A Method for Calculating Air Traffic Controller Communication Complexity

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Abstract. Verbal communication is currently the primary tool Air Traffic Controllers (ATCos) use to manage traffic and ensure separation [1]. For these verbal communications to be effective they need to be clear, concise, and use proper phraseology. Under increased workload, however, ATCos may issue multiple commands in one transmission. Pilots commonly cite message complexity and length as a potential source of frustration and error [2]. The current study discusses an algorithm for calculating communication complexity values. This algorithm is applied to a simulated environment involving different speeds and numbers of Unmanned Aircraft Systems (UAS), examining the communications between the ATCos and the surrounding conventional aircraft. The findings suggest that the computer program for calculating communication complexity is a helpful tool for examining ATCo-pilot communications and can be used in future studies to analyze communications in dynamic environments.

Keywords: Communication complexity · Unmanned aircraft systems · Air traffic control

1 Introduction

Air traffic controllers (ATCos) manage traffic by issuing verbal commands to pilots. To be effective, these need to be clear, concise, and use proper phraseology. Under conditions of high workload, however, ATCos may compensate by including multiple commands per message. Increasing the complexity of messages is problematic as it can lead to increased pilot read back errors and increased requests for clarification. Pilots have cited complexity and length of ATCo commands as a source of frustration and potential error [2]. The current study presents an algorithm for calculating ATCo communication complexity. It applies this algorithm to communications between ATCos and conventional aircraft in a simulated environment where the number of Unmanned Aircraft Systems (UAS) and their speeds varied.

Although issuing complex, lengthy messages might help to reduce ATCo workload, it can also elevate pilots' working memory load [3]. Increasing demands on pilots' working memory can lead to more pilot requests for clarification (e.g., "say again" or "repeat last transmission") as well as more pilot read back errors. Pilot requests for clarifications congest the radio frequencies and this can be a distraction to

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an ATCo when there is an abundance of radio traffic. Additionally, pilot read back errors can be disastrous if not caught by the ATCo. It may be difficult for ATCos to catch all of these read back errors under high-density traffic situations.

Examining communication complexity is therefore important. Indeed, analyzing message content and structure can help determine the contributing factors that lead to aviation accidents and incidents as well as help describe common practices in ATCo-pilot communications [4]. It is also imperative to address the issue of communication complexity when implementing new technologies. These communication issues, for example, must be examined given the current mandate for UAS to be integrated into the NAS.

The methods described herein were applied to a study examining ATCo command complexity as a function of speed and number of UAS in a simulated environment. ATCo-conventional pilot communications were analyzed for their communication complexity. We predicted that as the number of UAS is increased, ATCo communication complexity would also increase. This is because, with a greater number of UAS present, each with complex routes through the sector, it is likely that ATCos would require more interactions with conventional AC to maintain safe separation. Additionally, we predicted that the faster the UAS the greater the ATCo communication complexity for conventional AC. This is because when UAS are slow, it is easier to for ATCos to structure the flow of conventional aircraft around the UAS. When UAS are faster, geometries become more difficult to predict and would require more communication and coordination. It was also predicted that increased communication complexity would be positively correlated with increased number of Losses of Separations (LOS) and ATCo workload.

2 Method

To extract communication complexity values of ATCo clearances, transmissions were broken down into communication elements. In the context of aviation, communication elements are recognized by their functional purpose or associated action plan (e.g., clearance/instructions, request, etc.) and are limited to specific aviation topics (speed, heading, altitude; [1]). ATCo communications frequently contain multiple commands in one transmission, each being composed of multiple communication elements. To calculate an overall communication complexity value for each ATCo transmission, the sum of all communication elements within each transmission was calculated.

