

Agent-Based Modeling and Simulation of Collaborative Air Traffic Flow Management Using Brahms

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ABSTRACT

The air traffic demand on the US national airspace frequently exceeds its available capacity. In current operations, the Air Traffic Service Provider designs and implements air traffic management initiatives with minimal interaction with the airlines. NASA and its partners have developed a new collaborative air traffic flow management concept of operations that involves the users of the airspace to a greater degree. In this paper, we describe an agent-based simulation of the new concept of operations and our planned experimentation to determine if the new concept of operations will lead to better utilization of the national airspace.

INTRODUCTION

The current air traffic demand on the US national airspace frequently exceeds its available capacity, due to a large number of factors including bad weather, over-scheduling by the airlines, national security, and air traffic control equipment outages. This demand is only projected to increase significantly over the next decade [1]. In current operations, the Air

Traffic Service Provider (ATSP) designs and implements air traffic management initiatives (TMIs) [2] (such as ground delay programs) with minimal interaction with the airlines. NASA and its partners have developed a new collaborative air traffic flow management concept of operations [3] that involves the users of the airspace to a greater degree. Our primary research questions are determining if, and to what degree, collaboration can lead to better traffic management initiatives than the ATSP working alone. The new approach must not impose unmanageable workloads on the ATSP or permit manipulation by any organization in the system. Towards this end, we are using an agent-based modeling and simulation (ABMS) approach to model the individual participants using a multi-dimensional, multi-party negotiation protocol that enables the airlines and ATSP to solve the airspace congestion problem more collaboratively.

In this paper, we will report on our research plan using the Brahms [4,5] agent-based modeling and simulation environment. Brahms is an agent-oriented language using a belief-

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desire-intention (BDI) architecture developed at NASA. Using Brahms, we are modeling the airline operation centers and the ATSP as communicating BDI agents. We are also integrating FACET [6] (an airspace system simulation tool) as a separate simulated NAS agent within the simulated collaboration framework, allowing us to evaluate the performance of collaboration strategies in simulation. We then experiment with the simulation to determine if the new concept of operations will lead to better (i.e. more efficient) traffic flow and that the collaboration workload is tolerable to both the airlines and the ATSP.

This work builds on our previous analysis of the concept of operations in which we used low fidelity to determine that collaboration will lead to improved utilization of the NAS [17, 18, 19]. In this paper, we describe an analysis based on a higher fidelity simulation models to more accurately determine the benefits and limitations of the concept of operations.

We have structured this paper as follows. We first introduce the new concept of operations in detail. We then describe the Brahms systems and highlight some of its previous applications. With Brahms introduced, we describe the simulation of the concept of operations that we are building and the experiments we plan to undertake to evaluate it.

PROPOSED COLLABORATIVE CONCEPT OF OPERATIONS

In current operations, the ATSP is responsible for identifying demand and capacity imbalances in the NAS, designing TMs to counter them, then communicating the resulting initiatives to the users. The proposed concept of operations developed by NASA and its collaborators is structured into four phases and is designed to engage the airspace users throughout the process. We introduce each phase in turn.

PHASE 1: PROBLEM IDENTIFICATION

The users and the ATSP identify problems in the NAS that will lead to demand and capacity imbalances. This includes looking at factors such as weather reports, sector monitor alert parameters, ATSP staffing and maintenance plans, and special use airspace (SUAs). This phase is primarily about communicating to ensure that the users and the ATSP are equally aware of the set of problems facing the NAS.

PHASE 2: IMPACT ASSESSMENT

With a common understanding of the set of problem in the NAS, the users and service providers collaborate to understand the impact of those problems. The two groups bring different perspectives that are essential to determining a complete picture of an issue's impact. The service provider understands the demand across the NAS from all the users and the resultant total projected demand in a region at a given time. The users have a richer model of their individual flights contributing to the national demand including the importance of each within the context of its business model.

PHASE 3: FLOW PLANNING

With a common understanding of both the problems in the NAS and the impact of those problems on the users, the ATSP and users design TMs that will bring demand inline with capacity while minimizing the impact on the users and maintaining a safe and controllable flow of flights for the ATSP to manage.

