2013

Communication Sequences in Controller Pilot Communications

Jonathan Histon

Esa Rantanen

Cecilia Ovesdotter Alm

COMMUNICATION SEQUENCES IN CONTROLLER PILOT COMMUNICATIONS

Jonathan Histon
University of Waterloo
Waterloo, ON, Canada

Esa Rantanen and Cecilia Ovesdotter Alm
Rochester Institute of Technology
Rochester, NY, USA

Temporal patterns in the content of controller-pilot communications can reflect strategies and techniques used by controllers. Introducing data-based communication systems may profoundly impact these strategies and techniques. To establish a baseline of existing patterns in controller-pilot voice communications, analysis is presented of the content of air-ground communications between pilots and controllers from North American operations. Results are presented of the relative frequency of common sequences of communication events and how these vary in response to changes in weather conditions. Methodological challenges in sequence analysis as well as implications of the results for understanding effect of changes in communication technology on controller training and complexity management in future ATC environments are presented.

Introduction

This research examines the current, typical actions controllers perform on aircraft to better understand the strategies that controllers use in existing voice-based communications environment. Controller-pilot communications represent the primary (but not only) mechanism available to the controller to affect the evolution of the system being controlled. In particular, controller-pilot communications offer a robust indirect means to examine numerous aspects of controller performance and strategies that vary under different operational conditions, such as controller workload or weather conditions. In this paper we investigate sequences of transmissions from controllers to pilots. These sequences provide insight into the degree of standardization of the existing task. Examination of differences in the sequences under different conditions provides insight into how controller strategies vary with conditions. The primary focus of this paper is on documenting the analysis process. We also report initial results comparing sequences used in different weather conditions.

Previous Work on Communications Analysis

It is hardly surprising that controller-pilot communications have been studied extensively over the past several decades. Air traffic controllers' work is primarily cognitive and therefore difficult to observe. Until very recently, voice communications between controllers and pilots, and between controllers responsible for different airspaces, have provided the only observable indicators of controllers' decision processes, strategies, and workload. Because voice has been the only link between controllers and pilots, such communications have been used as an indirect measure of myriad variables of interest. Very briefly, voice communications have been analyzed in different ways to examine covert constructs such as controller workload (e.g., Manning et al., 2002), controller situation awareness (e.g., Metzger & Parasuraman, 2006; Gil et al., 2008), controller performance through communication errors (e.g., Prinzo et al., 2007; Cardosi, 1993), trust and preference for communication modes (e.g., Stedmon et al., 2007; Metzger & Parasuraman, 2006; Sharples et al., 2007), controller strategies (e.g., Histon, 2008; Filho, 2012), and language proficiency (e.g., Prinzo et al., 2008).

Controller workload is one of the most critical aspects of controller performance. Numerous studies have shown workload and communications having a strong and robust interrelationship, making communication activity a preferred nonintrusive measure of workload (McGann et al., 1998; Manning et al., 2002). Specific communication variables that can be measured from ATC voice recordings or transcripts include duration of and frequency of verbal communication events (e.g. Hurst & Rose, 1978; Manning et al., 2002; Porterfield, 1997). Rantanen, Naseri, and Neogi (2007) analyzed diverse operational data from different en route center sectors and showed strong correlations between metrics such as dynamic density (Laudeman, Shelden, Branstrom, & Brasil, 1998) and number of conflicts and controller communication time. In experimental settings, manipulating communication load affects both subjective ratings and objective measures of workload (Casali & Wierwille, 1983). A more detailed review of past work on ATC communication analysis is provided in Histon, Rantanen, and Alm (2012).

Continuing Importance of Communications Analysis

With the advent of the NextGen ATC modernization the traditional means ATC has been done, that is, through voice communications between controllers and pilots, will fundamentally change. Although this change is inevitable and in many cases for the better, for voice communication is prone to errors and a clumsy way to accomplish the goals of ATC, it is important to carefully monitor also the unintended consequences of NextGen. For example, the loss of so-called "party-line" information (Hansman, et al., 1998) has raised concerns about the ability of flight crews to maintain situation awareness (Signore & Hong, 2000). Although this loss in awareness may be partly offset by the ability to retain and review controller-pilot datalink (CPDLC) messages (Metzger & Parasaruman, 2006) and the less disruptive nature of CPDLC where the text from a command can be stored and recalled later to ease a pilot's working memory and prevent task disruption. Yet, the use of CPDLC will in all likelihood significantly alter conflict resolution strategies and representations of the traffic situation shared amongst controllers (Kapp & Celine, 2006).

