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Analysis of Pilot Response Time to Time-Critical Air Traffic Control Calls

Research and Development Service
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Kim M. Cardosi
Pamela W. Boole

John A. Volpe National Transportation Systems Center
Cambridge, MA 02142

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16. Abstract

One of the most important time-critical air traffic control messages for a pilot is one that required an immediate maneuver for traffic avoidance. This study examines the time required for an air traffic controller to successfully transmit such a message in the en route environment as measured from the beginning of the controller's message to the end of the pilot's correct acknowledgement. This total time is broken down into its component parts: the duration of the controller's message, the time between the end of the controller's message and the beginning of the pilot's response, and the duration of the pilot's acknowledgement. For comparison purposes, transmissions relaying clearances for turns for reasons other than traffic and traffic advisories were also examined.

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PREFACE

One of the most important time-critical air traffic control messages for a pilot is one that requires an immediate maneuver for traffic avoidance. This study examines the time required for an air traffic controller to successfully transmit such a message in the en route environment as measured from the beginning of the controller's message to the end of the pilot's correct acknowledgement. This total time is broken down into its component parts: the duration of the controller's message, the time between the end of the controller's message and the beginning of the pilot's response, and the duration of the pilot's acknowledgement. For comparison purposes, transmissions relaying clearances for turns for reasons other than traffic and traffic advisories were also examined.

This work was conducted for the Federal Aviation Administration's Automation Engineering Division (ANA-110) and was sponsored by the Research and Development Service (ARD-210). We would like to thank Alan Yost (ATR-421) for his technical expertise and Richard Koch and Gary Mileski of ATR-110 for obtaining the tapes necessary for this analysis.

METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0	1	2	3	4	5	6	7	8	9	10

CENTIMETERS 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 | 25.40

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

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EXECUTIVE SUMMARY

One of the most important time-critical air traffic control (ATC) messages for a pilot is one that requires an immediate maneuver for traffic avoidance. Forty-six hours of voice tapes from three different Air Route Traffic Control Centers were examined to determine the time required for an air traffic control specialist to successfully transmit time-critical messages in the en route environment. This was measured from the onset of the controller's speech to the end of the pilot's correct acknowledgement. For comparison purposes, transmissions relaying clearances for turns for reasons other than traffic and traffic advisories were also examined. Transmission was considered successful and complete when the pilot correctly acknowledged the message. This took into account the time required to repeat all or part of the transmissions, when necessary.

Approximately ten seconds were required for a controller to successfully transmit a message containing a turn, a maneuver necessary for traffic avoidance, or a traffic advisory to a pilot in an en route environment. This total time was broken down into its component parts: the duration of the controller's message, the time between the end of the controller's message and the beginning of the pilot's response, and the duration of the pilot's acknowledgement.

It is important to note that this average of ten seconds is only valid for the en route environment, since this was the only type of ATC facility that was sampled in the tapes. Response times to other types of calls in other environments may be different. For example, the time between a controller's transmission and the pilot's response may be shorter in the terminal environment where a pilot is more likely to expect an ATC transmission than en route where a call is not as likely. Also, it is only applicable to relatively short transmissions (e.g., a turn and a climb as opposed to a departure clearance). Longer ATC messages would be expected to result in longer times required to convey them.

1. INTRODUCTION

The time required for an air traffic controller to successfully transmit a time-critical message to a pilot has not been extensively studied. While this time parameter has important implications for many time-critical warning systems (e.g., Conflict Resolution Advisory), no conclusive data are available on which an estimate of this parameter could be based. There are many different factors that could contribute to this time estimate. For example, pilot response time would be expected to be quicker in conditions in which a call from air traffic control (ATC) is expected (e.g., in a terminal environment) than when the probability of a call is not as high (e.g., en route at 2 a.m.). The type of transmission is also important for several reasons, one of which is that the content of the call is a determining factor of the time required to speak the message.

There are many different time-critical ATC messages, perhaps the most important of which is one that requires an immediate maneuver for traffic avoidance. In this study, the message of interest was a maneuver required for traffic avoidance in the en route environment. The purpose of this study was to determine the time required for an air traffic controller to successfully transmit a message of this type as measured from the beginning of the controller's first transmission to the end of the pilot's correct or final acknowledgement. For comparison purposes, transmissions relaying traffic information and clearances for turns (for reasons other than for traffic) were also examined.