PHASE 4: FLIGHT PLANNING

With the main flows defined, the users and service provider work together to allocate individual flights to each flow. The users will seek to minimize the disruption to their business while the service provider works to ensure equity in the allocation of the flows between the users.

AGENT-BASED MODELING AND SIMULATION TECHNOLOGIES

Intelligent software systems, referred to as *agents*, perform tasks in the same way teams of humans perform them today. The community has produced a broad set of technologies that can be readily used to simulate the proposed concept of operations on computers. This simulation approach will allow a broad range of design options to be evaluated to determine if the proposed concept of operations is feasible and what factors it is sensitive to. The results will allow the design of focused human simulations to validate and refine the results before the concept is moved towards implementation.

A number of the technologies developed in this community are relevant to evaluating the concept of operations. While in this paper we focus specifically on *negotiation* techniques in Phase 3, we briefly outline all that are applicable here.

PHASE 1: PROBLEM IDENTIFICATION

This phase centers around principled discussions on what is projected to happen in the NAS. Users will disagree amongst themselves and with the ATSP based on different data and projection models, especially in the case of weather.

The agent-based community has developed argumentation technologies that allow agents (software and/or human) to structure their arguments in a principled way to ensure all parties are heard and a collective decision is made [7,8]. We are exploring the use of these technologies in an operational environment with the focused area of Collaborative Convective Forecast Product (CCFP) as a present day example of a comparable process.

PHASE 2: IMPACT ASSESSMENT

This phase has many of the same properties as phase 2. The agents' disagreements will be primarily rooted in different data and projection

models. Argumentation techniques are again readily applicable. Confidentiality is also an important issue as users will be reluctant to give away pieces of information that can be combined by competitors to infer competitive business intelligence. The agent-based community has much work in this area that could be applied to see if private and sensitive information is revealed during the discussions at this phase [9].

PHASE 3: FLOW PLANNING

Collaborative flow planning leads to a more competitive type of interaction where the goal of each individual user is to operate his business as cost effectively as possible, while maximizing market share. Negotiation and auction approaches [10] refined in the agent-based community from the rich work in game theory are designed specifically for these types of interactions. The application of these techniques is the focus of our work in this paper

PHASE 4: FLIGHT PLANNING

This phase is another example of competitive interaction where maximizing profit and market share are the drivers. A related research group within NASA is exploring the use of auction technologies to manage the collaboration at this phase [11].

BRAHMS AGENT-BASED MODEL SYSTEM TOOLSET

Brahms [4,5] is an ABMS, developed for over a decade, as a way to model and simulate people within a social and physical world. It has found multiple applications at NASA and is currently operational within mission control handling the previous human task of synchronizing files between the International Space Station and mission control [12, 13].

Brahms agents can represent individuals, groups of individuals or model-based systems such as software agents. Agents can belong to multiple groups. Agents represent the world

