ANALYSIS OF MULTIPLE OPEN MESSAGE TRANSACTIONS AND CONTROLLER-PILOT MISCOMMUNICATIONS

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Abstract

This study addresses an important and common problem to both voice-based and data link systems: multiple open message transactions and delayed responses in controller-pilot communications. The analyzed database includes 42 thirty-minute controller-pilot voice-recording samples, derived from 33 sectors, positioned in five Air Route Traffic Control Centers (ARTCCs). The database is used in modeling four Logit and Probit regression models.

Study findings indicate that increased multiple open message transactions cause miscommunications and delayed responses by controllers. Because the message transfer time in a data link environment appears to be longer than in the voice-based environment, any further delays in message transactions with data link should be avoided because such transaction delays could make the data link system less efficient and productive.

Introduction

Successful transformation of the National Airspace System (NAS) into the Next Generation Air Transportation System (NextGen) will depend significantly on the successful implementation of the Data Communications and automation enhancements. In the current Air Traffic Control (ATC) environment, traditional UHF and VHF radios are still the primary means of communication between controllers and pilots. The existing voice-based ATC concept is highly workload intensive, with a relatively short-term management focus. As the traffic demand continues to grow, the existing means of communications are becoming even more challenged in supporting the required level of safety, reliability, controller productivity, airspace capacity and efficiency. When miscommunications occur in such environments, air traffic controllers, in particular, experience additional stress, annoyance and workload, and are prone to make operational errors. This may cause route inefficiencies, reduce sector capacity and compromise safety. To improve some deficiencies of the current system, it is proposed that the Data Communications concept gradually become implemented in three segments, starting in 2012 and reaching NextGen final operating capacity in 2027. The Data Communications concept in support of NextGen will be implemented in the terminal, tower and en route areas, with each segment gradually supplementing certain ATC functions and voice-based instructions with the new Data Communications functions [1].

With the introduction of the advanced Data Communications, miscommunication messages among controllers and pilots will be reduced because all repetitive tasks will be automated and voice-communication messages will be replaced with data links. Consequently, radio-communication problems such as poor quality, high susceptibility to interference and high risk of blocked or stepped on transmissions will not exist. Although the controllers' and pilots' voice communications-related workload will be reduced in the NextGen/Data Communications environment, the estimation of distribution workload and its change from aural modality to visual modality is still being explored [2]. While the benefits of new technology and concepts might appear to be straightforward in resolving problems of radio-frequency congestion and poor message quality, one important issue, universal to both voice-based and data link environments, is the occurrence of multiple open message transactions and their impact on controller-pilot miscommunications.

Previous studies on miscommunication messages focus mainly on two problem areas: (i) analyses of the most common miscommunication message types [3],[4],[5] and (ii) impact of miscommunication messages on traffic safety [6], [7], [8]. While the previous literature offers a wealth of information on issues such as operational errors, miscommunication message categories, and message characteristics, it seems that limited attention has been given to the analysis of delayed responses and misheard messages in the context of multiple open message transactions.

When controllers or pilots send messages, they expect a quick response. However, it is quite common for controllers to wait for pilots' responses much longer than they anticipate. In such situations, especially in busy sectors, a controller usually initiates correspondence with a second or a third aircraft, while waiting for the delayed response from the first pilot, thus, maintaining several open message transactions at the same time.

It is widely acknowledged that the transfer times for data link are significantly longer than for voice-based communications [9],[10] because of delays in message transfers and the time it takes a pilot/controller to read and respond to each message. In the current system, delayed messages (i.e., no timely responses) are generally regarded as miscommunication problems, which could cause safety concerns and increase controller/pilot workload. Only recently, a metric known as cognitive utilization has been developed, which captures the duration of message transactions rather then the number of individual voice-messages [11]. The objective of this metric is to more precisely capture controller/pilot mental load, and to take into consideration two situations: (i) one transaction could include several sequential messages in order to complete a task, and (ii) a controller could maintain several open transactions at the same time.

Since the message transfer time in a data link environment appears to be longer than in the voice-based environment, any further delays in message transactions with data link would make the data link system less efficient and productive. Hence, it would be imperative to explore further the issues of multiple open message transactions in the current system and to investigate their impacts on message delays in particular. The results of such analyses would be useful to the data link concept in avoiding further message transaction delays. As depicted in Figure 1, the proposed analysis includes exploration of the factors that drive miscommunications (in general) and their usefulness to the data link concept.