To systematically evaluate the changes in controller strategies, situation awareness, and workload, which remain all-important components of controller performance also under fully implemented NextGen, it is critical to have a valid and established baseline against which any changes—for better of worse—can be measured. The analyses presented in this paper focus on sequences in the content of the communications and the implementation of controller commands. As far as we know, these particular aspects of controller-pilot communication have not been systematically researched before.

Method

To document the actions controllers currently perform, nearly 90 hours of voice-based communication data were collected and coded. The following is an abbreviated description of the analysis process; a complete description can be found in Histon (2008). Recordings of two-way controller-pilot communications were obtained from two internet websites: www.atcmonitor.com and www.liveatc.net. These websites archive and stream live controller-pilot radio communications using private radio scanners. Observations were collected for seven en route sectors in the US. The sectors represent a range of types of operation (en route arrival and departure sectors, and sectors containing mostly overflights) and cover a range of different altitude strata. Data were roughly categorized into "good weather" and "poor weather" conditions by historical weather radar images. For each time period the data were collected, an analyst classified the time period as "good weather" or "poor weather" based on the presence of widespread convective returns in the general geographic area of each sector.

The time, aircraft addressed, and content of each transmission from the controller were determined. The coding scheme focused on controller–pilot communications; with the exception of pilots announcing their presence on frequency ("check-in" transmissions), pilot-controller communications were not coded. To categorize the content for analysis, each transmission by a controller was reduced to elemental communication events, or the smallest decomposition of parts of a transmission that would retain meaning to the recipient. For example, the transmission "Turn left twenty degrees for spacing" was parsed into the elements of "turn left twenty degrees" and "for spacing." Each elemental event was stored as a separate entry in the database.

Elemental communication events were grouped into seven "Categories": (1) Command, (2) instructions, (3) gathering information, (4) giving information, (5) handoff, (6) other, and (7) unknown. Each category was further subdivided into individual "Types" of events. For example, "Commands" were defined as elemental communication events that modified an aircraft's clearance either by requiring or permitting a modification to the aircraft's trajectory. The results of the coding were collected and archived in a SQL Server database.

A time-ordered description was developed of the elemental communication events for each flight in the data set (for example see the left column in Table 1). The sequence as a whole was then used for subsequent analysis and reporting. Due to the way data were stored in the database, sequences could be generated reflecting three different levels of abstraction of the communication events: (1) "Specific" sequences, including all details of each element of each transmission, (2) "Types of" sequences, retaining only the "Type of" each element of each transmission, and (3) "Categories of" sequences, retaining only the "Category of" each element of each transmission. An example of each type of sequence is shown in Table 1. In addition, filters were developed allowing analysts to restrict which communication events were included in a sequence. This was used to focus, for example, just on the commands employed by controllers. It also allowed analysts to eliminate superfluous parts of the data collected; for the purposes of the analysis presented here, "Roger/Acknowledgement" communication events, which were originally collected, were filtered out of the data set.

Table 1.
Examples of Same Sequence at Different Levels of Abstraction (Data From Sector C).

Specific Sequence		"Type of" Sequence		"Category of" Sequence	
Sequence	% of Flights	Sequence	% of Flights	Sequence	% of Flights
•Gave Altimeter Setting •Cross <MULRR> at <100> (FL / 100 Feet) •Cross <MULRR> at <250> Knots •Checkout to <EVANSVILLE APPROACH> (126.1)	4.0%	•Altimeter Setting •Cross <Fix> at <X> Feet •Cross <Fix> at <X> Knots •Checkout	4.6%	•Providing Information •Command •Command •Handoff	7.9%

