases.

Hypothesis 2: Communication error will increase as air traffic volume increases.

Hypothesis 3: Procedure error will increase as air traffic volume increases.

Hypothesis 4: Instruction error will increase as air traffic volume increases

4.3.1. Test of Hypothesis 1

The error data obtained in the second period of the experiment was used to test hypothesis 1. The level of in-

Table 6. Frequency of error by the level of air traffic volume.

Level of Air traffic volume	Average Frequency of error	Level of Air traffic volume	Frequency of error
L1	1.370	L7	3.370
L2	1.550	L8	3.553
L3	1.962	L9	3.970
L4	2.350	L10	4.904
L5	2.765	L11	5.701
L6	3.178	L12	6.304

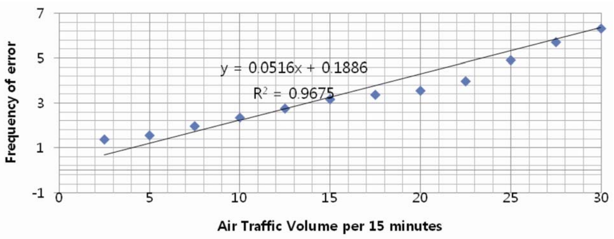

Figure 1. Regression result; frequency of error and level air traffic volume.

fluence that traffic volume has on frequency of error occurrence is presented in **Table 6**. First, we performed a correlation analysis to see the level of correlation between the two variables, traffic volume and frequency of ATC human errors. The result showed that 0.984 ($p < 0.01$) was the correlation coefficient. So, it can be said that there is very strong relationship between the level of air traffic volume and the error frequency of the air traffic controller. And we also performed a simple regression analysis utilizing traffic volume as the independent variable "x", and frequency of error as the dependent variable, "y". The result of the regression analysis was "$y = 0.0516\,x + 0.1886$" with an R^2 value of 0.9675, which also indicates high significance.

Although the overall equation shows a linear regression curve, there are some areas where one can detect unproportionally higher marginal increase in frequency of error. As you can see in **Figure 1**, the marginal increase in error frequency from the volume level 22.5 to 27.5 is higher than in other areas.

Table 7 shows the marginal increase in error frequency at each level of traffic volume. The value in the third column and sixth column of **Table 7** is calculated utilizing the following equations;

$$\Delta y = y_{i+1} - y_i$$

y_{i+1} = frequency of error at x_{i+1} traffic volume
y_i = frequency of error x_i traffic volume
where, x_i = traffic volume (number of aircraft controlled per unit time),

$$y_i = \text{frequency of error occurrence}$$

Referring to **Table 7**, it can be said that the marginal

Table 7. Marginal increase in frequency of error by air traffic volume.

Traffic volume (x_i)	Frequency of error (y_i)	marginal increase in frequency (Δy)	Traffic volume (x_i)	Frequency of error (y_i)	marginal increase in frequency (Δy)
2.5 a/c	1.370	0	17.5	3.370	0.200
5	1.550	0.180	20	3.553	0.183
7.5	1.962	0.412	22.5	3.970	0.427
10	2.350	0.388	25	4.904	0.934
12.5	2.765	0.215	27.5	5.701	0.797
15	3.178	0.418	30	6.304	0.603

Table 8. Error frequency by the level of air traffic volume.

Air traffic volume (V^*)	Error Type	Minimum frequency	Maximum frequency	Average frequency	Standard deviation
V1	Communication error	0	4	1.75	1.26
V2		1	5	2.73	1.19
V3		0	6	3.28	1.97
V1	Procedure error	0	5	1.51	1.05
V2		1	8	3.23	1.72
V3		1	10	5.00	2.24
V1	Instruction error	0	2	0.42	0.72
V2		0	5	1.59	1.53
V3		0	6	2.34	1.78

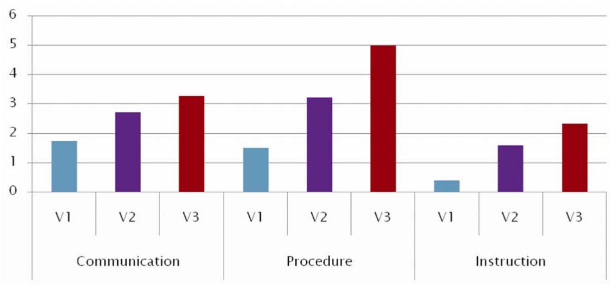

Figure 2. Air traffic volume and frequency of error.

increase in error frequency is highest at the level of traffic volume between 22.5 to 25.

4.3.2. Test of Hypotheses 2, 3 and 4

Hypotheses 2, 3, and 4 were tested with the data obtained in the first period of the experiment. Those hypotheses focus on error frequency variation of each error category, such as communication error, procedure error and instruction error, depending on the level of traffic volume. **Table 8** and **Figure 2** shows the distribution of average error frequency for each category of ATC human error. Each of the hypotheses was tested separately through ANOVA (Analysis of Variance) to see if the average error frequency of each category was significantly affected by the level of traffic volume. It was confirmed that all three hypotheses were accepted with the significance level of 0.05. This means that the error frequency of each category of ATC human error is influenced by air traffic volume in a statistically significant manner.