To better understand current miscommunication issues and improve the gradual transition into the Data Communications environment, this research undertakes a thorough analysis of underlying miscommunication messages that occur in the voice-based ATC environment, and explores parameters that can be easily utilized and transposed into the Data Link environment.

The importance of this work is reflected in its timelines and relevance to the implementation of Data Communications to Segment I, II and III in the en route environment as it explores the impact of multiple open message transactions on two distinguished types of voice-communication problems: delayed responses and misheard messages.

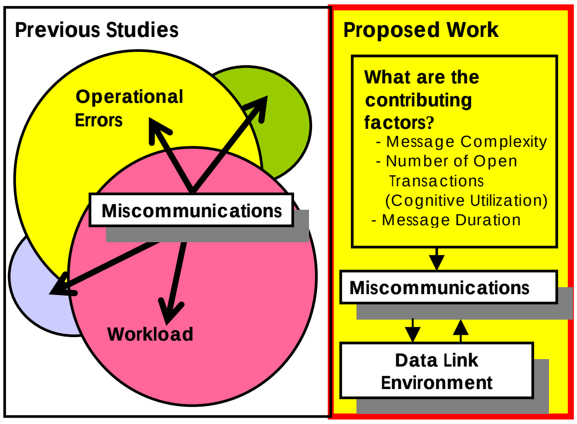

Figure 1. Study Area and Concerns

Methodology

Proposed methodology includes the following steps: (1) determining miscommunication messages, (2) general understanding of types and origins of miscommunication messages, (3) metrics and parameter formulation, and (4) regression model construction.

In the first step, the existing database of controller–pilot communication messages is re-examined and miscommunication messages are determined, based on the careful tracing of all underlying miscommunications. Special attention is paid to callback and read-back messages, while backtracking of all related messages is done to determine the origin of each callback and read-back message. Thus, all messages that appear to be correct, but have led to some type of miscommunication, are also considered as miscommunication messages.

Database and the Study Area

This study analyzes a database based on tape recordings provided by MITRE and the Federal Aviation Administration (FAA) Technical Center. The database includes 42 thirty-minute controller-pilot voice-recording samples, which represent sectors of different flight levels (FL), diverse physical sizes, complexity and traffic demands. Selected sectors include super high sectors (FL 330 and above) and high altitude sectors (FL 240 — 310). The samples are derived from 33 sectors positioned in five Air Route Traffic Control Centers (ARTCCs): Indianapolis (ZID), Memphis (ZME), Denver (ZDV), Dallas-Ft. Worth (ZFW) and Atlanta (ZTL). As an illustration, Table 1 and 2 display only a selected number of sectors for only two ARTCCs (Memphis and Indianapolis).

Table 1. Memphis ZME Center

Sector		Time Interval (ZULU)	Sector Size
Name	Altitude		
19	SH	19:15 – 19:45	large
24	SH	20:30 – 21:00	large
32	SH	19:45 – 20:15	large
61	SH	21:00 – 21:30	large
22	H	22:00 – 22:30	large
22	H	19:45 – 21:15	large
25	H	20:00 – 20:30	large
26	H	20:15 – 20:45	large
30	H	22:00 – 22:30	med/large
63	H	20:00 – 20:30	medium
62	H	21:00 – 21:30	med/large
62	H	19:45 – 20:15	med/large

Table 2. Indianapolis ZID Center

Sector		Time Interval (ZULU)	Sector Size
Name	Altitude		
92	SH	19:15 – 19:45	med/large
92	SH	21:45 – 22:15	med/large
95	SH	18:45 – 19:15	large
96	SH	20:30 – 21:00	medium
98	SH	22:30 – 23:00	med/large
80	H	18:45 – 19:15	small
83	H	21:15 – 21:45	medium
84	H	21:00 – 21:30	med/large
85	H	20:30 - 21:00	large
87	H	19:30 – 20:00	med/small
89	H	18:45 – 19:15	small

The most relevant fields of the database are presented in Table 3. The transcribed messages are categorized by *message type*, *complexity*, number of *open transactions*, etc. *Message types* are defined separately for pilots and controllers, and are used in the study to better understand the dynamics of controller-pilot communications, to reconstruct traffic scenarios, and to identify message complexity [12], [6], [13]. Message *complexity* is based on [6], [13] with the objective to find a number of separate elements contained in one message transmission. An element is defined as a set of words/digits that indicates a new piece of information (heading, flight level, frequency, etc). Aircraft ID, as a piece of information, is not considered a separate element but is always combined with the next piece of information. For the purpose of this study, each element has the same weight and does not take into consideration the length, number of digits or complexity of its content. The expansion and revision of the complexity formulation will be considered in the future work.