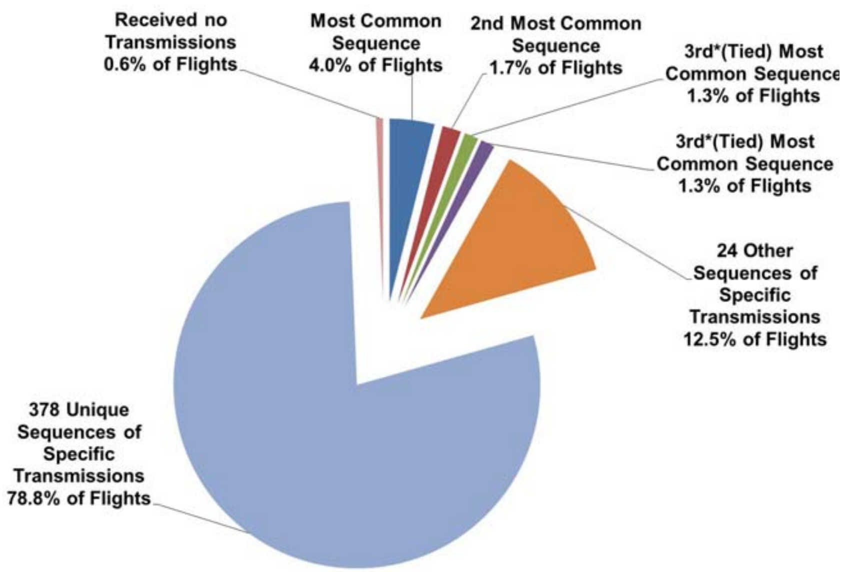
The results discussed below include consideration of unique sequences; a unique sequence is a sequence that one and only one aircraft received within the observation time for each sector. The results below report the total number of such sequences, rather than presenting each individual, unique, sequence.

Results

To demonstrate the effect of varying the level of abstraction on the frequency of sequences, Sector C is used as an illustrative case study. Figure 1shows the top 3 (and ties) most frequently occurring sequences when analyzing all transmissions at a "Specific" level of detail. The most common sequence reflects a standard pattern common to sectors that contain descending aircraft: an altimeter setting followed by a crossing restriction. In over 15.5 hours of data and nearly 500 flights, 75% of the "specific" sequences were completely unique to each aircraft.

The pattern of having a large number of unique "specific" sequences was observed across all sectors. More than half of all flights in every sector were unique in terms of the communication events generated by the controllers. This has important implications for both training and data-based operational concepts. A clear takeaway is that training is not about simply generating pre-determined scripts of actions; as much as observational evidence suggests there are regular recurring patterns in controller communications (Histon, 2008), in operational practice the specific communication events show significant variation in content. In addition, the high percentage of unique sequences also indicates that it is unlikely that standardized command sequences could be easily defined for a sector. Such standardized sequences could be one way of taking advantage of the ability of data-based communications.

To investigate whether similar patterns were found when the communication events are considered at a more abstract level, the same analysis was repeated for sequences generated using only the "Categories of" description of



Sequence	% of Flights
•Gave Altimeter Setting •Cross <MULRR> at <100> (FL / 100 Feet) •Cross <MULRR> at <250> Knots •Checkout to <EVANSVILLE APPROACH> (126.1)	4.0%
•Gave Altimeter Setting •Descend and Maintain <90> (FL / 100 Feet) •Checkout to <ZNY> (124.1)	1.7%
•Checkout to <ZNY> (132.5)	1.3%
•Direct to LRP (LANCASTER) •Cross <30 W OF LANCASTER> at <170> (FL / 100 Feet) •Gave Altimeter Setting •Checkout to <ZNY> (128)	1.3%

Figure 1. *"Specific Transmissions" sequences and % of flights observed for Sector C. Table shows details of top 3 (and ties) most common sequences.*

each communication event. The number of unique sequences was cut in half, while the proportion of flights receiving the most common sequences increased slightly (*Figure 2*).

