DEVELOPING VISUALIZATION TOOLS FOR THE DESIGN OF AIR TRAFFIC CONTROL EXPERIMENTS

ABSTRACT

While there has been significant research in the development of visualization tools for users of technology, little attention has been paid to developing visualization tools for human factors researchers designing experiments. From a design of experiments perspective, it is difficult to design video game-like experiments like those in found in air traffic control research because of the need to control potential confounds such as consistency of scenarios and possible learning effects. When designing scenarios, the state and consistency of initial conditions can critically affect the experiment's outcome. In this paper, we discuss several tools and techniques that were developed to better visualize these initial conditions and easily export them to interface software. The key feature of these tools is that they are straightforward and fast to use, they provide a graphical interface for the experiment designer, and ultimately they can reduce the total design time for each experiment.

INTRODUCTION

While there has been significant research in the development of visualization tools for users of technology, little attention has been paid to developing visualization tools for those human factors researchers and practitioners designing experiments. Designing an experiment that involves measuring human performance in a dynamic environment like that of Air Traffic Control (ATC) is difficult because of the complexity of the simulations. In addition, from a statistical design perspective, it is equally difficult to design video game-like experiments because of the need for controlling possible learning effects through counterbalancing, as well as the control of other potential confounds such as consistency of scenarios.

When designing test scenarios that involve dynamic entities such as aircraft that move in three dimensions, one critical concern is the establishment of initial conditions because the state and consistency of initial conditions can critically affect the experiment's outcome and results. Initial conditions are defined as "conditions at an initial time from which a given set of mathematical equations or physical system evolves" (Initial Conditions, n.d.). The state of the initial conditions will determine the possible states of system evolution. Initial conditions can determine whether or not a dynamic system remains stable (or bounded). For the purposes of this paper, and in the context of experimental design, "stability" can be defined as *that attribute of the dependent variable that allows it to be free from change or variation due to confounding and uncontrolled variables*. Under this context, an "unstable" experiment is defined as one whose dependent variables have been significantly confounded due to inappropriate selection of the initial conditions, to the degree that no valid conclusions can be drawn on the effect of the independent variables. For the experiment to be "stable" the impact of confounding variables on dependent variables due to initial conditions should be lower, on orders of magnitude, than the influence of the independent variables on dependent variables.

In many experimental contexts, such as in Air Traffic Control (ATC), inconsistent initial conditions and situations can confound the experiment (Johnson, 1995) The development and verification of the initial conditions can often be cumbersome and time consuming. It is therefore important to develop visualization tools that allow for a better comprehension of the effect and consequence of a set of initial conditions (Hurrion, 1993).Based on our experiences in developing ATC experiments, we have identified a number of core issues regarding the use of initial conditions and their importance in scenario generation. Below we discuss some of these issues and present visualization tools that we have developed in response to some of those issues.

SIGNIFICANCE OF INITIAL CONDITIONS IN EXPERIMENTAL DESIGN

We have identified several issues concerning the effect of the initial conditions on experimental design and validity. A primary concern is the consistency across the scenarios, so that only the independent variables of interest are varied. In every scenario it is usually desired that certain factors and parameters be kept constant so that the independent variables remain controlled and isolated. On the other hand, we often want scenarios to appear superficially different in order to minimize the learning effect, while keeping the experimental context as consistent as possible across the experimental conditions. Therefore the tool used to generate scenarios should have the capability of superficially transforming the initial conditions while still preserving the assumption that one is only manipulating the independent variables.

A second issue that has been identified in scenario design for experiments is that of aiding the prediction of unintended and unanticipated events that could unfold during the simulation. Scenario design tools that give the researcher the ability to visualize the initial states and perhaps also their discrete projection into some point in the future, as well as reduce the amount of required mental abstraction, Thus it is easier to detect and correct those problems that could have otherwise arisen (Wollkind, 2004). Furthermore the researcher gains a better understanding and expectation of what the human subject will encounter during the simulation prior to actually running it.