Table 3. Description of Data Fields

Field Name	Description
sector	Sector Name
corp	pilot (p) or controller (c) speaking
acid	aircraft id ("official")
text	message text
message type	message type
open transaction	(c) one transaction, (cc) double open transaction, (ccc) triple open transaction, etc, (b) interval between transactions
reasons	reasons for miscommunication and other mistakes (conclusions based on listening recorded pilot/controller communications)
complexity	number of elements in one message
tt	time each message (transaction) starts (in seconds)
arrival	(1) if an aircraft arrives into a sector, (0) for all other
departure	(1) if an aircraft departs form a sector, (0) for all other
number of a/c	number of aircraft in sector (based on the analysis of messages)
tmin	time each message/transaction begins (in minutes)
MAP	monitor alert parameter = maximum number of aircraft allowed in sector or declared value

Open transaction as a data field is also a part of a metric that captures the time an air traffic controller attempts to "think" about a particular aircraft upon entering the sector until a particular transaction is completed. It is assumed that each particular transaction can require a group of messages consecutively used to finish one complete message transaction. An illustration is the number of messages used to complete an initial call or altitude change for one aircraft. According to Ref. [11], this metric is based on the idea that 'during the time when a given communications transaction is open, the controller must continue to be aware of it,' and is defined as a "cognitive" metric. By definition, all time intervals during which at least one communication transaction remains open are summed up to represent a "cognitive utilization metric."

Other field names (i.e., variables) in the database depicted in Table 3 are self-explanatory.

Model Selection and Assumptions

In order to select an appropriate regression model for the analysis of multiple open transactions, all miscommunication messages were first classified according to the causes of miscommunication and their sources (controller or pilot). The initial results had indicated the following top reasons for miscommunications: (1) aircraft (AC) not responding, (2) controller not responding, (3) controller mishearing and (4) pilot mishearing.

Although the initial analysis results of miscommunication causes were quite consistent with the existing literature [14], they were briefly listed here because they were affecting the way the regression models were formulated in this study.

The analysis results revealed that in situations when a controller misheard a message, he most frequently didn't correctly hear the aircraft ID, some element of a message that related to a piece of information containing numbers, or he did not hear a message at all. Whenever a pilot misheard a message, it was most likely that he missed the radio frequency, missed an aircraft ID, or just didn't hear a message. In most cases, controllers and pilots had difficulties correctly "copying" numbers (i.e., digits) in various combinations (flight level, frequency, AC ID, etc), even if the quality of the radio reception was excellent.

One of the most interesting findings was the large number of delayed responses (i.e., no responses) from both pilots and controllers. As previously mentioned, pilots' delayed responses could cause a significant increase in stress and annoyance to controllers who, in turn, might use this delayed time to open new transactions with other aircraft and further increase their own cognitive load. Yet, from the initial message screening, it was not clear if the open transactions were further (i) affecting controllers' behavior and (ii) causing miscommunications. Thus, in exploring the causes of miscommunication messages, a natural step was to investigate the impact of open message transactions on delayed messages. Other problems were related to finding causes of misheard messages. Hence, four regression models were created to determine the factors that impacted miscommunication messages, and to specify what subject (controller or pilot) was more prone to make a specific type of miscommunication.

Model Construction

Since the objective of the research was to explore how miscommunication messages, as a dependent variable, were affected by sector traffic and communications characteristics (as independent variables), each message in the database was treated as a miscommunication message (Y=1) or successful communication message (Y=0) by creating a binary variable Y = {0,1}. Then, two regression models were created and explored, depending on the underlying assumption of the cumulative distribution function (CDF) for the dependent variable. The first regression model was Logit, with the standard logistic CDF for dependent variable; the second model was Probit, with the standard Normal CDF.