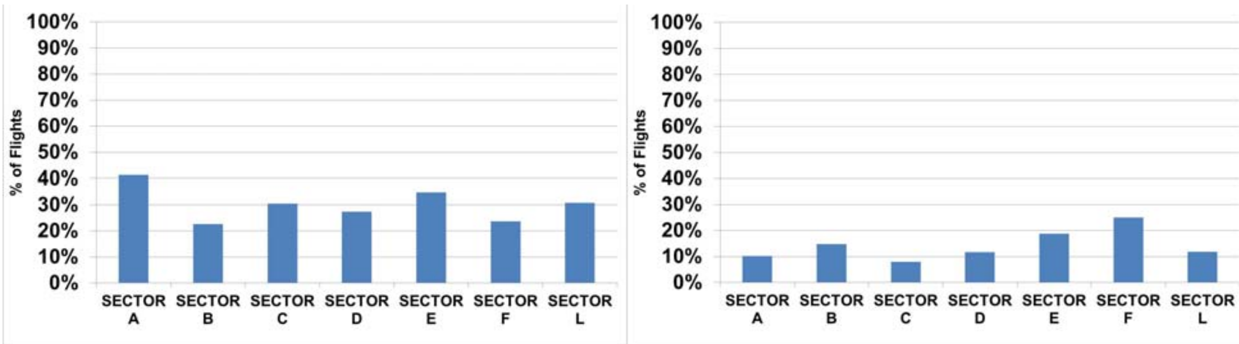


Figure 2. *Left, percent of flights receiving unique "Categories of" Transmissions" sequence for each sector. Right, percent of flights receiving the most common "Categories of" Transmissions" sequence in each sector.*

The analysis above took into account all of the transmissions in the dataset. To focus solely on actions taken by controllers that change an aircraft's trajectory, filters were created restricting the dataset to only those transmission events that are part of the "Command" category. Figure 3 (left) shows that the percentage of unique sequences of "Types of Commands" is relatively small but with some substantial sector-to-sector variation. The percentage of flights that receive the most common sequence is consistently approximately 10% across sectors (Figure 3, right).

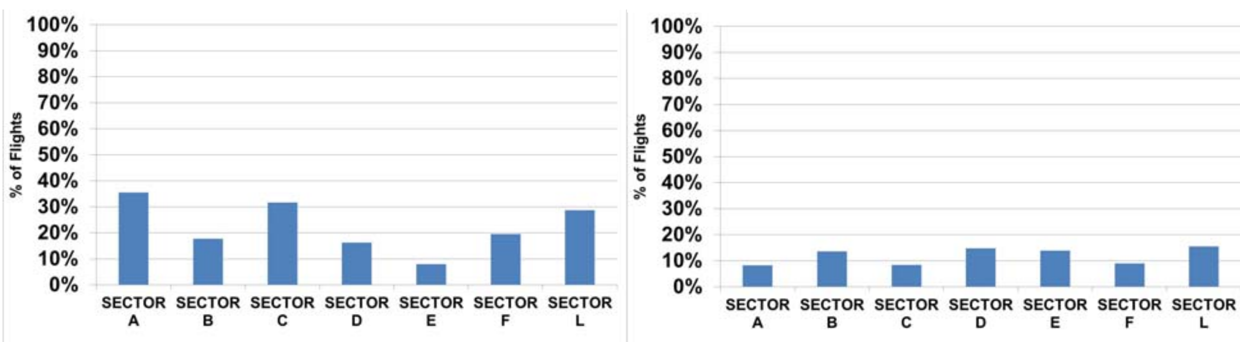


Figure 3. *Left, percent of flights receiving unique "Type of" commands sequence for each sector. Right, percent of flights receiving most common "Type of" commands sequence in each sector.*

These results illustrate how sequences of communication events can be analyzed at different levels of abstractions, and how the relative frequency of sequences varies across en route sectors. Of interest is also considering how sequences change under different operating conditions. Figure 4 shows the percentage of flights receiving unique sequences of commands generally increases under "Poor" weather conditions; this is consistent with the expectation that the presence of convection, poor rides, or other factors associated with poor weather would generate more pilot requests and more need for interventions in the system. There is also a general corresponding decrease in the percentage of flights that did not receive any commands at all.

Discussion

This paper is an initial exploration of the use of analysis of sequences of events. As described above, analysis can be conducted at different levels of abstraction of the communication events, and with different filters applied to support targeted analysis. Further work will address a number of opportunities to refine the techniques being developed and expand their use in controller strategy identification. In particular, the database has been developed in a way that promotes flexibility and the ability to incorporate alternate forms of analysis. For example, additional levels of abstraction could be introduced to refine analyses of commands; all altitude commands, or all speed commands can be grouped together providing the ability to discern patterns in which forms of maneuver are used and how this varies with conditions such as traffic load and/or weather conditions. There are also opportunities for integrating the use of computational linguistics modeling techniques for natural language data.