The time required for transmittal of ATC messages has several components each of which contributes to the variability of the total time. The first component is the length of the controller's message. This is followed by a lag time where the controller is waiting for the pilot's response. When a pilot response follows, the third component is the length and accuracy of the pilot's response. If the acknowledgement is inaccurate, contains a question (including "say again") or non-existent, the controller must repeat part or all of the original message. The total time for successful acknowledgement of a controller's transmission must take into account all of these elements.

2. METHOD

2.1 DESCRIPTION OF TAPES

Sixteen hours of ATC voice tapes were requested from four Air Route Traffic Control Centers (ARTCCs) for a total of 64 hours of tape. The tape request was designed to include different geographical locations, high and low altitude sectors, and two different workload levels. Half of the tapes were from periods of relatively high workload and half were from periods of moderate-low workload. (This was also quantified in the analysis by counting the number of controller communications per hour.) Within each workload level, half of the tapes were from high altitude sectors and half were from low altitude (both departure and arrival) sectors. All of the tapes from one ARTCC and one from each of two of the other centers were unintelligible. Forty-six hours of tape were suitable for analysis. The analysis included 16 hours from Los Angeles Center, 15 hours from New York Center, and 15 hours from Salt Lake Center.

2.2 PROCEDURE

The purpose of this study was to examine pilot response time to controller messages that relayed maneuvers necessary for traffic avoidance. This included transmissions in which a controller issued a maneuver followed by the words "for traffic" or an expression of urgency (e.g., "immediately") and calls that were known to be for traffic based on communications with the pilot or previous communications between controllers. For comparison purposes, two other types of transmissions were also examined. Controller transmissions relaying traffic information (traffic advisories in which a maneuver was not specified) and those relaying a turn for any reason other than traffic (as stated specifically as a turn or a change in heading) were analyzed in the same way as the transmissions issuing maneuvers required for traffic avoidance.

For each transmission, the following data were recorded:

a) the duration of the initial controller message - this is measured from the beginning of the controller's message (as determined by the onset of controller speech) to the end of the message (offset of controller speech);

b) the lag times - this is measured from the end of the first controller's message to the beginning of the pilot's response;

c) the duration of the pilot's response (usually an acknowledgement) - this is measured from the beginning to the end of the pilot's message;

d) the duration of the controller's second message (where applicable, e.g., as with a "say again") measured from the beginning to the end of the controller's message;*

e) the duration of the pilots second response (where applicable); and

f) the total time as measured from the beginning of the controller's first message to the end of the pilot's last response for that transaction.

In addition, the following measures were taken:

a) the number of controller to pilot transmissions per hour;

b) the number of controller to controller calls per hour; and

c) the total number of transmissions per hour (a+b).

These measures were obtained as indices of traffic load and controller verbal workload. They are not intended to be a complete measure of controller workload.

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* The only controller second messages that were counted as such were ones in which the controller had to repeat or clarify some part of the original message. Second transmissions that were independent of the first ones (e.g., ones that contained new information or an additional clearance) were not counted as second messages but were included in the total number of controller calls.

3. RESULTS

A total of 6,082 transmissions were contained in the 46 hours of tape. Fourteen percent of these were controller-to-controller calls leaving 5,205 controller-to-pilot transmissions for analysis.[2] The higher workload tapes contained an average of 140 controller-to-pilot communications and 19 controller-to-controller calls per hour. The lower workload tapes had an average of 91 controller-to-pilot and 20 controller-to-controller transmissions per hour.

Controller-to-pilot transmissions of interest were divided into three types for analysis: "Maneuvers for Traffic," "Turns Not for Traffic," and "Traffic Advisories." These three categories were mutually exclusive, that is, no single transmission could be counted in more than one category. There were 508 transmissions from these three categories: 80 maneuvers for traffic, 250 turns not for traffic and 178 traffic advisories. One hundred ninety of the 508 transmissions were from the 15 hours of tapes from the New York ARTCC, 170 were from the 16 hours of tapes from the Los Angeles ARTCC and 148 were from the 15 hours of Salt Lake ARTCC tapes.

