MODELLING THE ORAL COMMUNICATION PERFORMANCE OF AIR TRAFFIC CONTROL

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ABSTRACT

This study proposes a mechanism for measuring pilot-controller communication errors and develops a model to evaluate their communication performance. Empirical data based on 73 transcripts of communication from the Taipei Flight Information Region (FIR) are analyzed to validate the developed model and investigate communication issues. The results show that about 87% of all communication errors found in the transcripts had a relatively low level of influence on flight safety, while 13% had a severe influence. Additionally, the results of performance measurement indicate that the overall level of communication performance is relatively low. These findings are expected to be applicable to other countries whose native languages are not English. The performance model developed in this study can help management in the industry to evaluate radio communication performance of their aviation personnel.

Keywords: oral interaction, flight safety, air traffic control, communication errors, communication performance.

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1. INTRODUCTION

Efficient and appropriate communication between flight crews and Air Traffic Controllers (ATCs) is a major determinant of flight safety in the commercial aviation industry. Unfortunately, communication barriers do exist between pilots and ATCs, which can cause problems, even fatal aviation accidents. The Tenerife collision of two B-747 airplanes in 1977, the fuel starvation crash at the JFK airport in 1990, and the collision over India in 1996 are only a few examples that highlight defects with English communication among flight crews and ATCs. On the basis of a review of 340 accidents from January 1986 to September 1988 carried out by Morrison and Wright (1989), it was found that 42% of accidents can be attributed to communication errors. According to Rakas and Yang (2007), seventy percent of operational errors and pilot deviations were caused by communication problems. Recognizing the importance of language proficiency in pilot-controller communication, the International Civil Aviation Organization (ICAO) has set mandatory aviation English proficiency standards that are required of international pilots and ATCs. Additionally, Tsai (2009) reported that respondents believed familiarity with radiotelephony phraseology to be more important than English proficiency to ensure the accuracy and clarity of pilot-controller communication. The majority of subjects also indicate that training rather than testing is necessary to ensure the quality of pilot-controller communication, though in reality, the focus of aviation authorities and operators is more on testing than training.

In radiotelephony communication, there are more opportunities for communication with a pilot or controller who is a non-native speaker of English. While native speakers of English use different accents, non-native speakers use even more varieties of English. This raises questions concerning English limitations. Thus, radiotelephony phraseology plays a critical role in pilot-controller communication

(Tsai, 2009). To ensure safe, efficient, and coordinated movement of aircraft at international airports, pilots and ATCs have to improve both their English competence and radiotelephony phraseology.

Noble (2002) reviewed related research and concluded that assessing the language proficiency of nonnative English-speaking pilots in flight presents many challenges. He indicated that such proficiency cannot be measured directly and it can only be measured by observers in flight and is limited to reading the dials and instruments within the cockpit. Most research in the literature related to oral communication between pilots and ATCs focused on how communication context increased the workload of ATCs (eg. Galster et al., 2001; Metzger and Parasuraman, 2001; Wiersma and Mastenbroek, 1998). Recently, Skaltsas et al. (2013) made an effort to define communication errors and investigated factors that affect communication. The authors defined two types of communication errors: mishearing and not responding. They investigated a database of controller-pilot voice messages from high and super-high altitude en-route sectors of US airspace and concluded that the most important factors were length and context of the message, and radio frequency congestion.

On the basis of our literature review, quantitative models that measure the performance of oral communication with respect to communication errors are not available. Thus, the goal of the present research is to identify and categorize communication errors between pilots and ATCs from the prospective of radiotelephony phraseology, set up a mechanism to measure these communication errors, and finally develop a model to evaluate communication performance based on the number and severity of communication errors.

The concept for measuring communication errors and evaluating communication performance is discussed in the next section. The third section presents an empirical study with research findings and their implications on aviation safety. Finally, some discussions and conclusions are offered.