In addition, further analysis could incorporate the work of Filho (2012) in identifying subsets of traffic within each sector and examining the consistency of sequences for each grouping. While access to radar track data is not generally available, the sector an aircraft is handed off to is available for most of the data set and can be used as a crude measure for establishing groups. Alternate formulations of the underlying taxonomy could also be (relatively) easily introduced into the database and used for analysis. Distinguishing between different subtypes of en route sectors, for example distinguishing high level overflight sectors from low level arrival and departure sectors would allow for further comparisons and investigation of control action differences.

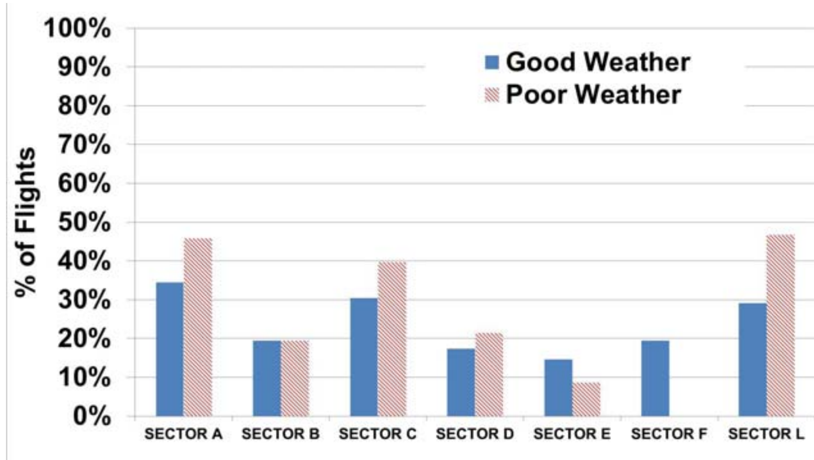


Figure 4. *Percent of flights receiving unique "Type of Command" sequences in "Good" and "Poor" weather for each sector.*

One of the challenges with the analysis of unique sequences presented above is that it is sensitive to the amount of data collected in each sector. The threshold for a unique sequence was always one aircraft; however, the likelihood of another aircraft sharing the same sequence of communication events is dependent on how long a time period is being analyzed. The longer the time period, the greater the chance of another aircraft receiving the same sequence. A more appropriate metric would be to consider "unique" sequences to be those that are received by less than a fixed percentage of aircraft (e.g. less than 0.5%). Using this definition, the proportion of unique sequences would not be affected by changes in the duration of data collected.

Finally, there are several methodological challenges to be addressed. A limitation of the current method is that it relies on analysts being able to hear and record the call sign for each flight. This can be difficult to maintain consistency of, particularly when a flight is present in two consecutive audio files; each file may be listened to by a different analyst, and establishing that the same call sign applies to flights recorded with different call signs is an ongoing challenge. While the data presented in this paper has been subject to quality control and validation tests, further work is needed to develop tools for making it easier to identify and correct mismatches in the data set.

Conclusion

In this paper we have reported novel means of analyzing controller-pilot communications. The primary purpose of the research was to develop methods for investigation of current patterns of communication that can be used to infer controllers' strategies, situation awareness, and workload. Communication sequences are very important in the current voice communication environment as standard sequences help reduce both controller and pilot workload and errors. Deviations from standard sequences may indicate nonroutine situations or high workload or degraded situation awareness. The latter inferences would have to be correlated with and corroborated by other measures, however. Our primary purpose with this research has been to establish a baseline of controller work to which changes brought about implementation of NextGen can be compared. Because of the envisioned extensive use of CPDLC under mature NextGen, it seems very important to have a thorough understanding of current ATC practices through objective measures derived from operational data.

References

Cardosi, K. M. (1993). Time required for transmission of time-critical air traffic control messages in an en route environment. *International Journal of Aviation Psychology, 3*(4), 303–313. doi:10.1207/s15327108ijap0304_4

Casali, J. G., & Wierwille, W. W. (1983). A comparison of rating scale, secondary- task, physiological, and primary-task workload estimation techniques in a simulated flight task emphasizing communications load. *Human Factors, 25*(6), 623– 641.

Filho, E. de A. (2012). *Analysis of airspace traffic structure and air traffic control techniques*. Unpublished Master's Dissertation, Massachusetts Institute of Technology.

