UNDERSTANDING CONTROLLER-PILOT INTERACTION DYNAMICS IN THE CONTEXT OF AIR TRAFFIC CONTROL

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Literature. New capabilities to modernize the U.S. National Airspace System (NAS) include support of real-time information streams derived from many data sources across the NAS. As an emergent property, safety of the NAS arises from interactions between many elements at different levels, ranging from those attributable to humans, technology, and the environment. Each component in the NAS needs to interact with other components, exchange resources and information, and operate under broad regulations to achieve overall system objectives (Harris & Stanton, 2010). Sometimes, incidents and accidents result from insufficient interaction (communication and coordination) between humans (e.g., pilot-controller). The content of communication provides value and supports understanding with a multitude of individual, group, team, and data sets within air traffic research. In addition, another dimension to communication with a potentially rich source of understanding is everything outside of its explicit meaning. Cooke and Gorman (2009) describe methods of communication flow between teams (considered to be a system) that have proven insightful. The first is a ratio of team members speech quantity, which can indicate the degree of influence one member has over others. Another is the communication required and passed score, or how much variation there is in actual team communication from expectations. Flow quantity represents how much speech each member of the team produces. Gorman et al.'s (2012) study applied discrete Recurrence Quantification Analysis (RQA) to team communication flow data in order to visualize and measure coordination dynamics of Unnamed Aircraft Vehicle (UAV) teams, both mixed teams (i.e., team members changed) and intact teams (i.e., team members stayed the same over successive experimental sessions). Interestingly, mixed teams were better able to adjust to unexpected perturbations; this ability was linked to team level coordination dynamics. That is, mixed teams adopted a globally stable pattern of communication while exhibiting strong temporal dependence (Gorman, Cooke, Amazeen, & Fouse, 2012). Similarly, Demir, Cooke, & Amazeen (2018) applied discrete RQA on human-robot interaction in an Urban Search and Rescue task and multivariate extension of RQA on human-synthetic team in a UAV task. They underline that metastable team coordination (not too stable nor too flexible) between team members is associated with the ability to successfully overcome novel events (i.e., team situation awareness) in a dynamic task environment. The current project addresses the question of how human factors related to air traffic control (ATC), specifically situation awareness and cognitive load, interact with other factors in the NAS to affect ATC performance and a result in a safe and effective NAS? One way to answer this question is focusing on ATC-pilot communication as a chief performance indicator. In the current study, we investigate the potential of dynamical systems perspectives to capture the differential dynamics of three cases between controller-pilot communication flow during incidents and accidents.

Method. One of the approaches for investigating interaction patterns between system components (in the controller-pilot case) and their change over time involves looking at communication flow using discrete Recurrence Plot (RP) and corresponding Recurrence Quantification Analysis (RQA), which quantifies how many recurrences with a certain length are present by multidimensional space (phase space) trajectory in a dynamical system (Marwan, Carmen Romano, Thiel, & Kurths, 2007). RP is the basis of discrete RQA (Eckmann, Kamphorst, & Ruelle, 1987), which is a visual tool for demonstrating a system's recurrent structure in the phase space when a system revisits specific states or sequences of states within a region of phase space over a period of time. In the case of two or more systems, discrete RP displays the times when two or more separate dynamical systems show a recurrence simultaneously (Marwan et al., 2007). Three cases of controller-pilot audio transmissions with their communication time stamps were obtained from "Cockpit Voice Recorder Transcripts" (2019), visualized using RP, and analyzed via discrete RQA. The cases represent situations of particular interest, communication, and coordination. Discrete RQA quantifies not only the effect of interventions (such as unexpected events) on instability, but also the dyad interaction processes and the dynamics that contribute to that process. The RQA was used to produce several measures, including percent recurrence rate, percent determinism (DET), longest diagonal line, longest vertical line, entropy, and laminarity. Of these, the focal variable was determinism (Marwan et al., 2007), which indicates the amount of organization in the communication of a system. DET is derived from the recurrence plot by examining how the recurrent points are distributed. Dyads with high determinism tend to repeat sequences of states many times, while a controller-pilot with low determinism rarely repeats a sequence of states, producing few diagonal lines.

Results and discussion. One of the objectives of this study is to monitor human performance indicators in real-time in the NAS to make predictions about risk. The current exploratory paper presents an idea about how to model human interaction between two or more roles with the larger purpose of developing NAS risk prognostics. We have presented three controller-pilot communication flows via discrete RP and RQA methods that differentiate three real cases based on discrete interaction sequences. The measures extracted from the RQA and visualizations of the interaction patterns show that effective communication and coordination is needed for effective situation awareness, i.e., overcoming the failures. Based on previous studies (Demir et al., 2018), we expected that the rigidity of the coordination dynamics between controller and pilot in one of the cases would associated with a fatal accident as well as lack of communication (confusion during the landing), resulting in a lack of situation awareness. On the other hand, two other incidents demonstrated more flexible behavior across the roles (controller-pilot) to adapt to the dynamic environment. In this case, the key lies in the dynamic transition between interaction and the environment. The controller and pilot are compelled to adjust their interaction patterns (flexibility) to adapt to changes in the environment and maintain a stable trajectory toward meeting their goals, such as landing safely. Thus, there are three crucial states for effective interaction in both temporal and spatial states: what needs to be communicated, when it needs to be coordinated, and how it needs to be communicated and coordinated".

Acknowledgements. This work is supported by a cooperative agreement award (NNX17AJ86A) from the National Aeronautics and Space Administration (NASA). The views expressed are those of the authors and do not reflect the official policy or position of the National Aeronautics and Space Administration, U.S. Government, or Arizona State University.

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