2. METHODOLOGY

2.1. Definition of Communication Errors

According to Shannon and Weaver (1949), communication includes a sender, a receiver, and some sources of disturbances. In the communication between pilots and air traffic controllers, either a pilot or a controller could be a sender or a receiver. The present study defines a communication error as a situation in which the information transferred between senders and receivers is influenced by some disturbances and results in a difference of understanding between both parties. It has been recognized that the disturbances result from four types of factors. Human factors are generally recognized as the main factor leading to communication errors. Other factors such as language barriers, environmental factors and communication technology also affect the efficiency and accuracy of communication between pilots and ATCs. Grayson and Billings (1981) and Monan (1998) made efforts to categorize the communication errors between pilots and controllers, including the contradiction between what one intends to say and the actual wording. This study, however, does not investigate the contradiction between a person's intention and his actual words and assumes a consistency between the speaker's intention and the spoken sentences. Only errors attributed to communication are investigated. Based on an in-depth literature review, twelve types of communication errors between pilots and controllers are defined, as listed in Table 1.

Table 1: The Definition of Error Types

	Error Type	Definition
T_1	Information not on time	The timing of information transfer is not right, making it not useful.
T_2	A controller forgets a delivered clearance	The controller forgets that he/she has already delivered a clearance in a communication.
T_3	Misunderstanding	Though the sender delivers a piece of information that is suitable, precise, and understandable, the receiver reads back correctly but misunderstands it.
T_4	Syntax error	The pattern, grammar, and vocabulary is imprecise and there exists a risk of misunderstanding.
T_5	Call-sign error	Omitting a call sign, or using an incorrect/unauthorized call sign.
T_6	Incorrect read back/listening	Some keywords are omitted or incorrect in reading back.
T_7	Incomplete clearance/information	The clearance or information delivered by a controller is incomplete, e.g., wind direction, QNH, flight information, direction, and altitude.
T_8	Incorrect reply	Pilots or controllers misunderstand the call sign and reply.
T_9	An incorrect call	A controller delivers a clearance to the wrong receiver, or the pilot calls the wrong control unit (probably using the incorrect frequency).
T_{10}	No reply	A party that has been called does not reply.
T_{11}	Incorrect phraseology	The sender uses incorrect phraseology.
T_{12}	Inefficient correction (repeated errors after being corrected)	The receiver finds an error in communication and tries to correct the sender, but the sender makes the same mistake in the next reply.

2.2. Mechanism for Measuring Communication Errors

A communication cycle i under investigation may make e_{ij} number of errors T_j, where j=1, 2,..., J. Here J is the number of error types defined by the researchers. J is equal to twelve in this study. Therefore the number of errors made during a communication cycle (i) between parties A and B ($E_{A\text{-}B,\ i}$) can be calculated as in equation (1).

$$E_{A\text{-}B,\ i} = e_{i1} + e_{i2} + \ldots\ldots + e_{i12} \qquad (1)$$

A communication cycle may include a few sentences between a sender and a receiver and both reach an agreement very quickly. The following fictional example of communication between AIR001 and Taipei Tower (TT) exemplifies how a pilot-controller communication cycle is formed. There is no error in this communication; therefore, $E_{AIR001\text{-}TT}$ is equal to zero.

AIR001: *Taipei tower, ready to taxi, AIR001.*

Tower: *AIR001, taxi to Runway 05 via Taxiway SS, SP, Taipei tower.*

AIR001: *Taxi to Runway 05 via Taxiway SS, SP, AIR001.*

In other cases, a communication may take a few minutes and barely reach an agreement. While errors may occur at any moment in an exchange between pilots and controllers, the severity of their potential consequences varies depending on their flight phase. A complete flight can be divided into nine phases: taxi, takeoff, initial climb, climb, cruise, descent, initial approach, final approach, and landing. Table 2 lists the possible communication contents in these flight phases. In practice, a communication cycle usually includes only one or a few communication contents. As shown above, the communication between AIR001 and Taipei Tower is comprised of contents H_1 and H_4.

Table 2: Possible Contents in a Communication Cycle

	Content
H_1	Pilots establish two-way communication with controllers
H_2	Request for clearance delivery
H_3	Request for startup/pushback
H_4	Taxiing instructions
H_5	Takeoff clearance
H_6	Change of flight headings, altitude, and speed
H_7	Holding instructions
H_8	Radar vector for approach
H_9	Landing clearance
H_{10}	Frequency change
H_{11}	Position confirmation
H_{12}	Traffic information
H_{13}	Declare an emergency

In order to take the severity of potential consequences into account, the relative influence of communication cycle i on flight safety can be quantified by S_i as calculated in equation (2). In equation (2), W_h is the relative influence of content h on flight safety and H is the number of types of possible contents in a communication. Here, H is 13; I_h is an index, with its value being equal to one if communication cycle i contains content h, zero otherwise.