Table 9. Frequency of each element of communication error by level of air traffic volume.

Level of Air Traffic Volume	Communication error (C)					
	C1	C2	C3	C4	C5	C6
V1	0.08	0.08	0.33	0.35	0.27	0.65
V2	0.23	0.15	0.35	0.54	0.52	0.94
V3	0.35	0.15	0.44	0.42	0.58	1.35

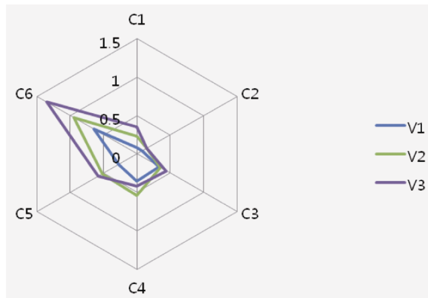

Figure 3. Frequency of communication error by air traffic volume.

Table 10. Frequency of each element of procedure error by level of air traffic volume.

Level of Air Traffic Volume	Procedure error (P)							
	P1	P2	P3	P4	P5	P6	P7	P8
V1	0.00	0.13	0.00	0.22	0.13	0.09	0.17	0.78
V2	0.91	0.91	0.04	0.43	0.00	0.17	0.17	1.39
V3	1.22	1.22	0.09	0.65	0.39	0.35	0.39	1.78

Table 9 is the distribution of error frequency for each element in the communication error category. **Figure 3** presents this information as a diagram. **Table 10** is the distribution of error frequency for each element in the procedure error category. **Figure 4** shows this in the form of a diagram. **Table 11** is the distribution of error frequency for each of the 6 elements in the instruction error category. **Figure 5** shows this information in the form of a diagram.

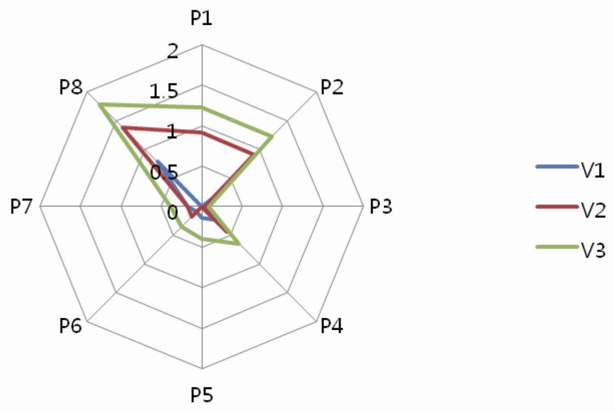

Figure 4. Frequency of procedure error by air traffic volume.

Table 11. Frequency of each element of instruction error by level of air traffic volume.

Level of Air Traffic Volume	Instruction error (I)					
	I1	I2	I3	I4	I5	I6
V1	0.04	0.09	0.04	0.09	0.04	0.00
V2	0.13	0.35	0.48	0.26	0.09	0.04
V3	0.09	0.48	0.96	0.26	0.22	0.13

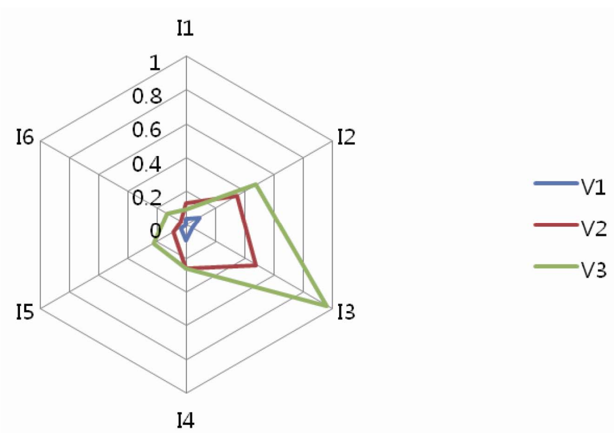

Figure 5. Frequency of instruction error by air traffic volume.

5. Conclusions

Despite the utilization of high-tech equipment, ATC is still mostly dependent on individual decision-making [11], which is always subject to probability of occurrences of human error. The main purpose of this research was to test a few hypotheses that claimed that the frequency of ATC human error will be influenced by the level of air traffic volume. The required data were gathered through experiments that utilized a sample of air traffic controllers who are currently working for the Korean ATC organization, and the ATC simulator.

We found there are significant relationships between ATC human error and the level of traffic volume. As the air traffic volume increases, the frequencies of error occurrence for most ATC human error elements defined by this study, were verified to increase. Especially, the increase of procedure errors was remarkably high compared to other error categories. The marginal increase in frequency of error from traffic volume 22.5 to 25 (number of aircraft) was revealed to be the highest. Therefore, it may be efficient to limit traffic volume to less than 22 aircraft per 15 minutes. However, it is necessary to consider differences that originate from factors such as air traffic control system of each air traffic control facility, sector conditions and flight procedures when determining the appropriate traffic volume.

It would be effective to assess the determined traffic volume on a regular basis, and to take corrective measures such as supplementing manpower, increasing controlling seats and enhancing air traffic control systems in case determined traffic volume is exceeded. We hope that the paper will make its contribution to aviation safety by providing a realistic basis for securing the proper amount of manpower and facility in accordance with the level of air traffic volume.

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