Logit model was defined as:

$$P\{Y=0\} = \Phi(\beta_0 + \vec{\beta}X') \qquad (1)$$

where

$Y =$ dummy dependent binary variable; a message is a miscommunication (i.e., $Y = 1$), or a successful communication (i.e., $Y = 0$)

$P\{Y=0\}$ = probability of a successful communication

$\Phi(.)$ = standard logistic (or standard Normal, for Probit model) cumulative distribution function (CDF)

β_0 = unknown intercept parameter in the linear model

$\vec{\beta}$ = unknown vector of coefficients to be multiplied by relevant explanatory variables

X = vector of explanatory variables

Because the core difference between Probit and Logit models was in the distribution of errors, another objective of the analysis was to compare the results of both models and explain the differences. By definition [15], Probit model had a thinner and higher peak as well as thinner tails (Figure 1) than the standard logistic probability distribution (Figure 2), and its PDF quickly approached zero on the left and one on the right. Consequently, the cumulative density function of the standard Normal distribution (Figure 3) had a higher gradient in the middle than the CDF of the standard logistic distribution (Figure 4). Since miscommunication messages belonged to rare events, we postulated that Logit model would be more appropriate in capturing rare events since Logit's thicker tail could better capture the presence of these rare events.

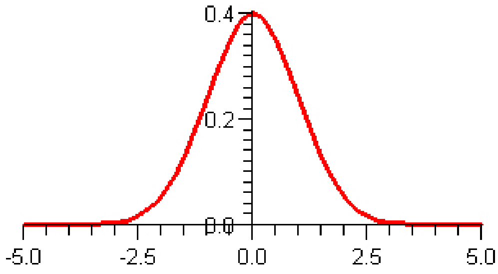

Figure 1. PDF of the Standard Normal Distribution [15]

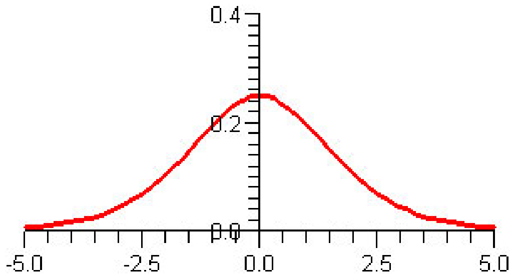

Figure 2. PDF of the Standard Logistic Distribution [15]

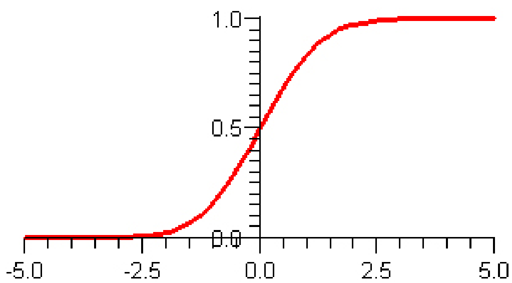

Figure 3. CDF of the Standard Normal Distribution [15]

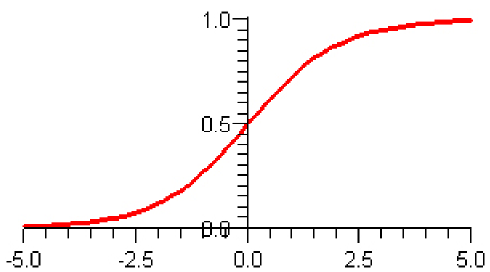

Figure 4. CDF of the Standard Logistic Distribution [15]

Then, the following initial independent explanatory variables were defined:

1. open transaction (or cognitive complexity):
   - (c, 1) = one transaction
   - (cc, 2) = double open transaction
   - (ccc, 3) = triple open transaction
   - (cccc, 4) = quadruple open transaction
2. complexity = number of elements in one message
3. interval = message duration (in seconds)
4. arrival = (1) if an aircraft arrives into a sector; (0) for all other
5. departure = (1) if an aircraft departs form a sector; (0) for all other
6. cumulative aircraft arrival
7. cumulative aircraft departure
8. number of a/c
9. monitor alert parameter (MAP)

Among the independent variables, *number of a/c* was calculated by subtracting *cumulative aircraft departures* from *cumulative aircraft arrivals*. Because *number of a/c* was derived from two *cumulative* variables, (i.e., its correlation factor was 1), only *number of a/c* was kept as an explanatory variable.