$$S_i = I_1 W_1 + I_2 W_2 + \ldots + I_h W_h + \ldots + I_H W_H \qquad (2)$$

Thus, the number of errors made during a communication cycle (i) between parties A and B can be represented by $E_{A\text{-}B,\, i}$ as calculated in equation (1), or by a weighted vale of $WE_{A\text{-}B,\, i}$ to address the relative influence of communication cycle i. The value is defined as the product of S_i and $E_{A\text{-}B,\, i}$. If there are more than one communication cycles between a pilot (party A) and a controller (party B), the weighted communication error between A and B ($WE_{A\text{-}B}$) can be calculated using equation (3), where Y is the number of communication cycles between parties A and B.

$$WE_{A\text{-}B} = S_1 E_{A\text{-}B,\, 1} + S_2 E_{A\text{-}B,\, 2} + \ldots + S_y E_{A\text{-}B,\, y} + \ldots + S_Y E_{A\text{-}B,\, Y} \qquad (3)$$

2.3. Model of Evaluating Communication Performance

No model is currently available in the literature to measure pilot-controller communication performance. Hence, the goal of this study is intended to develop a model capable of evaluating communication performance between pilots and controllers. According to the definitions of communication error and performance, it is reasonable to assume that the performance of communication between parties A and B is a function of the number of communication errors made during the communication between both parties ($E_{A\text{-}B}$), as presented in equation (4). In equation (4), $P_{A\text{-}B}$ is an indicator that represents the performance of communication between parties A and B.

$$P_{A\text{-}B} = f\,(E_{A\text{-}B}). \qquad (4)$$

It is obvious that there exists an inverse relationship between $P_{A\text{-}B}$ and $E_{A\text{-}B}$. We employ the formulation of the gamma function with theta being equal to two and alpha equal to one, $\Gamma(\theta=2, \alpha=1)$, as a vehicle to evaluate the communication performance. The chosen gamma function has a desired property of concave up and decreasing slopes. The function of $P_{A\text{-}B}$ is formulated as follows:

$$P_{A\text{-}B} = f_u\,(E_{A\text{-}B}) = k_u \,/\, (k_u + E_{A\text{-}B}). \qquad (5)$$

In equation (5), subscript u indicates the authority of air traffic control under which the communication takes place. In general, u could be Ground, Tower, Approach, or Center. k_u indicates a parameter that represents the maximum number of communication errors that can be tolerated when a pilot-controller communication takes place under authority unit u. The model expressed in equation (5) has the following properties that are suitable for evaluating communication performance:

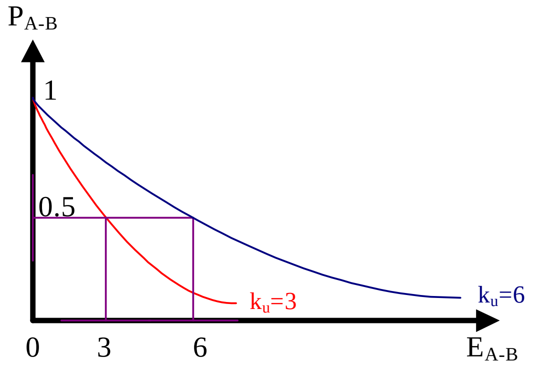
The maximum value of the performance indicator $P_{A\text{-}B}$ is one, indicating the best performance meaning no errors made in a communication cycle. The worst performance occurs when $P_{A\text{-}B}$ is close to zero and $E_{A\text{-}B}$ is a relatively large number compared to k_u.

When $E_{A\text{-}B}$ is equal to k_u, the maximum tolerable number of communication errors, $P_{A\text{-}B}$ is equal to 0.5, which can be considered as a minimum acceptable performance level.

As illustrated in Figure 1, the relationship between $P_{A\text{-}B}$ and $E_{A\text{-}B}$ is nonlinear, with a steeper slope near the point of best performance and a flatter slope where the value of $E_{A\text{-}B}$ becomes substantially large. This phenomenon indicates a decrease in the marginal effect of the number of communication errors with respect to the performance indicator, a meaningful phenomenon in performance evaluation.

Figure 1 shows that a lesser value of k_u is associated with a steeper slope near the point of best performance. This indicates that in a communication with a lower tolerable level of error is harder to reach the best performance.

