A FRAMEWORK FOR THE EVALUATION OF AIR TRAFFIC CONTROL COMPLEXITY

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Abstract

Many studies have been conducted in an attempt to determine the complexity involved in handling an Air Traffic Control (ATC) situation. As the aviation community moves towards a "free flight" environment, traffic complexity may not necessarily increase or decrease, but it will most certainly change. To that end, traffic complexity, as it is perceived by the controllers, who will still be ultimately responsible for traffic separation, becomes increasingly more important to understand. Previous studies of ATC complexity have based their measures on the amount of physical workload experienced by an Air Traffic Specialist (ATS). Unfortunately, many of these studies typically discount the importance of the cognitive activities of the controller, simply because this information is not easily measured. It is our position, however, that the complexity of ATC is better revealed through the analysis of controller strategies and decision making activities (cognitive tasks), and that this type of complexity may not be accurately reflected through measures of physical workload alone. In this paper, we will describe a framework for developing and evaluating a model of the perceived complexity of an air traffic situation, with specific regard to the traffic characteristics that impact the cognitive abilities of the controller. The framework does not depend on any specific type of procedures for ATC, so it may be used to evaluate complexity in both the current and future ATC environments.

Introduction

The motivation to develop and evaluate a model of air traffic complexity comes from the recent introduction of the "free flight" concept and procedures for Air Traffic Control (ATC) [10]. Many descriptions of the free flight system state that safety will not be compromised. However, to ensure safety in any complex system, it is necessary to understand the impact of any major changes in system procedures on the operators of that system. This proactive understanding enables procedures to be developed for maximum system benefits (in terms of safety and cost), without physically and mentally overloading the operators responsible for that system.

The basic premise of free flight is that pilots can choose the most direct (and presumably optimal) flight paths to reach their destinations [10]. In this scenario, normal separation assurance and traffic routing will be the responsibility of the pilots, while the controllers will assume a more passive, monitoring role. However, controllers will still be expected to assume control under certain conditions.* The question is whether or not controllers will be able to easily and effectively intervene when needed. The answer to this problem depends upon the complexity of the situation and the capabilities and limitations of the controller. Some interesting work has described the problems associated with requiring a system operator to quickly transition from a monitoring to an active control mode [3], and surely these findings can be generalized to the domain of air traffic control.

Other incarnations of free flight may not necessarily restrict the controller to assume a primarily monitoring role, but in any case, the fact remains that there are going to be new complexities associated with the future ATC system. These complexities will exist in both in the structure of the ATC environment and in the structure of the traffic itself. In order for us to move towards the best design for this future ATC system, it

* As proposed, controller intervention will only occur when: (1) tactical conflict resolutions are needed, (2) flow management requirements for busy airports need to be satisfied (3) resolution of unauthorized special use airspace (SUA) entry is needed, and (4) flight safety violations are imminent.

is important to be able to understand these complexities and the impact they will have on the human operators of that system.

In this paper, we describe a proposed method for evaluating the complexity of ATC. This framework is designed to help us determine and evaluate a model of the perceived complexity of an air traffic situation, with specific regard to the traffic and airspace characteristics that impact the cognitive and physical abilities of the controller. Controller input to the definition of complexity is extremely important, due to their extensive amount of knowledge of the domain. Consequently, this framework calls for expert controllers to be used to help identify and evaluate complexity factors and to participate in simulations designed to further develop the complexity measure.

The framework described herein does not necessarily depend on any specific type of procedures for ATC, but initial work will be focused on understanding complexity under current ATC procedures. Once our model of complexity has been tested and verified under current ATC procedures, it may be used to examine the impact that free flight procedures might have on the controller. In order to do so, we may be required to modify our model as the details of free flight procedures are further defined.

This paper will begin with a description of the mental and physical processes required to effectively control traffic. These processes will first be described in terms of how they are impacted by the complexity of an air traffic situation under current ATC procedures. Following this, a description of the expected changes in these processes, based on the proposed free flight procedures, will be presented.

After the controller task processes are described, a review of the existing literature will be presented. Previous studies have focused on the measurement of physical actions as an indication of ATC complexity. However, since a controller's mental processes are also heavily impacted by increased complexity, some illustrative examples are presented which support the argument that measures of physical processes are not enough in order to fully understand the complexity of ATC. This section will also describe some of the difficulties associated with evaluating and measuring the mental processes.

Finally, we present our framework for evaluating ATC complexity. This framework will describe the various means by which we are trying to identify factors that influence ATC complexity. Within the framework, we will also describe the methods used to evaluate the impact that complexity has on the mental processes undertaken by controllers.

The complexity of air traffic control is influenced by many factors, including the abilities of each specific controller, the equipment available, and the complexities of the ATC environment itself. While these aspects of complexity are meaningful to study, we chose to define our measure of complexity based on the air traffic situation itself. Therefore, in the discussion of ATC below, we focus on the events or factors in a traffic situation that impact the physical and cognitive processes required by the controller in order to maintain a safe and efficient flow of traffic.

