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Time Required for Transmission of Time-Critical Air Traffic Control Messages in an En Route Environment

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This article examines the time required for an air traffic control specialist to successfully transmit a message containing a maneuver required for traffic avoidance to a pilot in the en route environment. Time required was measured from the beginning of the controller's message to the end of the pilot's correct acknowledgement. Forty-six hours of voice tapes from three Air Route Traffic Control Centers were analyzed, yielding 80 maneuvers issued for traffic avoidance. The mean total time required for message transmission was found to be 11 sec. In the analysis, this total was broken down into its component parts: (a) duration of the controller's message, (b) time between the end of the controller's message and the beginning of the pilot's response, and (c) duration of the pilot's acknowledgment. Transmissions that relayed turn clearances for reasons other than traffic avoidance and relayed traffic advisories were also examined. Transmissions that were successfully completed with a single controller transmission were compared to those that required more than one controller call.

Previous studies of pilot–controller communications have examined voluntary reports of problems (e.g., Billings & Cheaney, 1981), the process of communication (e.g., Morrow, Lee, & Rodvold, this issue), and the time required to speak individual message elements, such as an altimeter setting or a pilot's position report (Hunter, Blumenfeld, & Hsu, 1974). However, the time required for an air traffic control (ATC) specialist to successfully transmit a specific type of time-critical message to a pilot has not been systematically examined. Although this time parameter has important implications for many time-critical warning systems, no

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conclusive data were available on which an estimate of this parameter could be based.

Many different factors could contribute to this time estimate. For example, pilot response time would be expected to be faster in conditions in which a call from 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 several different time-critical ATC messages, perhaps the most important of which being one that requires an immediate maneuver for traffic avoidance. In the present 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 acknowledgment. As a point of interest, 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 contributing to the variability of the total time: (a) length of the controller's message; (b) lag time, during which the controller waits for the pilot's response; and (c) length and accuracy of the pilot's response. If the acknowledgment is inaccurate, contains a question (including "say again") or is nonexistent, the controller must repeat part or all of the original message. The total time for successful acknowledgment of a controller's transmission must take into account all of these components.

METHOD

Description of Tapes

Forty-six hours of tape from three different Air Route Traffic Control Centers (ARTCCs) were analyzed. This included 16 hr from the Los Angeles ARTCC, 15 hr from the New York ARTCC, and 15 hr from the Salt Lake ARTCC.[1] To obtain a sampling of only relatively busy periods, half the tapes were requested from periods of relatively high workload and half were requested from periods of moderate workload. The workload level was determined by the quality assurance specialist who recorded the tapes at each site; it was also quantified in the analysis by counting the number of controller communications per hour. Within each workload level, half the tapes were from high-altitude sectors and half were from low-altitude (both departure and arrival) sectors.

[1]Sixteen hours of ATC voice tapes had been requested from four ARTCCs for a total of 64 hr of tape. However, all tapes from one ARTCC and one tape from each of two of the other centers were found to be unintelligible.

Procedure

All instances of pilot responses to ATC messages that relayed maneuvers necessary for traffic avoidance were examined, including transmissions in which a controller issued a maneuver followed by the words "for traffic" or an expression of urgency (e.g., "immediately"). It also included 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 and those relaying a turn for any reason other than traffic were analyzed in the same way as the traffic-avoidance transmissions.

For each transmission, the following data were recorded and the values rounded to the nearest second:

1. The duration of the initial controller's message, 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).
2. Lag times, measured from the end of the first controller's message to the beginning of the pilot's response.
3. The duration of the pilot's initial response (usually an acknowledgment), measured from the beginning to the end of the pilot's message.
4. The duration of the controller's second message, where applicable (as with a "say again"), measured from the beginning to the end of the controller's message.
5. The duration of the pilot's second response, where applicable.
6. 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 the rare case of three or more components in a transaction (e.g., as with a pilot's third response), the individual durations of these components were not analyzed, but they were all included in the total time.

Note that the only second controller transmissions that were counted as such were those 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., those that contained new information or an additional clearance) were not counted as such but were included in the total number of controller calls.

In addition, measures were taken of (a) number of controller-to-pilot transmissions per hour, (b) number of controller-to-controller calls per hour, and (c) 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. It should also be noted that the only controller-to-controller transmissions recorded here were the ones that were recorded on the tape. Not included are the communications with or by the Data-side controllers or with other controllers when the use of the land lines was not necessary. The number of transmissions, therefore, does not accurately reflect the full level of communication among controllers.