Figure 1: Relationship between the performance indicator and the number of communication errors



3. EMPIRICAL ANALYSIS

3.1. Data

The communication related data analyzed in this research are based on seventy-three transcripts of pilot-controller transmissions from 2002 to 2004. The transcripts were reproduced by the Civil Aeronautical Administration of Taiwan because of their involvement in some incidents or accidents. However, not all parties included in the transcripts are key players of the involved incidents/accidents. All transcripts were carefully analyzed by researchers with expertise in radiotelephony phraseology. The elapsed time for each transcript ranges from five to fifteen minutes. For reasons of confidentiality, most identification in each transcript was deleted.

Additionally, a panel of ten senior supervisors in various air traffic control authorities was surveyed to elicit their opinions on the level of influence of communication errors on flight safety and the maximum number of errors tolerable in each communication.

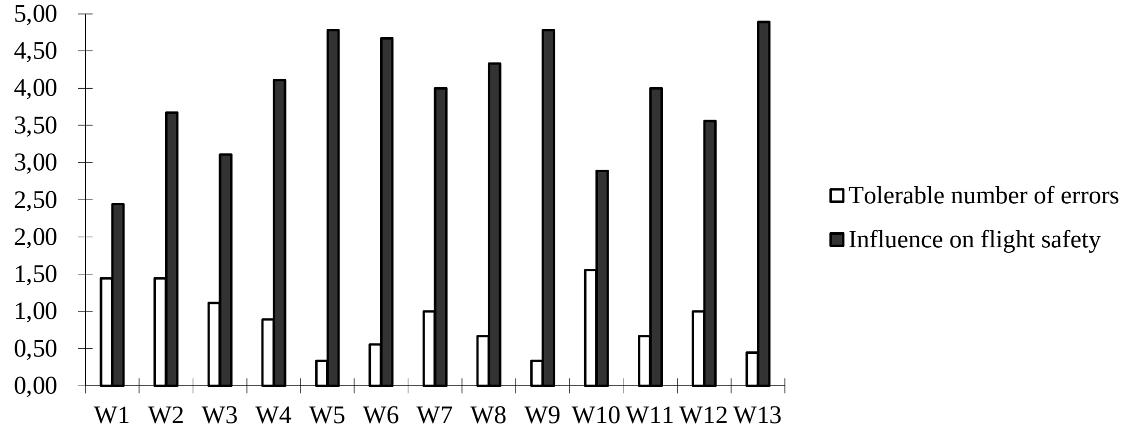
The subjects were asked to rate the level of severity of each type of communication content, on a scale from 1 (very *little*), 2 (*a little*), 3 (*neutral*), 4 (*severe*), to 5 (*very severe*). Nine out of the ten returned questionnaires were usable and included in the analysis presented in the next section.

3.2. Influence Levels and Maximum Tolerable Number of Errors in Various Communication Contents

Figure 2 illustrates the panel's opinions on the influence level and maximum tolerable number of errors in each category of the communication content. With respect to the influence level of communication contents, the average scores in the eight categories are greater than 4.0, the *severe* level, H_4 to H_9, H_{11}, and H_{13}. Communication contents related to aircraft maneuvers such as taxi, takeoff, and landing are generally included in these categories that would have *severe* to *very severe* influences on flight safety should communication errors be made. On the other hand, only two categories have average scores of less than 3.0, the *neutral* level, including communication establishment (H_1) and frequency change (H_{10}). The levels of influence of the remaining three categories (H_2, H_3, and H_{12}) are in-between.

The maximum tolerable number of errors in each content category has an inverse relationship with its associated influence level, as illustrated in Figure 2. For example, the three categories with the highest influence level (H_5, H_9, and H_{13}; 4.78, 4.78, and 4.89, respectively) have the least average tolerable number of errors, 0.33, 0.33, and 0.44, respectively. That is, in these three categories (takeoff, landing, and emergency) few errors can be tolerated.