A computer program was written using Visual Basic 2012 to separate ATCo transmissions between conventional pilots. The program analyzed transcribed audio files and extracted ATCo communications. The program cross-referenced ATCo communications against a researcher-defined database of complex and non-complex ATCo phraseology. If a phrase was not found in either database, the program would prompt the researcher with, “Is the presented phrase complex or not”? If the phrase was judged as non-complex the program would add it to the non-complex database. Otherwise the researcher was prompted to decide the phrase’s complexity value, number of aviation topics, and specific aviation topics. The complex phrase and its complexity value, number of aviation topics, and specific aviation topics were stored in the corresponding database. The program then calculated complexity values, number of aviation topics, and aviation topic types for each ATCo communication. From these calculations, average complexity, average number of aviation topics, and total word count were calculated for each transcribed file.

The Instruction Complexity Guide and Advisory Complexity Guide from [5] were used to ensure consistency and reliability of coding communication complexity values for ATCo phraseology. Consistent with these documents, each ATCo transmission was broken down into aviation topics (e.g., altitude, heading, speed) and each was assigned a complexity value; the larger the complexity value the more complex the transmission. The complexity guides have a column that consists of ATCo phraseology taken from [6]. The Instruction complexity guide examples can be seen in Table 1.

Table 1. Excerpt from the instruction/clearance complexity guide

AVIATION TOPIC	COMPLEXITY	PHRASEOLOGY EXAMPLE
Altitude	3	*(altitude) two digits* + THOUSAND
	2	*(altitude) one digit* + THOUSAND
	3	*(altitude) two digits* + HUNDRED
	2	*(altitude) one digit* + HUNDRED
	2	*(altitude) two digits*
	1	*(altitude) one digit*
	6	DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND *(altitude)* HUNDRED *three* *five*
	5	DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND *one zero*
	4	DESCEND/CLIMB & MAINTAIN *(altitude)* THOUSAND *four*
	*4-8	CONTINUE CLIMB/DESCENT TO *(altitude)*
	*4-8	AMEND YOUR ALTITUDE DESCEND/CLIMB AND MAINTAIN
	*3-7	*(altitude)* AMEND YOUR ALTITUDE MAINTAIN *(altitude)*
	*3-8	DESCEND/CLIMB TO *(altitude)*
	*2-6	MAINTAIN *(altitude)*
	*1-2	(*altitude,* omitted “THOUSAND” “HUNDRED”)

The coding scheme of [5] had 2 raters encode the same set of 25 randomly selected messages with an agreement rate of 95 %. A follow up analysis of 125 messages (using Krippendorff’s alpha) produced a value of .9898, indicating high inter-rater agreement. The current study’s coding scheme was similar to [5] and assigned a complexity value of 1 to every anchor, qualifier, direction, fix, waypoint, etc., as determined by the phraseology in [6]. To ensure consistency of data coding, two raters encoded the same set of 25 randomly selected messages and computed an agreement analysis against the computer program, which exceeded 0.80. For the present study seventy-two, forty-minute, audio recordings were transcribed and analyzed.

3 Results

The complexity coding method was applied to a study examining the influence of number and speed of UAS on ATCo's ability to manage traffic in a simulated environment that included both, conventional aircraft and UAS. ATCos received 9 experimental trials, each lasting 40 min. The trials differed in the number of UAS (1, 2, or 4) in the sector and the relative speed of the UAS (slow, mixed or fast).

A 3 (Speed: slow, mixed, or fast) X 3 (Number of UAS: 1 UAS, 2 UAS, or 4 UAS) ANOVA was conducted on the dependent variable Communication Complexity (calculated by the computer program). Due to the small sample size alpha was set at 0.10 for the current study. The analysis revealed a main effect of the Number of UAS on communication complexity, F(2,14) = 4.06, p = .041, η2 = .37 (see Fig. 1). However, contrary to the hypothesis, as the number of UAS increased, communication complexity decreased. Post hoc tests revealed that the 1 UAS scenarios (M = 6.22) had a higher complexity value than 2 UAS scenarios (M = 6.01; p = .026). They also revealed a difference between 1 UAS scenarios (M = 6.01) and 4 UAS scenarios (M = 5.98; p = .067).