RESULTS

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

Controller-to-pilot transmissions of interest were divided into three categories for analysis: *maneuvers for traffic avoidance, turns not for traffic,* and *traffic advisories.* These categories were mutually exclusive—no single transmission could be counted in more than one category. There were 508 transmissions from these three categories. One hundred ninety of these transmissions were from the New York ARTCC, 170 were from the Los Angeles ARTCC, and 148 were from the Salt Lake ARTCC tapes.

Maneuvers for Traffic Avoidance

Maneuvers for traffic avoidance 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 hr of tapes.[2] As can be seen from Table 1, the total time required for successful transmission of a message containing a maneuver for traffic avoidance varied from 4 to 40 sec with a mean of 11 sec. Ninety-five percent of the transmissions were completed within 23 sec. Deleting all data points 3 *SD* above the mean left a total of 76 data points and yielded a mean total time of 9.9 sec (*SD* = 4.0 sec). Because the data were skewed, with most of the total times being less than the mean, the median was also examined and was found to be 9 sec.

The total time required for successful transmission of a message was broken down into several components.[3] As can be seen in Table 2, the mean duration of the controller's initial call (C1TIME) was 4.85 sec. The mean time between the end of the controller's message and the beginning of the pilot's response (LAG TIME) was 3.31 sec, and the mean duration of the pilot's response (P1TIME) was 2.61 sec. The most variable component of this total was LAG TIME; the longest

[2]Five of these controller transmissions immediately followed a pilot transmission (e.g., an aircraft's initial check-in).

[3]It should be noted that it is not possible to discern from the tables the number of instances of the different communication sequences. There were, for example, instances in which a pilot would catch his own readback error and transmit again without a second controller transmission (C1-P1-P2) and instances in which a controller would repeat part of a message, but this second controller transmission would not be acknowledged (C1-P1-C2).

TABLE 1
Total Time Required for Transmission of Maneuvers Required for Traffic Avoidance

Time (Sec)				Percentile		
Minimum	*Maximum*	*M*	*Median*	*90th*	*95th*	*99th*
4	40	10.85	9	17	23	40

TABLE 2
Maneuvers for Traffic Avoidance

		Time (Sec)			
Variable	*n*	*Minimum*	*Maximum*	*M*	*SD*
C1TIME	80	1	11	4.85	2.30
LAG TIME	80	1	31	3.31	4.80
P1TIME	76	1	11	2.61	1.83
C2TIME	13	1	6	3.31	1.32
P2TIME	15	1	4	1.87	0.92
Total[a]	80	4	40	10.85	5.91

[a]Time from beginning of controller's initial transmission to end of pilot's last response.

delay between the controller's message and the pilot's response was 31 sec. Only 84% of the controller transmissions were successfully completed on the first attempt. On 16% of the calls, the controller had to repeat or clarify part or all of the transmission. Thirty-one percent of these repeats (5% of the total calls) occurred because the controller received no response from the pilot on the first attempt to contact and had to try again. The mean duration of these second calls (C2TIME) was 3.31 sec, and the mean duration of the pilot's final acknowledgment (P2TIME) was 1.87 sec.[4] These times are included in the total time because the calls were necessary for successful transmission of the message

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

Forty-three of these transmissions were from the high-altitude sectors and 37 were from low-altitude sectors. The difference in total time between high- and low-altitude sectors was less than 1 sec and not statistically significant, $t(78) = .69$, $p > .05$.

[4]For all three categories of controller transmissions, on the few occasions where more than two pilot responses were required for a correct acknowledgement, P2 was measured as the length of the final acknowledgment. The durations of the previous pilot responses and the lag times were included in the total transmission times but not analyzed separately.

Turns Not for Traffic

Turns not for traffic involved a turn for any reason other than traffic avoidance. 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. It also did not include transmissions involving a vertical clearance or other type of information.

There were 250 such transmissions in the 46 hr of tape. As can be seen from Table 3, the total time required for a successful transmission of a message of this type varied from 4 to 52 sec (M = 10 sec). When all data points that were 3 SD above the mean were removed for analysis, the remaining number of transmissions was 235 and the mean total time changed to 9 sec (SD = 3.6 sec). The median total time required for transmission of a turn not issued for traffic avoidance was 8 sec, and 95% of the transmissions were completed within 21 sec.

As can be seen in Table 4, C1TIME was 4.62 sec, LAG TIME was 2.68 sec, and P1TIME was 2.66 sec. Only 87% of the controller transmissions were successfully completed on the first attempt. On 13% of the calls, the controller had to repeat or clarify part or all of the transmission. Nine percent of these repeats (1% of the total transmissions) were because the controller received no response from the pilot on the first attempt to contact and had to try again. This second call (C2) averaged 3.78 sec, and the pilot's final acknowledgment (P2) averaged 2.65 sec.