The Complexity of Air Traffic Control

Required Task Processes

A controller's primary task is to maintain separation. In order to do so, s/he must use aircraft information, information on the airspace, and any other available resources to effectively control and predict potential conflicts that jeopardize this separation. These conflicts can include conflicts between two aircraft, conflicts between aircraft paths and airspace, and conflicts between the demand and capacity of a particular airport. Air traffic control, with respect to conflict resolution, typically has four main processes: planning, implementation, monitoring, and evaluation. These processes, along with a discussion of how they are impacted by air traffic complexity, are presented below.

In the planning process, the controller's goal is to determine the best course of action needed to resolve each traffic conflict. This process typically results in a set of re-routes, vectors, speed assignments, altitude changes, coordination with other controllers, or other control actions. However, as part of this planning process, the controller must also evaluate the impact that a given control action, which is intended to solve one particular conflict, might have on the rest of the system. Once the controller completes the planning process and has determined the necessary control actions to be taken, the controller implements the plan through the use of various communication and data entry tasks. Although this implementation may be viewed as only being a physical task, if the implementation itself requires some sort of planned coordination, then the distinction of whether the implementation is a physical task or a mental task is not entirely clear. After implementation, the controller must then monitor the situation to ensure the conformance of the situation to the plan, and to evaluate the effectiveness of the plan in resolving the conflicts.

The complexity associated with these processes stems from the fact that all of the above tasks, except, perhaps, the actual implementation of the plan, rely heavily on the cognitive abilities of the controller. Further, each of these tasks is continuously being performed for different aircraft at different times, and each of the processes may result in the initiation of another process, as shown in the diagram below.

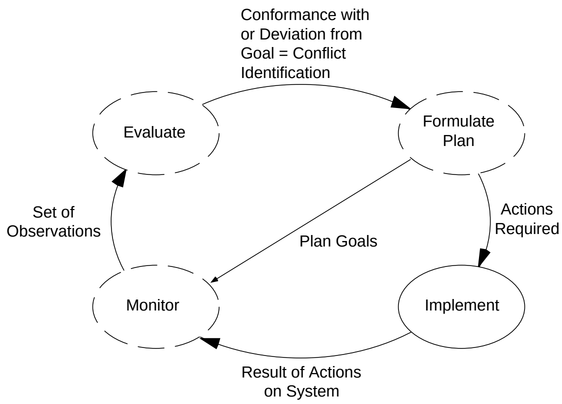

Figure 1. Mental and Physical Processes Required in Air Traffic Control

The "Implement" process is comprised of the physical actions required to carry out a specific plan. According to this diagram, this process is indicated by a solid oval and is the only externally observable process in air traffic control. The other processes, indicated with dashed ovals, are internal processes that combine to determine the level of mental effort required for air traffic control. According to the diagram above, then, the complexity of ATC is realized through the evaluation of the combination of the physical and mental tasks or processes that a controller needs to perform.

Current Vs. Future Complexities

The complexity of air traffic control is of particular importance in the study of the free flight concept for ATC. The removal of many of the procedures that are currently used for the control of air traffic as advocated by the free flight concept will most likely affect all of the task elements (both physical and mental tasks) that must be conducted by the ATS. For example, the process of evaluating a traffic situation and determining the conflicts that will arise will most likely become more difficult for a number of different reasons. The loss of the current existing organization of traffic flows that is created through the use of non-free flight ATC procedures will potentially increase the number of possible conflicts that might occur. By assigning each aircraft to a specific route selected from a finite and relatively small set of routes, today's controller is significantly reducing the number of locations at which aircraft may come into conflict. Additionally, when two aircraft are assigned to the same route, they are separated by altitude or by time along the route. This separation can then be easily maintained and monitored through the use of various methods, such as speed control. The controller simply ensures that the distance between the aircraft does not decrease below that which is acceptable, by assigning speeds if necessary.

Two or more aircraft on the same route, with speeds matched to ensure separation, combine to form what is referred to as a 'stream.' By creating multiple streams of aircraft, the current ATC procedures allow the controller to primarily focus on the intersection point of two streams, rather than having to analyze every aircraft against every other aircraft for a potential conflict. As mentioned above, separation is easily maintained and monitored through speed control, within a stream. Between streams, the particular aircraft that may conflict are easily identifiable because, based on speed, there will generally only be a few aircraft, at most, in each stream that have the potential to be involved in a conflict situation. The establishment of streams allows a simple identification of potential conflicts and further reduces the complexity (as experienced by the controller) of the air traffic situation.