In the next step, a new variable was added to the list of independent variables, as a ratio between traffic volume (i.e., *number of a/c*) and capacity (i.e., *MAP*) in the form *V/C* (Volume/Capacity). Then, Logit and Probit models were used in the analysis of the four models described below.

The initial model, as depicted in Figure 1, was a linear combination of all proposed explanatory variables that provided the basic information about the impact of proposed explanatory variables on miscommunication messages (*Miscommunication* =1; *Non Miscommunication*=0). As the significance of explanatory variables was further tested, Model 1 was refined and divided into Models 1a (all variables), Model 1b (selected variables: *open transactions*, *complexity*, *interval*, *arrival*, *departure*, *number of a/c*, and *MAP*), and Model 1c (selected variables: *open transactions*, *complexity*, *interval* and *V/C*).

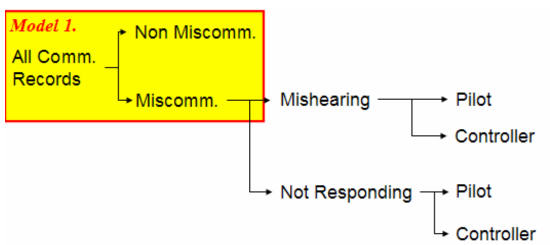

Figure 1. Model 1

Model 2 focused on two major types of miscommunication problems: *Mishearing* and *Not Responding*. The objective of this model was to determine the impacts of *open transactions*, message durations (*interval*) and *complexity* on problems of *Mishearing* and *Not Responding*. By determining such impacts further recommendations could be made to the development and deployment of the data link concept.

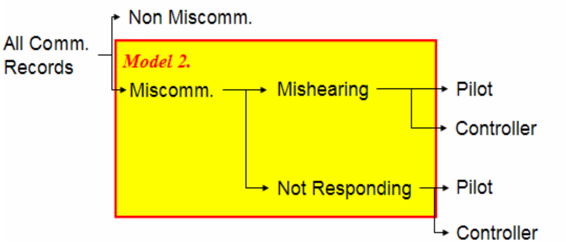

Figure 2. Model 2

Model 3 examined *Mishearing* cases for controllers and pilots. Precisely determining who was more prone to mishearing messages and under what conditions misheard messages occurred would be important in improving the distribution and the format of messages in the data link environment. If similar call signs or the presence of long numeric pieces of information was a *Mishearing* problem in a voice-based environment during multiple open transactions, translating such problems into a data link environment would be necessary. In addition, the impact of multiple open transactions on the problem of similar call signs, in terms of sonority of words, could be compared to the problem of (for example) overlooking a letter S and a number 5 in the data link environment.

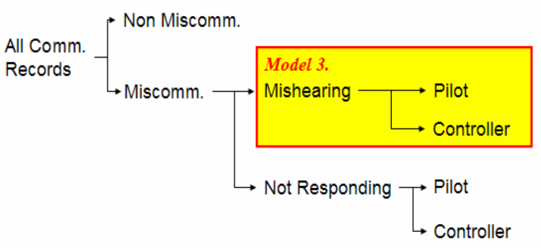

Figure 3. Model 3

Model 4 focused on the impact of sector traffic and communications characteristics on *Not Responding* cases and the miscommunications distribution between pilots and controllers. It was postulated that such information would be useful in the data link environment in determining the impact of open transactions, traffic volume and capacity on delayed responses.

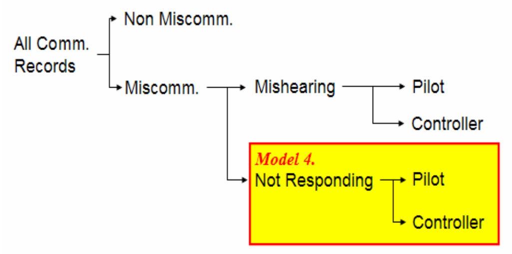

Figure 4. Model 4

Analysis Results

The results of all four models were summarized in Tables 1-2 (for Logit model) and Tables 3-4 (for Probit model). All significant variables were marked in bold.