Gil, F. O., Vismari, L. F. & Camargo Junior, J. B. (2008). Analysis of the CPDLC real time characteristics and the Mode S data link capacity. *Anais do VII SITRAER Anais... Rio de Janerio: Universidade Federal do Rio de Janeiro, v.1*, p. 92-99.

Hansman, R. J., Endsley, M., Farley, T., Vigeant-Langlois, L., & Amonlirdviman, K. (1998). The effect of shared information on pilot/controller situation awareness and re-route negotiation. *Proceedings of the 2nd FAA/Eurocontrol International Air Traffic Management R&D Seminar (ATM 98)*, Washington DC: FAA.

Histon, J. M. (2008). *Mitigating complexity in air traffic control: The role of structure-based abstractions*. Unpublished doctoral dissertation, Massachusetts Institute of Technology. Available from http://hdl.handle.net/1721.1/42006

Histon, J., Rantanen, E., & Alm, C. O. (2012). Air traffic control voice data analysis to validate NextGen procedures. In S. Landry (Ed.), *Advances in Human Aspects of Aviation (Advances in Human Factors and Ergonomics Series)* (pp. 129-138). Boca Raton, FL: CRC Press.

Hurst, M. W., & Rose, R. M. (1978). Objective workload and behavioural response in airport radar control rooms. *Ergonomics, 21*(7), 559-565.

Kapp, V., & Celine, C. (2006). Designing an ATC CPDLC environment as a common information space. *Proceedings of 2006 IEEE/AIAA 25TH Digital Avionics Systems Conference*, Portsmouth, OR.

Laudeman, I. V., Shelden, S. G., Branstrom, R., & Brasil, C. L. (1998). *Dynamic density: An air traffic management metric* (NASA-TM-1998–112226). Moffett Field, CA: NASA Ames research Center.

Manning, C. A., Mills, S. H., Fox, C. M., Pfleiderer, E. M., & Mogilka, H. J. (2002). *Using air traffic control taskload measures and communication events to predict subjective workload*. (DOT/FAA/AM-02/4). Washington, DC: FAA Office of Aerospace Medicine.

McGann, A., Morrow, D., Rodvold, M., & Macintosh, M. A. (1998). Mixed-media communication on the flight deck: A comparison of voice, data link, and mixed ATC environments. *International Journal of Aviation Psychology 8*, 137–156.

Metzger, U. & Parasuraman, R. (2006). Effects of automated conflict cuing and traffic density on air traffic controller performance and visual attention in a datalink environment. *International Journal of Aviation Psychology 16*(4): 343-62.

Porterfield, D. H. (1997). Evaluating controller communication time as a measure of workload. *International Journal of Aviation Psychology, 7*(2), 171-182.

Prinzo, O. V., Hendrix, A., Hendrix, R., (2007). The computation of communication complexity in air traffic control messages. *Proceedings of the 7th FAA/Eurocontrol ATM R&D Seminar*. Barcelona, Spain.

Prinzo, O. V., Hendrix, A. M., & Hendrix, R. (2008). *Pilot English language proficiency and the prevalence of communication problems at five U.S. air route traffic control centers*. (DOT/FAA/AM-08/21). Washington, DC: FAA.

Rantanen, E. M., Naseri, A., & Neogi, N. (2007). Evaluation of airspace complexity and dynamic density metrics derived from operational data. *Air Traffic Control Quarterly, 15*(1), 65-88.

Sharples, S., Stedmon, A., Cox, G., Nicholls, A., Shuttleworth, T. & Wilson, J (2007). Flightdeck and air traffic control collaboration evaluation (FACE): Evaluating aviation communication in the laboratory and field. *Applied Ergonomics 38*(4), 399-407.

Signore, T. L., & Hong, Y. (2000). Party-line communications in a data link environment. *In 19th Digital Avionics Systems Conference, Vol. 1* (pp. 2E4–1–2E4/8). IEEE.

Stedmon, A. W., Sharples, S., Littlewood, R., Cox, G., Patel, H., & Wilson, J. R. (2007). Datalink in air traffic management: Human factors issues in communications. *Applied Ergonomics, 38*(4), 473–480. doi:10.1016/j.apergo.2007.01.013