It can be argued that both the evaluation and planning tasks will become more difficult under free flight procedures because of the increased flexibility that will be afforded aircraft. Under free flight, the controller will no longer know the <u>exact</u> route that an aircraft is expected to follow. The current RTCA definition of free flight allows aircraft the flexibility of selecting their own route, speed and altitude, with consideration for aircraft to aircraft conflicts, aircraft to airspace conflicts, capacity constraints, and safety [10]. Thus, a controller will be required to consider the possible conflicts that may occur in a region around an *estimate* of the route that the aircraft will follow in the evaluation and planning process. In this case, the controller experiences a considerable increase in the number of degrees of freedom that need to be managed.

The level of difficulty of monitoring an air traffic situation will most likely increase for a similar reason. Aircraft have the flexibility to select their own route under free flight procedures, and to change the route that they will fly at their discretion. Thus, it will be more difficult to predict the actions and intentions of aircraft. Controllers will have to monitor the flight path of each aircraft more closely to determine when an aircraft has decided to change course or speed.

Finally, the implementation task will most likely become less difficult under free flight. This is because free flight places much of the decision making process in the cockpit of the aircraft, unless the controller must take action for aircraft or airspace separation assurance, or for traffic management purposes. As stated above, under free flight, aircraft will select their own route. Thus, controllers will not provide route instructions, unless they have been required to take action for the previously identified reasons. However, implementation may be quite simple or very difficult, depending on the traffic structure and the goals of the aircraft.

Since humans have limited processing capabilities, and air traffic complexity impacts all of the processes described above, it is very possible that a controller can reach his or her limit of the level of complexity that is manageable. Therefore, it would prove useful to be able to create a measure of complexity that would allow us to determine when a controller is approaching the limits of his or her processing abilities. This measure could be used in the current ATC environment to predict and/or manage when a controller will reach his or her processing limits. Equally important is the fact that this measure could potentially be used to help understand the impact that free flight procedures will have on the air traffic controllers.

Previous Work

"Measures" of Complexity

A number of studies have already addressed the issue of measuring the complexity of an ATC situation (see [6] for an in-depth review). In some cases, these works have focused on an analysis of the amount of physical work required of an ATS [11, 12, 15]. In these studies, the goal was to use a measure of physical workload as an indication of the level of complexity of the situation under study. Data that provides an indication of the amount of time that a controller spends performing specific, identifiable, physical tasks in the process of handling the traffic situation is collected and analyzed. Results from these types of studies suggest that an increase in the amount of time spent performing these physical tasks is the result of an increase in controller workload; which can be considered to be the result of increased complexity.

An example of a system designed to collect this type of information is the Sector Design and Analysis Tool (SDAT) [8]. The SDAT provides a measurement of controller workload by processing System Analysis Recording (SAR) data from the FAA Host computer system. The SAR data contains all flight plan and radar track data for all aircraft that were handled in each of the sectors at an Air Route Traffic Control Center (ARTCC). In addition to this data, the SAR process records a significant amount of other system data, including all of the data entries that are made by an ATS in the process of controlling traffic. The SDAT tool then uses the number of recorded entries as an indication of the relative level of controller workload during that period of time.

Other studies have used a measurement of the amount of time a controller spends in communication, either with aircraft or with other controllers, as a measurement of workload. Thornhill [15] used the number of entries made by an ATS, the amount of time spent in communication, and other traffic-related factors to create a measure of the workload required to handle a traffic situation. Suggested applications of his work include the dynamic scheduling/staffing of controllers based on physical workload capacity. In this case, as complexity increases, he suggests that additional controllers may be required.

Still other studies have examined various traffic and airspace elements [5, 13] as a measure of complexity. In these studies, numerical counts such as the number of aircraft present in a sector, the number of arrivals, or the number of departures during a specific traffic period is used as a measure of complexity. Results from these studies suggest that an increase in the amount of traffic is related to an increase in traffic complexity. Another study examined the impact that sector geometry, combined with traffic density, had on controller performance [1]. Although performance may not necessarily be directly associated with complexity, this work did uncover a strong interaction between sector geometry and traffic density that could have implications for any study examining the effects of traffic density on perceived complexity.

Two Types of Workload

While many factors contribute to the complexity of an air traffic control situation, the impact of this complexity on the controller can be examined in terms of both physical and mental workload, as stated above. Throughout the remainder of this paper, "physical workload" will be used to refer to the level of physical activity required by a controller, resulting from performing tasks that are simply the interfaces of the controller with his or her operating environment. In other words, physical workload tasks are those tasks that are measurable external actions of the controller, used to implement a plan of action that has been previously determined. These types of tasks include the communications and data entry tasks that have been discussed above.