Figure 2: Panel opinions on the influence level and maximum tolerable number of errors in each category of communication content

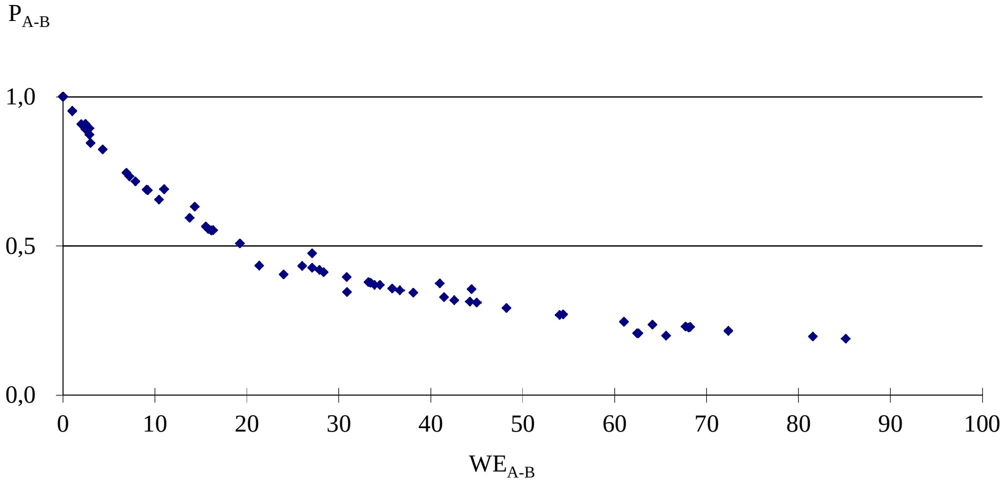


3.3. Measuring Communication Performance

All of the communication cycles in the 73 transcripts available to the authors were analyzed and the associated communication performance was calculated using the measuring model presented in equation (5). Communication cycles under the same transcript were combined and a performance indicator was calculated for each transcript. Figure 3 illustrates the distribution of the performance indicators. The mean value of the performance indicators is 0.55, which is slightly above the minimum acceptable performance level with $P_{A\text{-}B}$ being equal to 0.50. The result implies that the overall communication performance based on the seventy-three transcripts is barely acceptable. It should be noted that the transcripts investigated in this research were associated with some incidents or accidents.

There are nine transcripts with performance indicators equal to 1.0, the best performance according to the developed model, which account for 12.3% of the sample. Additionally, 26 performance indicators (35.6%) fall into the interval between 0.50 and 0.99. The performance demonstrated that 38 of the transcripts falls under the minimum acceptable level, which is equivalent to 52.1% of the sample, another indication of the relatively low performance levels found overall.

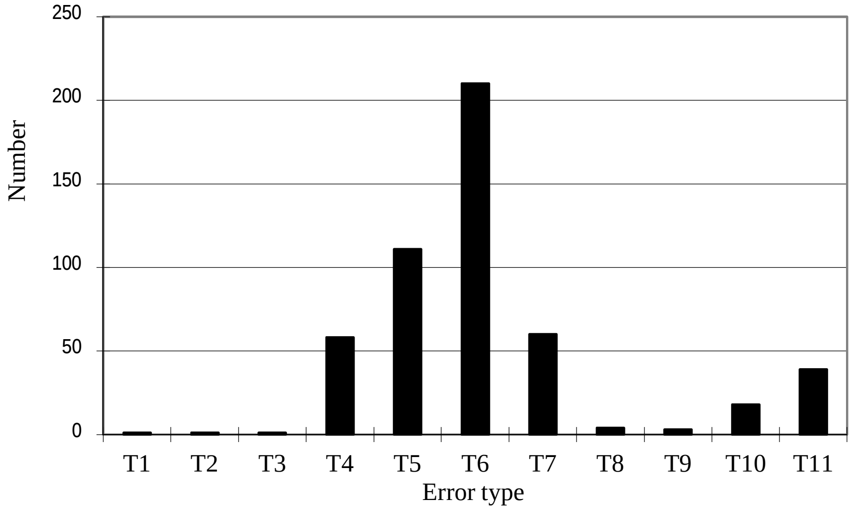
Figure 3: Distribution of performance indicators with respect to weighted number of errors across seventy-three studied transcripts



3.4. Distribution of Error Types

Figure 4 illustrates the distribution of the number of communication errors made in each error type. Among the 506 communication errors in the 73 transcripts under investigation, 210 (41.50%) of them can be categorized as type 6, incorrect read back/listening. Type 5, call-sign error, accounts for 21.34% (111) of the total error, which is followed by types 7 (incomplete clearance/information) and 4 (syntax error), with the numbers of errors being 60 (11.86%) and 58 (11.46%), respectively. According to the aviation experts surveyed in this research, the severity level of these four types of errors and type 1 (information not on time) can be considered relatively low. There are 440 (86.96%) errors in these five types. Errors categorized in other seven types (2, 3, 8, 9, 10, 11, and 12) are considered more severe, compared with the other five types. There is no error in type 12 and this number is not shown in Figure 4. Among the 66 errors with a relatively high level of severity, 39 (7.71%) can be categorized into type 11, incorrect phraseology, and 18 (3.56%) into type 10, no reply. Other types with severe influences contain only few errors.