Tools that allow the better comprehension of the effects and consequences of a set of initial conditions, combined with the ability to generate multiple scenarios that are governed by the same set of rules are therefore of great use in maintaining experimental stability. These tools also reduce the amount of time it takes to design a valid experiment.

In the next section we discuss several tools and techniques that were developed for our ATC experiments. These tools made it easier to better visualize the initial conditions, create the scenarios and quickly export the data as variables into the interface software.

ATC INITIAL CONDITIONS AND SCENARIO GENERATION TOOLS

In order to address some of these design of experiments issues in the ATC domain, we have developed computer-based tools that can considerably shorten the time expended in designing an experiment. We will first briefly discuss the basic requirements that an initial conditions generator (ICG) is expected to fulfill in order to ensure its convenience for use, and then briefly explain how this sort of tool was used in ATC experiments.

First, an ICG has to ensure a user-friendly interface that provides ease of data manipulation (Herren, 1997). Second, just as it is important to aid analysts of large problem spaces through visualization (Schneiderman, 1987), is equally important that experiment designers have a visual interface that can enhance the understanding of the Initial Conditions (IC) setup. Oftentimes, ICs require the satisfaction of certain constraints and hence many parameters may need to be computed. This laborious and time-consuming task can many times be incorporated to the ICG. Finally, as its name suggests, an ICG should produce a list of statements, usually a algorithmic code, that can be saved and loaded by the experimental interface. It is also very desirable for the ICG to be able to generate other ICs given certain transformation rules.

An aircraft, waypoint and no-fly-zone (AWAN) ICG was developed for an Air Traffic Control (ATC) experiment and is presented below. For this specific experiment, seven characteristics needed to be set for each aircraft (Figure 1). The blue table to the left represents the user interface and the grid space to the right represents the design space.

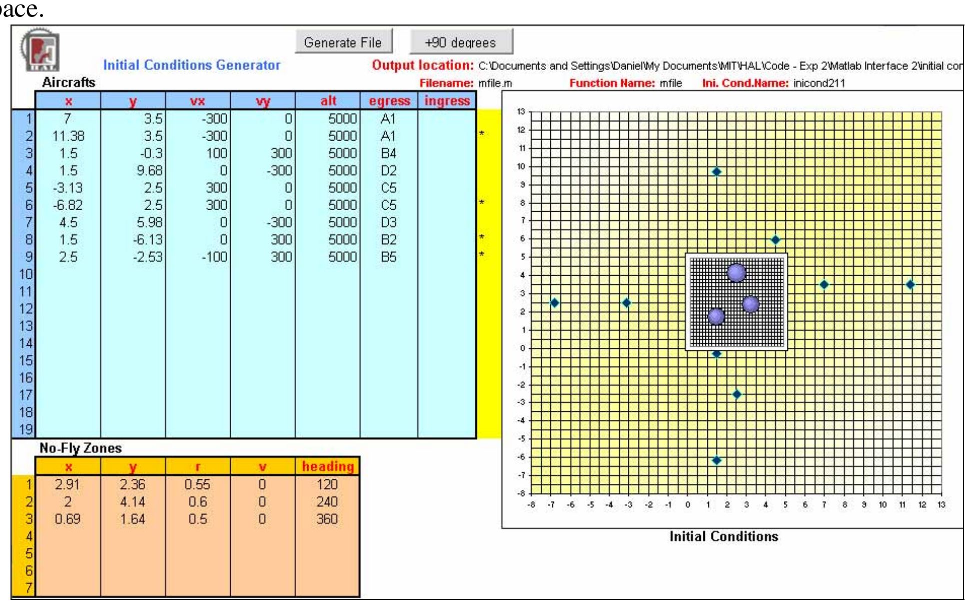

Figure 1: ICG interface (Aircrafts and No-Fly-Zones)

In addition, five others characteristics for the no-fly-zones and three for each waypoint needed to be defined. Furthermore, in some scenarios optimal routes had to be calculated. In this experiment, over six hundred and fifty constants had to be set.