"Mental workload" will be used to refer to the amount of cognitive activity spent performing such tasks as the evaluating, planning, and monitoring necessary for effective air traffic control. A method for examining the factors that impact the performance of these types of tasks (mental tasks that require significant cognitive activity), and how a greater understanding of them may be incorporated into a measurement of complexity, will be described below. It must be noted that although these definitions treat physical and mental workload separately, problem solving and resolution typically places demands on both the physical and mental capabilities of the controller.

An Incomplete Picture

Although measurements such as the type and length of physical activity can be used as an indication of the complexity of an air traffic situation, many studies discount the fact that the amount of physical activity observed in a particular situation may not necessarily reflect the amount of cognitive activity required. In many of these studies, the focus has been on measuring the physical activity levels, and inferring the level of cognitive effort required. However, this inference may not necessarily be correct. Examples to support this argument are presented in the following scenarios.

Some of the procedures that are established for the control of air traffic require multiple or lengthy instructions to be communicated to every aircraft. Often, repetitive data entries may also be required. These tasks in themselves (i.e., not including the planning for these tasks) may become very familiar and automatic to the controller and require very little cognitive activity, even though a high level of physical workload may be required. For example, in some cases the planning necessary to vector an aircraft around an SUA may require a minimal amount of cognitive activity because the controller has performed the task multiple times in the past and is intimately familiar with the headings that will be required. However, this process may in fact require many clearances to be communicated to the aircraft, and may require a re-route to be entered into the system. Other examples of such tasks are vectoring aircraft on a standard traffic pattern, clearing an aircraft for an approach, making entries to hand an aircraft off to another sector, or entering common re-routes into the system. In this particular example, some previous studies might have identified the situation as being complex due to the high level of physical work activity (i.e., number of communications, number of data entries, etc.) required for control. Nevertheless, it is likely that the level of mental workload experienced would be relatively low.

Another example can be made of the process of turning an aircraft onto the base leg in a standard traffic pattern. While the implementation of this task requires only one brief clearance to the aircraft, the planning for this task requires the identification and creation of a slot for the aircraft on final approach, considering all other aircraft that are currently competing for such slots. This process in itself may require other planning, implementation and monitoring tasks to be performed, in order to create the needed slot. The key difference in this situation is that there is a great deal of cognitive activity involved in preparing for one short clearance. The task time and effort needed to issue a single clearance will not provide a meaningful measure of the amount of cognitive activity involved.

As mentioned before, we believe that the dependency on measuring physical activity and inferring the level of mental activity may not be the most appropriate method to understand air traffic complexity. As in the first example above, previous measures might have identified the situation as being complex due to the high level of physical activity required. However, it is likely that the complexity of the situation, viewed from a cognitive standpoint, would be considered low. Therefore, our measure will primarily focus on the factors of the air traffic situation that impact a controller's mental processes.

Measuring Mental Workload

Theoretically speaking, the "concept" of workload is better defined as a construct. That is, workload itself is not directly observable or measurable, but must be inferred, based on measures and observations of other elements (such as mental and physical tasks) [6, 14]. The selection of these elements will shape our definition and understanding of the workload being inferred.

Measurements such as the number of communications and data entries, as well as numerical counts of aircraft have been adopted primarily because this physical data is some of the only direct data that is readily available. Directly measuring the cognitive load that is being experienced is more difficult and, unfortunately, highly intrusive in a real-world, operational setting. However, if we maintain the position that simple keystrokes for data entry purposes eventually become somewhat of an automatic process, then it remains that the mental calculations and planning work required by a controller is the far more difficult aspect of the job. Therefore, a useful measure of complexity also needs to consider the details of an air traffic situation that affect the cognitive abilities of the controller, and not just the physical workload.

This paper will not attempt to define an exact model for measuring the cognitive functions of an ATS during control. As well, the work described in this paper was not designed to measure the amount of mental workload experienced by an ATS during problem solving (i.e., conflict detection and resolution) activities. Although an accurate mental workload measure would be very useful, and work has been done in this area, it is beyond the scope of this paper primarily because of the many problems associated with the measurement of mental workload associated with a particular task [9, 16]. Also, as stated in Charlton [2], there is very little agreement in the scientific community as to which measures should be used to best quantify the level of mental workload experienced in a given situation.

Therefore, the work in this paper presents a framework and an approach for measuring and evaluating the *perceived* complexity of an air traffic situation, with an emphasis on the traffic characteristics that impact the cognitive activity of the controller. Since we are dealing with the perceived complexity involved in an air traffic situation, we are required to communicate with as many controllers as possible in order to get a proper sampling of their perceptions, and a better understanding of the complexity associated with their jobs. The framework, as well as the various methods used to gain insight into controller perceptions of complexity will be described below.