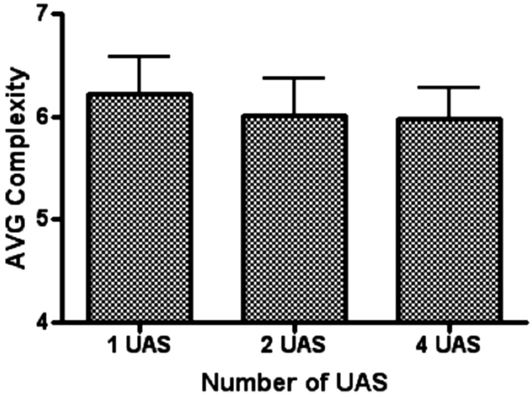

Fig. 1. Main effect of number of UAS on complexity

There was no effect of speed on communication complexity. However, there was a significant interaction between speed of UAS and number of UAS on communication complexity, $F(4,28) = 2.50$, $p = .065$, $\eta^2 = .26$. Simple effects analysis revealed a significant difference in communication complexity for different numbers of UAS when the UAS speed was fast, $F(2,14) = 4.29$, $p = .035$, $\eta^2 = .38$. Post hoc tests revealed communication complexity values significantly decreased as the number of UAS increased from 1 Fast UAS ($M = 6.27$) to 4 Fast UAS ($M = 5.86$; $p = .07$; see Fig. 2). There was no difference between 1 Fast UAS and 2 Fast UAS ($p = .401$) or 2 Fast UAS and 4 Fast UAS ($p = .997$). Simple affects analysis revealed no significant effects for number of UAS for Mixed or Slow speed scenarios.

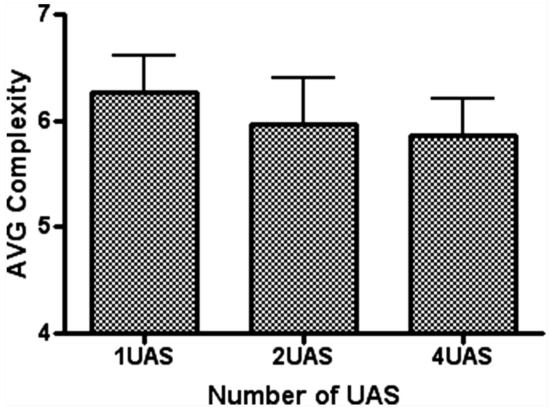

Fig. 2. Simple effect of number of UAS for fast speed

A simple effects analysis also revealed a significant difference in communication complexity for different speeds but only when there was 1 UAS in the sector, $F(2,14) = 4.16$, $p = .038$, $\eta^2 = .37$. Post hoc tests revealed a trend indicating that complexity values increased as the UAS speeds changed from 1 Slow UAS ($M = 5.94$) to 1 Mixed UAS ($M = 6.46$; $p = .16$). Complexity values decreased from 1 Mixed UAS to 1 Fast UAS ($M = 6.27$; $p = .54$). There was no communication complexity difference between 1 Slow UAS and 1 Fast UAS ($p = .338$; see Fig. 3). There were no simple effects of speed for 2 or 4 UAS. There were no other significant differences for number and speed of UAS.

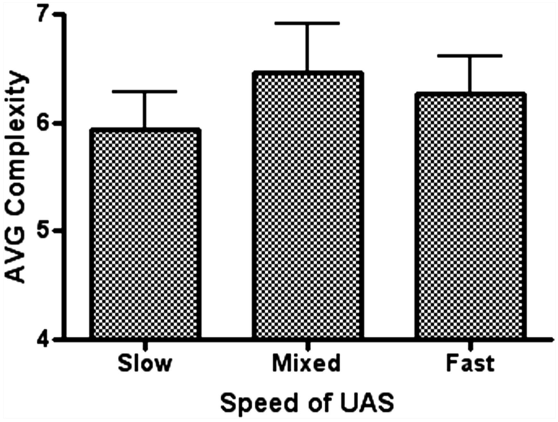

Fig. 3. Simple effect of speed for 1 UAS

Correlations were calculated relating communication complexity to ATCo workload (NASA-TLX) and safety (LOS). Beginning with workload, one significant positive correlation was found when examining communication complexity and workload in the mixed speed scenarios, $r = +.762$, $p = .029$; as the communication complexity increased the workload also increased. Although all other correlations for number and speed of UAS were not significant they were all positive, indicating a trend that workload and complexity are positively correlated (see Table 2).