Fifty-seven of these transmissions were from the moderate-workload tapes and 193 were from the high-workload tapes. The difference in total time for the transmissions in these two conditions was less than 1 sec and was not statisti-

TABLE 3
Total Time Required for Transmission of Turns Not for Traffic

Time (Sec)				*Percentile*		
Minimum	*Maximum*	*M*	*Median*	*90th*	*95th*	*99th*
4	52	10.04	8	16	21	34

TABLE 4
Turns Not for Traffic

		Time (Sec)			
Variable	*n*	*Minimum*	*Maximum*	*M*	*SD*
C1TIME	250	1	26	4.62	2.98
LAG TIME	250	1	41	2.68	4.60
P1TIME	247	1	11	2.66	1.58
C2TIME	32	1	12	3.78	2.35
P2TIME	34	1	8	2.65	2.00
Total	250	4	52	10.04	5.90

TABLE 5
Total Time Required for Transmission of Traffic Advisories

Time (Sec)				Percentile		
Minimum	*Maximum*	*M*	*Median*	*90th*	*95th*	*99th*
4	86	10.96	9.5	16	18	42

TABLE 6
Traffic Advisories

		Time (Sec)			
Variable	*n*	*Minimum*	*Maximum*	*M*	*SD*
C1TIME	178	1	15	6.47	2.41
LAG TIME	178	1	73	2.67	6.25
P1TIME	177	1	9	1.90	1.37
C2TIME	15	1	11	3.00	2.83
P2TIME	18	1	5	1.78	1.22
Total	178	4	86	10.96	7.26

cally significant, $t(248) = .82, p > .05$.

Ninety-four of these transmissions were from the high-altitude sectors and 156 were from low-altitude sectors. The difference in total time between high- and low-altitude sectors was approximately 1 sec and was not statistically significant, $t(248) = 1.65, p > .05$.

Traffic Advisories

There were 178 instances of controllers issuing traffic information to pilots in the 46 hr 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, because the controller may give the pilot a detailed description of the traffic (e.g., type of aircraft, company, and heading, in addition to altitude and relative position) or a shorter description.

As can be seen from Table 5, the total time required for successful transmission of a traffic advisory varied from 4 to 86 sec (M = 11 sec). The median total time required for transmission of a traffic advisory was 9.5 sec, and 95% of the transmissions were completed within 18 sec.

As can be seen in Table 6, C1TIME was 6.47 sec, LAG TIME was 2.67 sec, and P1TIME was 1.90 sec. Approximately 92% of the controller transmissions were successfully completed on the first attempt. Eight percent of the traffic advisories had to repeated or clarified. One of these repeats (<1% of the total controller transmissions) occurred because the controller received no response from the pilot

on the first attempt to contact and had to try again. C2 averaged 3.0 sec, and P2 averaged 1.8 sec. Again, only those calls that contained clarifications necessary for successful transmission of the message were included as second controller calls and therefore included in TOTAL.

Sixty-five of these transmissions were from the moderate-workload tapes and 113 were from the high-workload tapes. The difference in total time for the transmissions in these two conditions was approximately 1 sec and was not statistically significant, $t(176) = 1.25, p > .05$.

Seventy-five of these transmissions were from low-altitude sectors and 103 were from high-altitude sectors. The difference in total time between high- and low-altitude sectors was minimal, $t(176) = .16, p > .05$, ns.

Miscommunications

In 12% of the 508 communications examined, part or all of the initial controller transmission had to be repeated. Although some of these cases are accounted for by a lack of a pilot response to the controller transmission (5% of maneuvers for traffic, 1% of turns not for traffic, and <1% of traffic advisories), the bulk of the miscommunications were ones in which a pilot missed or incorrectly read back the controller's message.

One way of looking at these miscommunications is to examine the differences between single- and multiple-loop transmissions. For the purposes of this study, a *single-loop transmission* was one in which only one controller transmission was required for successful reception of the message. An example of a single-loop transmission is a clearance followed by a correct pilot's acknowledgment. A *multiple-loop transmission* was one that required more than one controller transmission. Examples of a multiple-loop transmission include clearances followed by a "Say again," an incorrect readback, or no response. In each case, the controller must repeat part or all of the transmission.