Logit Model Analysis Results

In Table 1 we could see that all three models had a negative *intercept*, meaning that successful communications messages were more likely to occur, which was also intuitive. For example, in Model 1b, the number of *open transactions*, message duration (*interval*) and the *number of a/c* all had positive signs and were significant variables, indicating an impact of these variables on miscommunication messages. When the number of *open transactions* was high, it was more likely that a miscommunication would occur. This was somewhat consistent with findings in Ref. [11], where a very limited analysis of increased cognitive utilization (i.e., open transactions) was linked to a pilot's delayed response and to the opening of new transactions by the controller. We postulated that an increase in the number of open transactions affected the controllers' mental load (i.e., cognitive utilization), which, in turn, caused miscommunications. Another interesting result revealed that arriving aircraft (*arrival*) into the sector were more prone to miscommunications. This could be explained by the fact that aircraft entering a sector had to exchange a significant amount of numeric information, which were all critical and commonly miscommunicated pieces of a message. It was postulated that such problems would also occur in a data link environment.

Message duration (*interval*) was also a significant variable with a positive sign indicating that longer messages had an impact on miscommunications. This was consistent with our estimation of average message duration for miscommunication messages (3.46 seconds) vs. successful communications (2.94 seconds).

Table 1. Parameter Estimation with Logistic Distribution

Dependent Variable: Miscommunication Underlying Distribution: Logistic				
Explanatory Variable	**Parameter**	**Model 1 Estimates**		
		Model 1a	**1b**	**1c**
Intercept	β_0	***-4.2522***	***-4.1717***	***-4.0445***
	Significance at 0.05 level	(0.0000)	(0.0000)	(0.0000)
open transaction (1, 2, 3, 4)	β_t	***0.4384***	***0.4579***	***0.4960***
		(0.0002)	(0.0001)	(0.0000)
complexity	β_c	-0.0002	-0.0002	-0.0004
		(0.8087)	(0.8247)	(0.6762)
interval (min)	β_n	***0.1082***	***0.1085***	***0.1401***
		(0.0000)	(0.0000)	(0.0000)
arrival (0, 1)	β_a	***0.5648***	***0.5643***	
		(0.0000)	(0.0000)	
departure (0, 1)	β_d	-31.9719	-31.9596	
		(1.0000)	(1.0000)	
cumulative arrivals	β_{ca}	***0.0268***		
		(0.0272)		
cumulative departures	β_{cd}	-0.0180		
		(0.1950)		
number of A/C	β_{ac}		***0.0276***	
			(0.0230)	
MAP	β_m	-0.0003	-0.0003	
		(0.1816)	(0.1660)	
VC (Volume/Capacity)	β_{vc}			-0.0002
				(0.3208)
	Number of Observations (Y=1/Y=0)	368/7597		

The *complexity* variable was not significant, although intuitively we might think that the number of elements in one message could impact the occurrence of miscommunication messages.

The analysis of data indicated that 24 sector-cases had larger average complexity of successful communications in comparison with miscommunications (out of 42 sector-cases that were analyzed). After plotting average complexity values, as depicted in Figure 9, and performing visual inspection, we could see that there was no significant disparity between communication and miscommunication messages regarding message complexity, which was consistent with results of regression analysis.

The finding could be explained by the fact that *complexity* was defined as a number of elements in one message, regardless of the length and complexity of each element in the same message. It was suggested that the definition of *complexity* be revisited and redefined, and that the length of each element of a message be additionally analyzed.

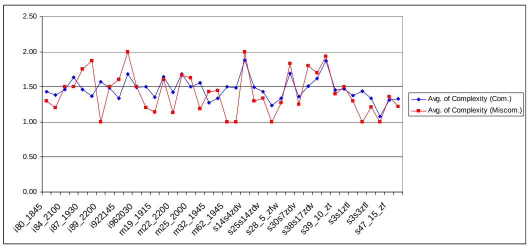

Figure 9. Average Complexity for Communication and Miscommunication Messages across 42 Sectors