The Evaluation Framework

The remainder of this paper is organized as follows: A list of initial complexity factors, identified by the researchers at Wyndemere, will first be presented. This will be followed by a description of a number of initial, exploratory simulations that were conducted to uncover any additional factors which could also be used in the final complexity measure. To further develop the complexity measure, a TMC from the Denver ARTCC facility was interviewed, and the information gained from this interview, as well as the manner in which it was obtained, is described. Next, a justification for, and a description of a "Complexity Focus Group" will be presented. This group will consist of a number of Full-Performance Level (FPL) controllers of varying levels of experience and from different control areas to help fine-tune the weightings assigned to the complexity factors used in our measure. Finally, a description of the proposed validation simulations will be presented.

Identifying Initial Complexity Factors

The researchers at Wyndemere have extensive hands on experience working in operational ATC facilities. For example, in developing air traffic control automation tools, Wyndemere staff have spent many hours working with controllers, traffic management specialists and other FAA personnel in various ARTCC facilities and Terminal Radar Approach CONtrol (TRACON) facilities. Many Wyndemere staff members have also attended full controller training courses at ATC facilities in order to gain or maintain an in depth understanding of the operations at a given facility.

Researchers at Wyndemere, relying on their experience in air traffic control procedures, airspace design and adaptation, air carrier operations, systems engineering, systems optimization, and airspace, route and trajectory analysis, held a number of meetings designed to identify a set of initial complexity factors that might be useful for a measurement of air traffic complexity. Input to these meetings included reviews of existing studies and various ATC manuals, which provided a background of information that could be used as a basis for identifying complexity factors. These meetings resulted in the identification of the following factors believed to influence perceived air traffic complexity:

- Special Use Airspace
- Proximity of Potential Conflicts to Sector Boundary
- Aircraft Density
- Number of Facilities
- Number of Aircraft Climbing or Descending
- Number of Crossing Altitude Profiles
- Variance in Aircraft Speed
- Variance in Directions of Flight
- Performance Mix of Traffic
- Winds
- Distribution of Closest Points of Approach
- Angle of Convergence in Conflict Situation
- Level of Knowledge of Intent of Aircraft
- Separation Requirements
- Coordination Required

Exploratory Simulations

In order to verify these factors as contributors to complexity, as well as to identify additional complexity factors, a number of ATC simulations were held at Wyndemere. For these simulations, current FPL controllers participated in a real-time, controller-in-the-loop ATC simulations of both current and free flight procedures. For simulation purposes, "free flight" was defined as each aircraft flying a direct route from a departure airport to an arrival airport.

The simulation system used in this study (the Pseudo Aircraft System (PAS) developed by Syre, a subsidiary of Logicon) utilizes pseudo-pilots at computer workstations who communicate with the controllers via headsets. The pseudo-pilots receive voice clearances and instructions from the controllers and enter the clearances into the simulation system. The system then simulates the dynamic response of the aircraft to the entered clearance. The aircraft locations are presented to the controllers on a workstation display that very closely resembles an actual controller radar display.

For the simulation sessions, the controllers were presented with two scenarios that use current flight procedures and two scenarios that use free flight procedures, as defined above. The scenarios were designed for a single sector simulation utilizing a high altitude sector in the southern region of Denver ARTCC. Controllers were given flight strips for each of the flights in the scenario. These flight strips indicated an airway-based route of flight for the current procedure scenarios and a direct route of flight for the free flight scenarios. The controllers were asked to 'think aloud' as they made their decisions on how to deal with the traffic situation. This verbal protocol data was collected, along with researcher comments on the thoughts and plans expressed by the controllers, during the simulation sessions [4]. Additional data recording was handled by the PAS simulation system. After each scenario, the controller was asked to assign a rating to the scenario as to how difficult the scenario was to control, considering both safety and efficiency.

Results from these simulations are still being analyzed, and additional simulations are being planned. However, a number of interesting initial results have been identified, which support some of the reasons for the expected increase in complexity under free flight procedures, and also provide some support for our initial complexity factors.

Preliminary Simulation Results. The first plot below (Figure 2) shows the latitudinal / longitudinal flight paths that would be followed by aircraft in one of the free flight scenarios, if no maneuvers were instructed or executed to avoid the conflicts. This scenario was designed to be the most complex free flight scenario with almost all of the aircraft in the scenario approaching a very small area of airspace at the same time.