The fact that the mean for the total time required for multiple-loop transmissions was almost twice the mean for single-loop transmissions is not surprising. As can be seen in Table 7, the bulk of this difference is accounted for by the longer lag times as the controller waited for the pilot's response. What is surprising is that the initial controller transmission for multiple-loop transmissions was significantly shorter than those for single-loop transmissions, $t(506) = 3.12, p < .01$. That is, for the brief messages examined, the controller transmissions that were approximately 1 sec (20%) shorter were more likely to require repetition. An analysis of this type by category of controller transmission (see Tables 8, 9, and 10) shows that shorter initial controller messages were associated with the need to repeat the transmission for both maneuvers for traffic avoidance, $t(78) = 2.02, p < .05$, and turns not for traffic, $t(248) = 2.19, p < .05$.

This intriguing difference needs to be verified and investigated. Whether it was due to a slightly slower speech rate, a longer initial pause after the aircraft call sign, or some other factor is not yet known and will require further study.

There was no significant difference between the length of the first controller transmission for the single- and multiple-loop transmissions with traffic advisories,

TABLE 7
Total Transmissions by Loop

	Loop					
	Single			Multiple		
		Time (Sec)			Time (Sec)	
Variable	*n*	*M*	*SD*	*n*	*M*	*SD*
C1TIME	448	5.44	2.84	60	4.35	2.50
LAG TIME	448	1.67	3.50	60	11.03	8.15
P1TIME	448	2.35	1.52	60	2.53	1.94
C2TIME	–	–	–	60	3.48	2.30
P2TIME	–	–	–	51	2.12	1.35
Total	448	9.42	5.20	13	18.50	8.62

TABLE 8
Maneuvers for Traffic Avoidance by Loop

	Loop					
	Single			Multiple		
		Time (Sec)			Time (Sec)	
Variable	*n*	*M*	*SD*	*n*	*M*	*SD*
C1TIME	67	5.04	2.33	13	3.85	1.86
LAG TIME	67	1.60	0.74	13	12.15	6.90
P1TIME	67	2.73	1.90	13	1.69	0.63
C2TIME	–	–	–	13	3.31	1.32
P2TIME	–	–	–	12	2.00	0.95
Total	67	9.32	4.05	13	18.69	7.75

TABLE 9
Turns Not for Traffic by Loop

	Loop					
	Single			Multiple		
		Time (Sec)			Time (Sec)	
Variable	*n*	*M*	*SD*	*n*	*M*	*SD*
C1TIME	218	4.74	3.08	32	3.81	2.09
LAG TIME	218	1.37	0.60	32	11.59	8.55
P1TIME	218	2.68	1.49	32	2.44	2.05
C2TIME	–	–	–	32	3.78	2.35
P2TIME	–	–	–	28	2.29	1.58
Total	218	8.80	3.98	32	18.50	9.20

TABLE 10
Traffic Advisories by Loop

	Loop					
	Single			Multiple		
		Time (Sec)			Time (Sec)	
Variable	*n*	*M*	*SD*	*n*	*M*	*SD*
C1TIME	163	6.52	2.33	15	5.93	3.17
LAG TIME	163	2.10	5.72	15	8.87	8.38
P1TIME	163	1.76	1.18	15	3.47	2.17
C2TIME	–	–	–	15	3.00	2.83
P2TIME	–	–	–	11	1.82	1.08
Total	163	10.28	6.75	15	18.33	8.62

$t(176) = .70, p > .05$. This is because the content of these advisories was much more variable than the content of the messages in the other two categories.

DISCUSSION

Approximately 10 sec are required for an ATC specialist 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 12% of the transmissions, either in part or entirely. It is important to note that this average is only valid for relatively busy periods in the en route environment, because this was the only type of voice tape that was sampled. Response times to other types of calls in other environments may be different. Also, it is only applicable to relatively short transmissions (e.g., a turn or a climb as opposed to a lengthy routing change). Longer ATC messages would be expected to result in longer times required to convey them.

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REFERENCES

Billings, C. E., & Cheaney, E. S. (1981). *Information transfer problems in the aviation system* (NASA Tech. Paper No. 1875). Moffett Field, CA: NASA Ames Research Center.

Hunter, J. S., Blumenfeld, D. E., & Hsu, D. A. (1974, July). *Modeling air traffic performance measures: Vol. I. Message element analyses and dictionaries* (Rep. No. FAA-RD-73-147, I). Atlantic City, NJ: Federal Aviation Administration, National Aviation Facilities Experimental Center.

ADDENDUM

A subsequent study was performed to investigate the difference found in the length of the controller's transmission between multiple- and single-loop transmissions (i.e., those that did and did not require repeating). When these transmissions were carefully matched to controls (e.g., for the same controller, number of speech acts, and content of the message), no differences were found along any of the factors examined (duration of transmission, number and length of pauses, and speech rate).

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