Table 2. Parameter Estimation with Logistic Distribution

Dependent Variable:		Mishearing/ Not Responding	Mishearing (Pilot / Controller)		Not Responding (Pilot / Controller)	
Underlying Distribution: Logistic						
Explanatory Variable	Parameter	Model 2 Estimates	Model 3 Estimates		Model 4 Estimates	
			Model 3a	3b	Model 4a	4b
Intercept	β_0	0.7657	1.4364	-0.1267	***2.0193***	0.6778
	Significance at 0.05 level	(0.1326)	(0.3202)	(0.8854)	(0.0440)	(0.3934)
open transaction (1, 2, 3, 4)	β_t	***-0.8232***	-0.2662	-0.1652	-0.5795	***-0.8075***
		(0.0047)	(0.5400)	(0.7106)	(0.1315)	(0.0342)
complexity	β_c	-0.0054	-0.3907	-0.4432	0.1404	0.2422
		(0.7711)	(0.2565)	(0.2072)	(0.7441)	(0.5685)
interval (min)	β_n	0.1378	***0.4873***	***0.4853***	0.1413	0.1258
		(0.1985)	(0.0150)	(0.0164)	(0.4137)	(0.4568)
number of A/C	β_{ac}				***-0.1223***	
					(0.0213)	
MAP	β_m		***-0.1337***		-0.0001	
			(0.0818)		(0.9150)	
VC (Volume/Capacity)	β_{vc}	0.0004		-1.0602		-0.0007
		(0.4920)		(0.1661)		(0.5397)
	Number of Observations (Y=1/Y=0)	144/122	78/66		67/45	

Table 2 summarized the results for Models 2-4 (for Logit) and offered another set of interesting findings.

In Model 2 (*Mishearing=1; Not Responding=0)* the most common miscommunication messages were further analyzed. The most significant finding was that the number of open transactions had an impact on *Not Responding* (i.e., delayed responses) rather than on Misheard messages. We postulated that pilots and controllers would have very different reasons for *Not Responding*, but Model 2 did not provide additional information on this issue. However, the results of Model 3 and Model 4 addressed some of these issues and revealed another set of interesting findings.

In Model 3 (*Pilot Mishearing=1; Controller Mishearing = 0*) *Mishearing* messages were analyzed for pilots and controllers. The analysis results revealed that longer *interval* (i.e., longer message duration) could cause *Pilot Mishearings* rather than *Controller Mishearings*. This appeared to be intuitive since pilots were the main recipients of lengthy flight instructions issued by controllers and not vice-versa. Thus, whenever a lengthy message occurred in the system, it was more likely to be *Misheard* by pilot. Once the *complexity* variable was redefined, it would be interesting to analyze the level of message complexity with *interval*.

Another interesting result revealed that an increase in sector capacity (*MAP*) had an impact on *Controller Mishearing* messages. This could be explained by the fact that a controller could become very busy in such sectors, handling a large volume of traffic and exchanging an increased volume of messages with pilots, which consequently could lead to misheard pieces of information send by pilots.

In Model 4 (*Pilot Not Responding*=1; *Controller Not Responding=0)* the analysis of no responses (i.e., delayed responses) was conducted for pilots and controllers. Because Model 2 indicated that the number of *open transactions* had an impact on delayed responses (i.e., *Not Responding*), it was expected that Model 4 would offer additional explanations on how these delayed responses related to controllers and pilots. Model 4 results revealed that an increased number of open transactions had a larger impact on controllers' delayed responses rather than on pilots'. This might appear counterintuitive, particularly because pilots' delays in responding to controllers would allow controllers to start communication with other pilots, i.e., to start opening additional transactions. However, under such circumstances pilots' delayed responses and an increased number of open transactions could also cause annoyance and increased workload to air traffic controllers. The net effect of this cycle would be in delayed responses by controllers.

Table 3. Parameter Estimation with Normal Distribution from

Dependent Variable: Miscommunication Underlying Distribution: Normal				
Explanatory Variable	**Parameter**	**Model 1 Estimates**		
		Model 1a	**1b**	**1c**
intercept	β_0	***-2.2822***	***-2.2424***	***-2.1968***
	Significance at 0.05 level	(0.0000)	(0.0000)	(0.0000)
open transaction (1, 2, 3, 4)	β_t	***0.2094***	***0.2180***	***0.2366***
		(0.0006)	(0.0003)	(0.0000)
complexity	β_c	-0.0001	-0.0001	-0.0002
		(0.7750)	(0.7876)	(0.6858)
interval (min)	β_n	***0.0597***	***0.0600***	***0.0766***
		(0.0000)	(0.0000)	(0.0000)
arrival (0, 1)	β_a	***0.2648***	***0.2644***	
		(0.0001)	(0.0001)	
departure (0, 1)	β_d	-6.3163	-6.3096	
		(1.0000)	(1.0000)	
cumulative arrivals	β_{ca}	***0.0119***		
		(0.0380)		
cumulative departures	β_{cd}	-0.0075		
		(0.2506)		
number of A/C	β_{ac}		***0.0123***	
			(0.0311)	
MAP	β_m	-0.0002	-0.0002	
		(0.1832)	(0.1653)	
VC (Volume/ Capacity)	β_{vc}			-0.0001
				(0.3390)
	Number of Observations (Y=1/Y=0)	368/7597		