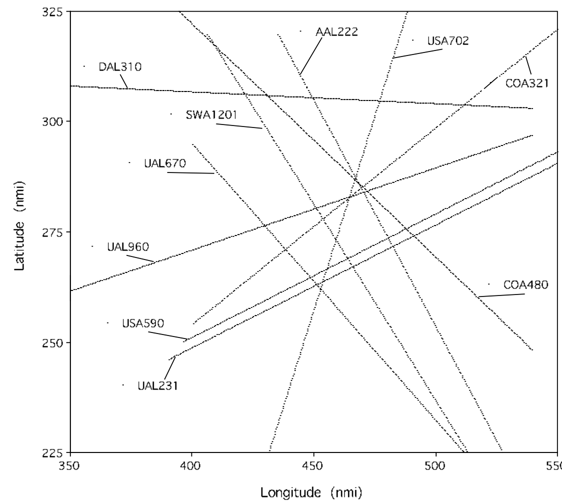

Figure 2. Latitudinal/Longitudinal Flight Tracks of Aircraft Under Simulated "Free Flight" Procedures

Figure 2 leaves out two critical dimensions of the four dimensional scenario--altitude and time. This particular scenario presented all aircraft at flight level 350, so it is not necessary to show a graph of aircraft altitudes. However, the conflict situations cannot be properly identified without a representation of the time dimension. The next two plots (Figures 3 and 4) show the longitudinal and latitudinal coordinates of each flight as a function of time, respectively.

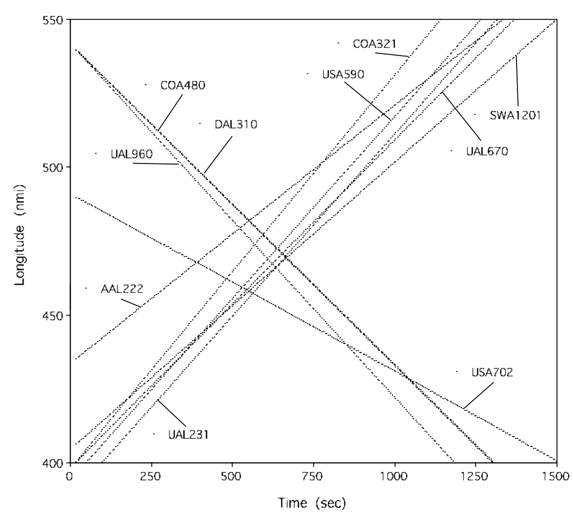

Figure 3. Longitudinal Position vs. Time for Simulated "Free Flight" Aircraft

It can be seen that many aircraft are within 5 miles of an (x) position of 470 miles (Figure 3) and a (y) position of 285 miles (Figure 4) from the coordinate system origin, approximately 8 minutes into the simulation. The density of traffic in this simulation was judged to be fairly high, and added to the complexity of the situation.

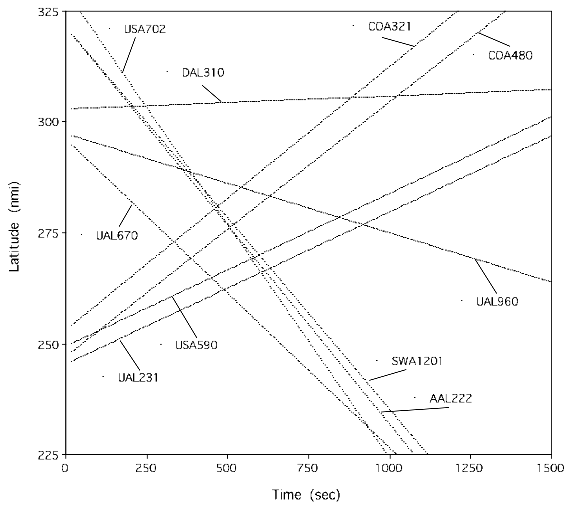

Figure 4. Latitudinal Position vs. Time for Simulated "Free Flight" Aircraft

Figure 5 shows the same scenario as controlled by a simulation subject. Again, the plot shows the latitudinal/longitudinal positions of each aircraft. The simulation subject was an FPL controller at an ARTCC facility. The controller used only 15 vectors to attempt to resolve the conflicts within a 10 minute time period. Clearly, the task time of implementing the plan that the controller developed was not excessive. This fact serves to confirm our belief that measures of physical task time alone are insufficient indications of complexity.

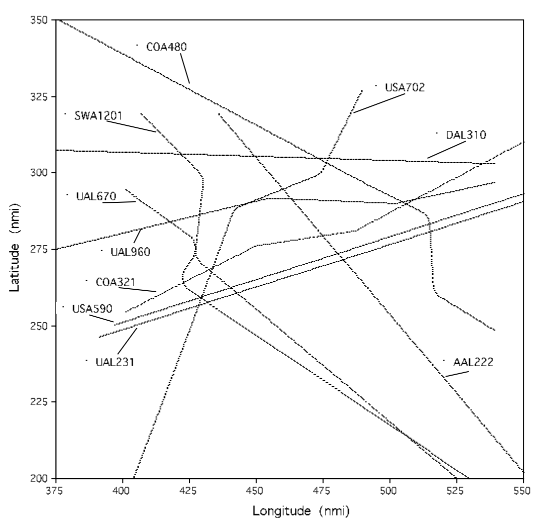

Figure 5. Latitudinal/Longitudinal Flight Tracks of Aircraft With ATC Commands Issued

The next two plots (Figures 6 and 7) again show the longitudinal and latitudinal coordinates of each flight, as controlled, as a function of time. Notice that UAL670 and COA321 were within 5 miles of each other at approximately 314 seconds into the simulation.