3.1 MANEUVERS FOR TRAFFIC

Maneuvers for Traffic" included calls in which a controller issued a maneuver followed by the words "for traffic" or an expression of urgency (e.g., "immediately") and calls that were known to be for traffic based on previous communications between controllers. There were 80 maneuvers for traffic in the 46 hours of voice tapes. As can be seen from Table 3-1, the total time required for a successful transmission of message containing an avoidance for traffic maneuver varied from four to 40 seconds with an average time of 10.8 seconds ($s = 5.9$).[3] Since the data are skewed with most of the total times being less than the average, the median (time at the 50th percentile) is a more representative measure than the mean. The median total time required for transmission of a maneuver for traffic was 9 seconds.

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[2] The only controller-to-controller transmissions recorded here are the ones that are recorded on the tape. They do not include the communications with or by the D-side controllers or other controllers where the use of the land lines is not necessary. They are not, therefore, an accurate reflection of the full level of communication among controllers.

[3] Deleting all data points three standard deviations above the mean left a total of 76 data points and yielded a mean total time of 9.9 seconds ($s = 4.0$).

TABLE 3-1. MANEUVERS FOR TRAFFIC

Variable	Minimum	Maximum	Mean	Standard Deviation
C1TIME	1	11	4.85	2.30
LAG TIME	1	31	3.31	4.80
P1TIME	1	11	2.61	1.83
C2TIME	1	6	3.31	1.32
P2TIME	1	4	1.87	0.92
TOTAL TIME	4	40	10.85	5.91

Total Number of Observations = 80

C1TIME is the duration of the first controller transmission.

LAG TIME is the delay between the end of the controller's initial transmission and the beginning of the pilot's response.

P1TIME is the duration of the pilot's initial response to the controller's first transmission.

C2TIME is the duration of the controller's second transmission to the same pilot.

P2TIME is the duration of the pilot's second response

TOTAL TIME is the time from the beginning of the controller's initial transmission to the end of the pilot's last response.

In 95 percent of the cases, the total time was less than 23 seconds, and 90 percent of the total times were equal to or less than 17 seconds.

The total time required for successful transmission of a message was broken down into several components. The average duration of the controller's initial call was 4.8 seconds. The average time between the end of the controller's message and the beginning of the pilot's response was 3.3 seconds, and the average duration of the pilot's response was 2.6 seconds. The most variable component of this total was the lag time; the longest delay between the controller's message and the pilot's response was 40 seconds ($s = 4.8$). On 6 percent of the transmissions, the controller received no response from the pilot on the first attempt to contact and had to try again. On 14 percent of the calls, the controller had to repeat or clarify part or all of the transmission once contact was established. This second call lasted an average of 3.2 seconds and the pilot's final acknowledgement averaged 1.7 seconds. These times are included in the total time since the calls were necessary for successful transmission of the message.

Forty-nine of these calls were from the high workload tapes and 31 of these calls were from the lower workload tapes. The difference in total time for the transmissions in these two conditions was minimal and not statistically significant [t (78) = .23, $p > .05$].

3.2 TURNS NOT FOR TRAFFIC

"Turns Not for Traffic" involved a turn for any reason other than traffic. This included any changes in heading and turns when stated as such. It did not include clearances direct to a fix, clearances to join airways, or any other clearance in which a turn may be implied but is not stated as a turn. There were 250 such transmissions in the 46 hours of tape. As can be seen from Table 3-2, the total time required for a successful transmission of a message of this type varied from four to 52 seconds with an average time of 10.0 seconds (s = 5.9).[4] The median total time required for transmission of a turn not isuued for traffic avoidance was 8 sec. In 95 percent of the cases, the total time was less than or equal to 21 seconds, and 90 percent of the total times were equal to or less than 16 seconds. The average duration of the controller's initial call was 4.6 seconds, the average time between the end of the controller's message and the beginning of the pilot's response was 2.7 seconds, and the average duration of the pilot's response was 2.7 seconds.

On 1 percent of the transmissions, the controller received no response from the pilot on the first attempt to contact. On 13 percent of the calls, the controller had to repeat part or all of the transmission once contact was established. This second call lasted an average of 3.8 seconds and the pilot's final acknowledgement averaged 2.6 seconds. These times are included in the total time since the calls were necessary for successful transmission of the message.