In summary, delayed responses by controllers could be explained by the following reasoning: once an air traffic controller began initiating additional transactions, he tended to start delaying his responses when too many transactions were open due to the mental workload increase (i.e., cognitive utilization increase). Such situations could appear also in the data link environment, causing additional delays in message transactions and affecting systems efficiency and controllers' productivity.

Interestingly and similarly – it was also found that an increasing number of aircraft in a sector (*number of A/C*) had an impact on delayed responses (i.e, *Not Responding*) by controllers. It was expected that certain delayed responses would occur in a data link environment for the same reason.

The results of Probit model were consistent with the Logit model results in terms of significance of explanatory variables and their signs, as depicted in Tables 3 and 4. The only difference in the analysis results between the two models was in the parameter estimation values, with Logit values being significantly higher, as expected. Hence, Logit model was indeed more appropriate in capturing miscommunication messages since Logit's thicker tail could better capture the presence of rare events.

Table 4. Parameter Estimation with Normal Distribution

Dependent Variable:		**Mishear./ Not Respond.**	**Mishear. (Pilot/ Controller)**		**Not Responding (Pilot/ Controller)**	
Underlying Distribution: Normal						
Expl. Variable	**Para-meter**	**Model 2**	**Model 3**		**Model 4**	
			3a	**3b**	**4a**	**4b**
intercept	β_0	0.4624	0.9259	-0.046	***1.257***	0.416
	Signif. at 0.05 level	(0.1332)	(0.2982)	(0.93)	(0.03)	(0.38)
open transact. (1, 2, 3, 4)	β_t	***-05015***	-0.1615	-0.096	-0.343	***-0.475***
		(0.0033)	(0.5486)	(0.72)	(0.12)	(0.02)
complex.	β_c	-0.0027	-0.2362	-0.269	0.062	0.132
		(0.7488)	(0.2674)	(0.21)	(0.80)	(0.60)
interval (min)	β_n	0.0864	***0.2895***	***0.289***	0.080	0.076
		(0.1905)	(0.0123)	(0.01)	(0.44)	(0.46)
number of A/C	β_{ac}				***-0.074***	
					(0.01)	
MAP	β_m		***-0.0830***		-0.000	
			(0.0787)		(0.92)	
VC (Volume/ Capacity)	β_{vc}	0.0003		-0.662		-0.000
		(0.4907)		(0.15)		(0.53)
	# of obs. (Y=1/ Y=0)	144/122	78/66	67/45		

Summary, Conclusions and Recommendations

Because the Next Generation Air Transportation System will depend largely on the successful implementation of Data Communications System, this study addresses an important and common problem to both voice-based and data link systems in support of NextGen: the problem of multiple open transactions and the occurrence of delayed responses.

The study findings indicate that an increased number of multiple open message transactions affect the occurrence of miscommunications, and in particular the delayed responses by controllers. Since the message transfer time in a data link environment appears to be longer than in the voice-based environment, any further delays in message transactions with data link should be avoided because the delayed transactions could make the data link system less efficient and productive.

It is recommended that the problem of multiple open transactions be further studied in the Data Comm/NextGen Environment for Segments I, II and III by juxtaposing the en route traffic and communication messages, and that the following issues should be further explored:

(1) the effect of open transactions on controllers' delayed responses and the impact on sector capacity.

(2) the effect of open transactions on controllers' delayed responses and the impact on routing efficiency. Although the introduction of data link and the reduced voice channel occupancy would result in faster vectoring of aircraft onto their original routes in cases where they previously have been vectored off-route to resolve potential aircraft conflicts, it would be useful to explore the routing efficiency in the presence of multiple open transactions and increased traffic volume with data link.

While NAS gradually transitions into NextGen, another useful study would include the estimation of controller productivity with multiple open transactions since controllers' workload increases in the presence of open transactions.

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Acknowledgments

The authors would like to thank professor Matthew Karlaftis from the National Technical University of Athens, Greece for his useful suggestions and comments.

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