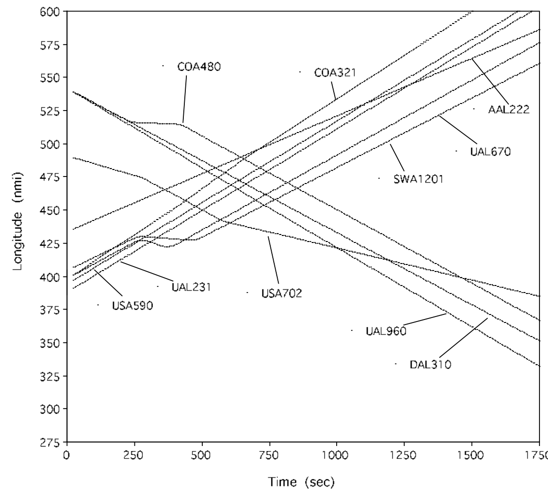

Figure 6. Longitudinal Position vs. Time for Controlled "Free Flight" Aircraft

The fact that the controller subject allowed these two aircraft to pass within the acceptable separation requirement might have been the result of the simulation environment itself. During the simulation, controllers were asked to verbally describe their actions, goals and strategies while controlling the aircraft [4]. Since most controllers are not required to provide protocol data during real-world operations, they are not entirely practiced at doing so for simulation purposes. However, as mentioned above, these were merely exploratory simulations and the key to the success of the simulations was to understand as much as possible about what the controller was doing and thinking during control. If verbal protocol data is collected in the same manner for the validation simulations, controllers will be given time to become practiced at providing this verbal data, to minimize the impact that it may have on the process of control.

Still, the presence of an operational error (with respect to separation minima) is an interesting issue worth further investigation. The error might suggest that the controller was operating too near the limits of his abilities. Although this was most likely due to the fact that the controller was asked to provide verbal information while controlling the aircraft, the high level of complexity of the scenario may have left very little mental resources available to provide this verbal protocol data along with acceptable performance. Additional simulations, designed to address the issue of complexity on operational errors, are currently being discussed.

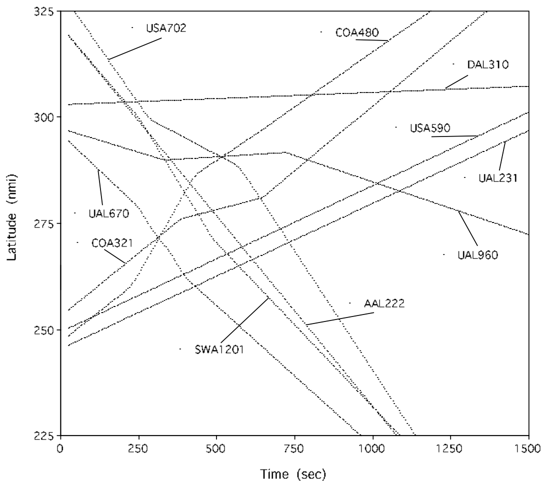

Figure 7. Latitudinal Position vs. Time for Controlled "Free Flight" Aircraft

An additional interesting result of the exploratory simulations was the significance that controllers placed on the knowledge of intent, or lack thereof, of the aircraft. The use of the PAS system did not allow sufficiently realistic pilot interactions for a true "free flight" scenario. As stated by the RTCA white paper on free flight [10], aircraft have the flexibility of VFR flight while being offered IFR protection. However, since the pseudo-pilot was controlling as many as twelve aircraft, it was not possible for the pseudo-pilot to determine what maneuvers would be realistic for each individual aircraft to make, in order to exploit that flexibility. This created a situation in which the scenario was no longer a true free flight scenario, because the controllers were able to trust that the aircraft wouldn't do anything that they were not instructed to do by the controller.

In simulation debriefings with the controller subjects about the issue of intent, it was indicated by the controllers that a strong difference in the level of complexity of the traffic situation would result if the aircraft were to actually maneuver on their own. Assessing this issue will be another focus of the future simulations that are currently being planned, and will be added to the list of factors that impact the perceived complexity of an air traffic situation.

Critical Decision Interview

In an attempt to verify our identified complexity factors, as well as to gain insight to other factors which contribute to traffic complexity, a Wyndemere researcher organized a meeting with a TMC from Denver ARTCC. During this meeting, the TMC participated in an interview session that was based on the Critical Decision Method of knowledge elicitation, developed by Klein, Calderwood, and MacGregor [7]. In the interview, the TMC was asked to identify past scenarios that stand out in his memory due to the fact that they were high in complexity. As part of the interview, the TMC was asked to describe his goals and expectancies for the situation, the cues used for action, the actions taken, the other available options, and the explicit factors responsible for making the scenario complex. The TMC was also allowed access to maps of Denver ARTCC airspace on which he could draw out the scenarios as he described them.