Figure 4: Number of communication errors made in each error type



4. DISCUSSION AND CONCLUSION

Efficient and appropriate communication between pilots and controllers is a major determinant of flight safety. While communication barriers do exist, little has been done to quantitatively measure communication performance between these two major players in the aviation industry. The only available research in the literature that measures pilot-controller communication errors defines two types of communication errors: mishearing and not responding (Skaltsas et al., 2013). The present research identifies 13 types of communication contents and 12 types of communication errors between pilots and controllers from the prospective of radiotelephony phraseology. It also sets up a mechanism to measure the communication errors and develops a model to evaluate the communication performance that considers both the number of errors and the severity of the communication contents. Empirical data from 73 transcripts of pilot-controller transmissions are used to validate the proposed measuring model.

The proposed model for communication performance measurement is useful for several parties. Firstly, such a performance index includes information of the number of errors and the severity of communication contents, and may allow ATC authorities to better evaluate the overall communication performance, which provides a bigger picture than counting of individual errors. Secondly, if the identity of the aircraft and ATCs included in the transcript can be released, the proposed model can be used to evaluate the communication performance with respect to any available segmentation, such as nationality, title, age, gender. This information is expected to be very useful for pilots and ATCs training.

Additionally, communication errors related to aircraft maneuvers are considered to have *severe* to *very severe* influences on flight safety and few errors can be tolerated in these contents. The empirical study conducted in this research indicates that 87% of the total communication errors under investigation can be included in the categories with a relative low level of influence on flight safety, while 13% have severe influence. Finally, the results of performance measurement indicate that level of communication performance in the examples under investigation is relatively low. Hence, measures to further improve pilot-controller communication are necessary to ensure flight safety.

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REFERENCES

- Clifford E. Noble II (2002) *Predicting the language proficiency of Chinese student pilots within American airspace: single-task versus dual-task English-language assessment*, Dissertation, United States International University, San Diego, California, US.

- Galster, S.M., Duley, J.A., Masalonis, A.J., and Parasuraman, R. (2001) ‘Air traffic controller performance and workload under mature free flight: conflict detection and resolution of aircraft self-separation’, *The International Journal of Aviation Psychology*, 11(1), 71–93.
- Grayson, R.L. and Billings, C.E. (1981) ‘Information transfer between air traffic control and aircraft: Communication problems in flight operations’*, Information Transfer Problems in the Aviation System. NASA Technical Paper* 1875, 47-62.
- Metzger, U. and Parasuraman, R. (2001) ‘The role of the air traffic controller in future air traffic management: An empirical study of active control versus passive monitoring’, *Human Factors*, 43(4), 519-528.
- Monan, C. (1988) *Human factor in aviation operations: The hearback problem*, Report No. 177398, NASA Contractor.
- Morrison, R. and Wright, R.H. (1989) ATC Control and Communication Problems: An Overview of Recent ASRS Data. In R. S. Jensen (ed*), Proceedings of the Fifth International Symposium on Aviation Psychology*, 901-907, Columbus, The Ohio State University.
- Rakas, J., Yang, S. (2007) Analysis of multiple open message transactions and controller-pilot miscommunications. *Seventh FAA/EUROCONTROL Seminar on ATM Research and Development,* Barcelona.
- Shannon, C. and Weaver, W. (1949) *The mathematical theory of communication,* The University of Illinois Press, Urbana, USA.
- Skaltsas, G., Rakas, J., and Karlaftis, M.G. (2013) ‘An analysis of air traffic controller-pilot miscommunication in the NextGen environment’, *Journal of Air Transport Management* 27, 46-51.
- Tsai, W.L. (2009) ‘The role of language in radiotelephony communication: The perspective from pilots and controllers*. English Education and English for Specific*

Purposes, The Crane Publishing Co., London.

- Wiersma, E. and Mastenbroek, N. (1998) ‘Measurement of vessel traffic services operator performance’, *AI & Society* 12, 78-86.