In this context, the ICG enabled the designers to delegate the task of laborious coding to automation and the visual interface considerably reduces the amount of mental abstraction required to appreciate the airspace arrangement and troubleshoot potential problematic scenarios (Figure 2). The platform also allowed the user to effortlessly change and save the ICs.

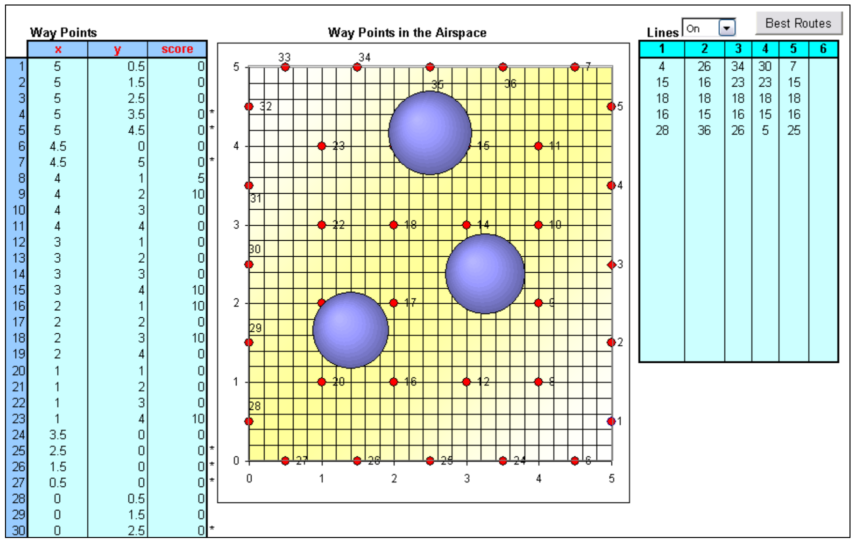

Figure 2 - ICG interface (waypoints and best routes)

In this particular experiment, four scenarios were necessary and had to be the same across the experiment except for two independent variables. However, in order to avoid predictability and the effect of learning within the scenarios, to the scenarios needed to appear completely different to the subjects. Therefore the foundation scenario was rotated by ninety degrees to create another three views. This simple transformation would have been very time consuming if not automated. It was done by multiplying all the relevant initial condition vectors by a 2D rotation matrix. The ability to automate any parameter's calculation is extremely helpful during this phase of the experimental design. Finally, since the interface was coded in Matlab©, the ICG was required to produce a code compatible with that interface. The resulting experimental test bed interface and associated IC output during a scenario can be seen in Figure 3.

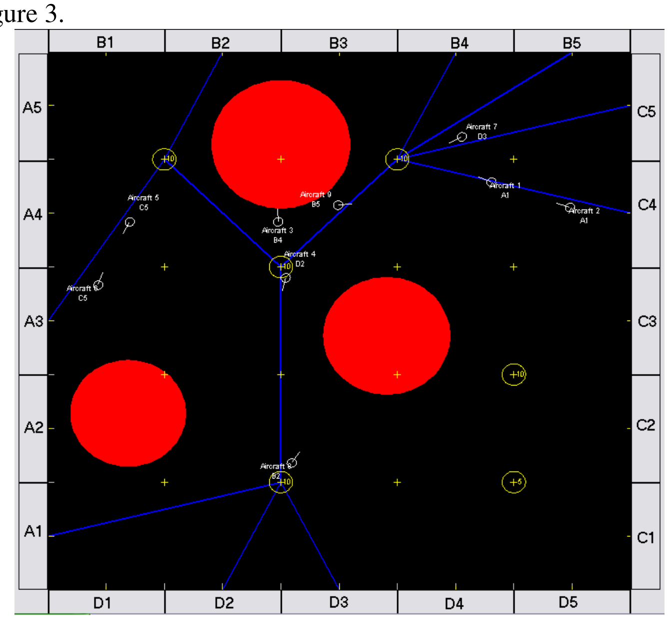

Figure 3: ATC experimental interface that made use of the AWAN ICG

Another tool has also been developed in order to aid in the design of a distinct ATC experiment. In this experiment, aircraft flew at constant altitude, speed, and heading, but were presented in different structural configurations. As there was no user intervention in the scenario, the initial conditions of the aircraft involved uniquely determined all events that would occur during the course of the experiment. In order to ensure the consistency of the scenarios that were developed across the multiple structural configurations, a Trajectory Visualization Tool (TVT) was developed. A screen shot of the tool is shown in Figure 4. The tool:

- presented a list of all aircraft involved in the scenario (listing at left)
- highlighted those involved in conflict situations (red background in listing at left),
- highlighted those involved in near conflicts (yellow background in listing at left),
- provided a timeline of entry and exit times for all aircraft (important for managing total number of aircraft on-screen at any time in the experiment)
- displayed spatial representation of aircraft trajectories (upper right)
- showed relative distance as a function of time (lower right).

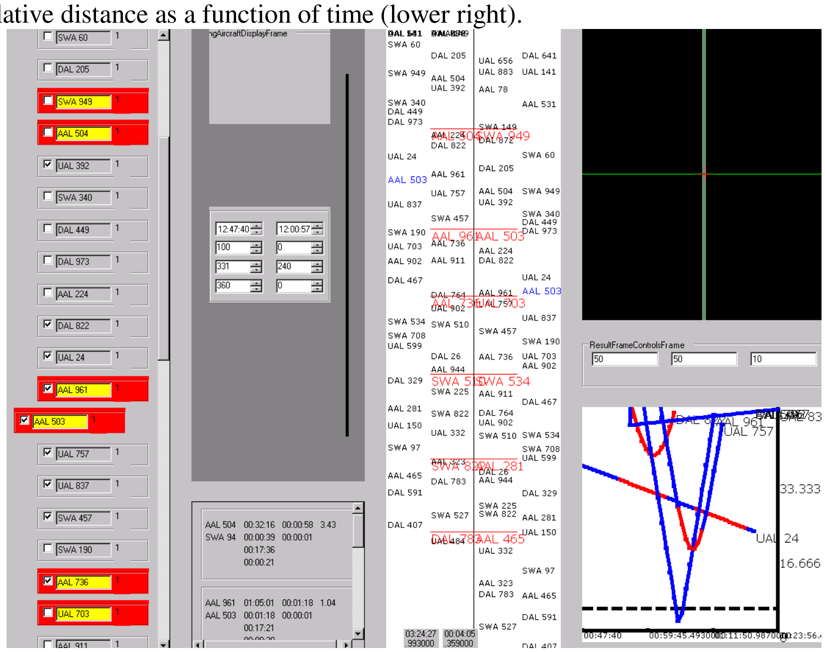

Figure 4: TVT interface.

An important criterion in the scenario design was to ensure that there were no near conflicts (aircraft that came close, but did not violate the separation standard). Because of the deterministic dynamics in the experiment, the tool could be used to evaluate the points of closest approach amongst the set of aircraft. This allowed the quick visualization of the changes brought about by small adjustments in the initial conditions for one aircraft. For example as the speed for an aircraft was increased, the separation distance at the point of closest approach for all aircraft was automatically updated in the temporal display (lower right). This provided an ability to understand the dependencies that existed between aircraft in the scenario, and eliminated the unexpected and undesired “accidental” conflicts or near conflicts from all scenarios.

CONCLUSION:

As summarized above, this paper conveys the importance of developing visualization tools for human factors researchers designing experiments. In this paper we introduced the concept of experimental stability and explained the importance of selecting appropriate initial conditions. Visualization tools help us control potential confounds such as the consistency of scenarios and possible learning effects. Therefore scenarios must be able to be transformed on a superficial level that does not introduce confounding uncontrolled variables.

The tools presented in this paper are developed in the context of ATC, but the same general principles and concepts can be extended to experiments in other dynamic environments. The key feature of these tools is that once developed, the process of scenario generation becomes much more efficient. Initial condition visualization tools provide a graphical interface for the experiment designer, and can ultimately reduce the total design time for each experiment, while improving the quality of the results.

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