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[4] When all data points three standard deviations above the mean were removed for analysis, the total number of transmissions was 235 and the total time changed to 9.0 seconds (s = 3.6).

TABLE 3-2. TURNS NOT FOR TRAFFIC

Variable	Minimum	Maximum	Mean	Standard Deviation
C1TIME	1	26	4.62	2.98
LAG TIME	1	41	2.68	4.60
P1TIME	1	11	2.66	1.58
C2TIME	1	12	3.78	2.35
P2TIME	1	8	2.65	2.00
TOTAL TIME	4	52	10.04	5.90

Total Number of Observations = 250

C1TIME is the duration of the first controller transmission.

LAG TIME is the delay between the end of the controller's initial transmission and the beginning of the pilot's response.

P1TIME is the duration of the pilot's initial response to the controller's first transmission.

C2TIME is the duration of the controller's second transmission to the same pilot.

P2TIME is the duration of the pilot's second response

TOTAL TIME is the time from the beginning of the controller's initial transmission to the end of the pilot's last response.

3.3 TRAFFIC ADVISORIES

There were 178 instances of controllers issuing traffic information to pilots in the 46 hours of tapes. These transmissions consisted of traffic advisories that required pilot vigilance, but did not specify a maneuver. These calls would be expected to be the most variable in terms of total time required to complete the call since the controller may give the pilot a detailed description of the traffic (e.g., type of aircraft, company, heading, in addition to altitude and relative position) or a shorter description. As can be seen from Table 3-3, the total time required for a successful transmission of a traffic advisory varied from four to 86 seconds with an average time of 11.0 seconds (s = 7.3).[5] The median total time required for transmission of a traffic advisory was 9.5 seconds. In 95 percent of the cases, the total time was less than or equal to 18 seconds., and 90 percent of the total times were equal to or less than 16 seconds. The average duration of the controller's initial call was 6.5 seconds, the average time between the end of the controller's message and the beginning of the pilot's response was 2.7 seconds, and the average duration of the pilot's response was 1.9 seconds. On fewer than 1 percent of the transmissions, the controller received no response from the pilot on the first attempt to contact. On 8 percent of the calls, the controller had to repeat or clarify part or all of the transmission once contact was established. This second call lasted an average of 3.0 seconds and the pilot's final acknowledgement averaged 1.8 seconds. Only those calls that contained clarifications necessary for successful transmission of the message were included as second controller calls, and therefore, included in the total time.

[5] When all data points three standard deviations above the mean were removed for analysis, the total number of transmissions was 169 and the total time changed to 10.1 seconds (s = 3.7).

TABLE 3-3. TRAFFIC ADVISORIES

Variable	Minimum	Maximum	Mean	Standard Deviation
C1TIME	1	15	6.47	2.41
LAG TIME	1	73	2.67	6.25
P1TIME	1	9	1.90	1.37
C2TIME	1	11	3.00	2.83
P2TIME	1	5	1.78	1.22
TOTAL TIME	4	86	10.96	7.26

Total Number of Observations = 178

C1TIME is the duration of the first controller transmission.

LAG TIME is the delay between the end of the controller's initial transmission and the beginning of the pilot's response.

P1TIME is the duration of the pilot's initial response to the controller's first transmission.

C2TIME is the duration of the controller's second transmission to the same pilot.

P2TIME is the duration of the pilot's second response

TOTAL TIME is the time from the beginning of the controller's initial transmission to the end of the pilot's last response.

4. CONCLUSIONS

Approximately ten seconds are required for a controller to successfully transmit a message containing a maneuver, such as one necessary for traffic avoidance, to a pilot in an en route environment. For the purposes of this analysis, transmission was considered successful and complete when the pilot correctly acknowledged the message. This took into account the time required to repeat 14 percent of the transmissions either in part or in their entirety. It is important to note that this average is only valid for the en route environment, since this was the only type of ATC facility that was sampled in the tapes. Response times to other types of calls in other environments may be different. For example, the time between a controller's transmission and the pilot's response may be shorter in the terminal environment where a pilot is more likely to expect an ATC transmission than en route where a call is not as likely. Also, it is only applicable to relatively short transmissions (e.g., a turn and a climb as opposed to a departure clearance). Longer ATC messages would be expected to result in longer times required to convey them.