Results from this meeting reinforced the importance of a controller having knowledge of the intent of other aircraft. Also, the TMC indicated the complexities associated with certain air traffic situations and the impact they have on the amount of available airspace for use by a controller. For example, from the TMCs standpoint, the primary impact that a weather cell has on a sector is the fact that that area of the sector is no longer available for use by the pilots and controllers. In effect, the volume of usable airspace within a sector decreases in size when a weather cell is present. This, in turn, affects the overall density of aircraft distributed throughout the rest of the sector, which reduces the amount of freedom the controller has for aircraft routing. Therefore, sector density and the presence of weather are two factors that might be considered to contribute to the perceived complexity of an air traffic situation.

Complexity Focus Group

The next step in the process will be to assign weighting values to each of the complexity factors, for use in the complexity measure. In order to properly assign these weightings, the collection of complexity factors will be presented to a sample of current FPL controllers. The overall impact on the cognitive abilities of controllers of each of the individual factors may also have dependencies on some of the other factors. Therefore, the multiplicative effects between factors and even within multiple occurrences of the same factor, if appropriate, will also be examined. During these sessions, the controllers will be asked to rate the factors in terms of their absolute level of contribution to the complexity of an air traffic situation. In addition, the controllers will be asked to rank these factors (and factor pairs) against themselves in order to understand the relative relationships between these factors, and how the relationship affects the perceived complexity.

The results from this part of the study will aid in the identification of the factors that contribute to the complexity of an air traffic situation. In addition, the relative weighting portion of the study will provide some insight as to how factor weightings should be assigned.

Validation Simulations

Validation of the complexity measure, once the algorithm is completed and the weightings have been assigned, will be the focus of future simulation experiments. This validation has the potential to be very complicated due to the large number of factors that may be included in the model. However, the planned validation methodology is to generate a number of scenarios of varied levels of complexity. Each of these scenarios will be controlled in simulation by a number of different controller subjects. After each test case, the controller subjects will be asked to evaluate the complexity of the traffic scenario using an established ranking scale. This ranking scale will use specific questions about the ease with which safety was maintained, the difficulty of providing an efficient flow, as well as an indication of the overall perceived complexity. The rankings from all of the controllers on each scenario will then be combined, and the distribution of these rankings will be used as an indication of the accuracy of the ranking. We will then compare these rankings with the complexity measure calculated by our model, to determine whether or not our model accurately represents a controller's perception of air traffic complexity.

In addition to the controller subject's ranking of the scenario, various simulation data items will be recorded. This data will include the flight paths followed by each aircraft and the commands given by the controller subject to the pilots. This data will be analyzed to determine if any operational errors occurred during the simulation, and to determine the level of efficiency of the flights in the scenario. Lower levels of efficiency may be an indication that the controller was too busy to provide a more efficient flight, thereby providing an indication that the particular scenario was overly complex. Similarly, operational errors may be considered as indications that the controller was again too busy with other tasks to notice a conflict or to resolve a conflict in a timely manner. Note that these 'other tasks' include all the tasks involved in the air traffic control process, not necessarily just the cognitive tasks. Finally, the measurement of the number of commands that the controller issues to aircraft during the test case will be used as a measurement of the controller's physical workload during the simulation test case.

Conclusions

A framework for evaluating the characteristics of an air traffic situation that impact the cognitive abilities of the controller has been presented. The approach described in this paper is currently being implemented, and a complexity analysis tool that analyzes an air traffic situation and computes the level of complexity is currently being developed. This complexity measurement will be further validated through simulation experiments, to be conducted once the model is complete.

Utilizing a measurement of the communications and data entry tasks is not an effective method to measure the complexity of the air traffic situation. The processes and tasks involved in the control of air traffic are highly cognitive tasks and it is not necessarily true that the observable implementation (physical actions) of the results of these cognitive tasks provides a good correlation with the complexity of the cognitive processes themselves. Therefore, to better understand the complexity of an air traffic situation, we need to consider the cognitive tasks required of the controller--the planning, monitoring, and evaluating tasks

The information gained from a validated measurement of the complexity of a controller's task can be used in many aspects of air traffic management, planning, and the development of new procedures. This measurement would prove even more useful if it could be used in a predictive manner. Such a measurement/prediction would allow traffic management decisions to be made with consideration for the impact they will have on individual controllers and sectors. As well, this measurement would also be useful for understanding the impact that proposed procedural changes will have on the controller and the ATC system. Finally, a complexity prediction capability could also be incorporated in the development of new ATC automation tools, so that the suggestions and advisories generated by the tools would be required to consider the resulting complexity of the air traffic situation.

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