Table 2. Correlations between communication complexity and workload-number and speed

Number	1 UAS WL	2 UAS WL	4 UAS WL	Speed	Slow WL	Mixed WL	Fast WL
1UAS complexity	+.568			Slow complexity	+.470		
2UAS complexity		+.519		Mixed complexity		+.762*	
4UAS complexity			+.505	Fast complexity			+.494

*Correlation significant at the 0.05 level (2-tailed).

Correlations between communication complexity and LOS were also examined. A significant correlation was found when there were 2 UAS in the sector (see Table 3). Although the remaining correlations for LOS and complexity were not significant, there was a trend toward LOS and complexity being positively correlated; the strongest correlations were for 2 UAS and Slow speed.

Table 3. Correlations between communication complexity and LOS-number & speed

Number	1UAS LOS	2UAS LOS	4UAS LOS	Speed	Slow LOS	Mixed LOS	Fast LOS
1UAS complexity	+.508			Slow complexity	+.530		
2UAS complexity		+.634**		Mixed complexity		+.424	
4 UAS complexity			+.225	Fast complexity			+.381

**Correlation significant at $p < .10$ (2-tailed).

4 Discussion

This study examined the effects of varying number and speed of UAS on ATCo communication complexity when issuing commands to conventional aircraft in a simulated environment. Results indicated that as the number of UAS increased in the sector the communication complexity actually decreased. Regarding workload, for UAS at mixed speeds workload was positively correlated with communication complexity. There was also a trend showing complexity was positively correlated with LOS when 2 UAS were in the sector.

The finding that as the number of UAS increased the communication complexity of ATCo commands to conventional pilots decreased was counter to expectations. One reason this may have occurred is that when there were less UAS in the sector there were more conventional aircraft present. The airspace may therefore have become more complex, and ATCos may have been forced to issue simpler (but more frequent) commands to conventional aircraft.

In support of this claim, [7] examined the same simulation and found there were in fact more ATCo-conventional pilot communications (per aircraft) with 4 UAS in the sector compared to when 1 or 2 UAS were in the sector. Therefore, when there were more UAS in the sector ATCos may be issuing less complex commands at a higher volume to conventional aircraft, simply because they cannot predict what commands should be issued ahead of time.

With respect to effects of UAS speed on communication complexity, there were no main effects, though the effect of speed did interact with number of UAS present. The general lack of significant results may simply reflect the fact that UAS speeds were in general slow compared to conventional aircraft and the fact that the number of UAS in the sector may be the most critical factor, and not speed, at least in terms of affecting communication complexity.

We predicted that number of LOS per scenario and ATCo workload would be positively correlated with communication complexity. We found that the complexity of ATCo commands was in fact positively correlated with workload when the UAS speeds were mixed. The changing UAS speed may thus have posed a challenge to ATCos, compared to when UAS speeds were constantly fast of slow.

Contrary to expectations, there were no statistically significant results relating LOS and communication complexity, possibly due to a small sample size. However, all correlations were positive, indicating a trend that when communication complexity increased the number of LOS also increased. Although further research is required, our findings thus suggest that decreasing communication complexity may help decrease the number of LOS.

To conclude, this study demonstrates that the method of calculating complexity can be a helpful tool for examining the safety and efficiency of the airspace. Moreover, it suggests that communication complexity is an important factor to consider when introducing new technologies, such as UAS, into the air traffic management system.

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