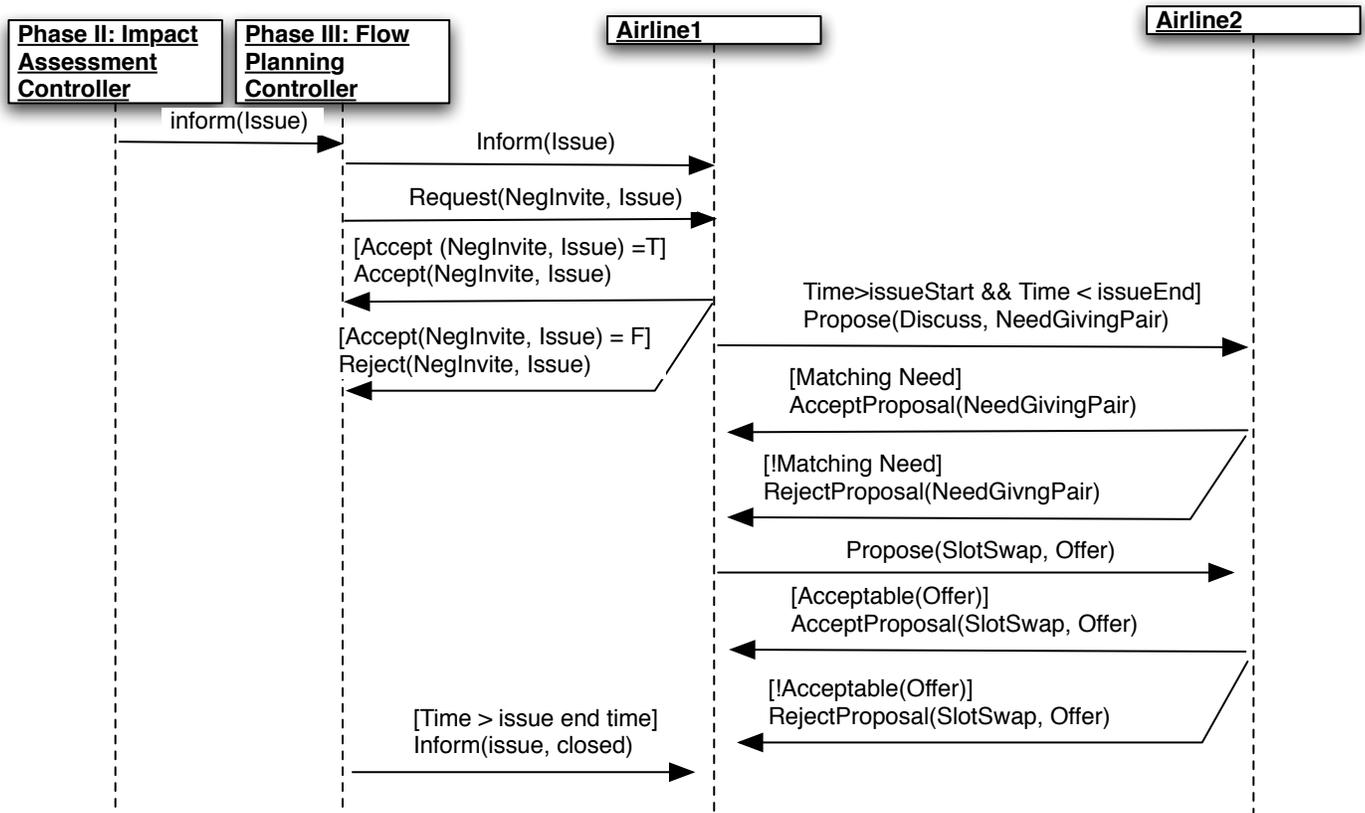


Figure 1: Negotiation Protocol

state internally as propositions called beliefs. It is possible for agents to have contradictory beliefs. For example, National Airline 1 might believe that the thunderstorm will move north while Regional Airline 7 may believe the storm will fade out in the same time window.

All agent behavior is represented in terms of activities. Brahms has an activity-based subsumption architecture by which an agent's activities can be decomposed into subactivities.

An agent engaged in a low-level activity is still performing the high-activity of which it is part, for example posing a question while in a meeting. Activities can be interrupted and resumed just like humans multitask

Like humans, agents exchange information through communication activities and activities are triggered by changes to an agent's beliefs.

Brahms' focus on providing constructs for modeling interactions between organizations

and people is precisely the tool set required to evaluate the concept of operations through simulation.

PHASE 3 NEGOTIATION PROTOCOL DESIGN AND IMPLEMENTATION IN BRAHMS

Our task is to design and evaluate a negotiation mechanism that will allow airspace users and the ATSP to find traffic flow plan solutions that maximize the overall benefit to the users while maintaining equality and a safe controllable airspace for the ATSP. The ABMS community's negotiation approaches are designed to manage just this type of competitive collaboration. In a negotiation, each agent may make offers to the general community of agents that are in turn accepted, rejected or countered. Agents typically make low initial offers and increase their value until mutually beneficial solutions are found.

A negotiation framework is composed of a protocol defining the possible messages and

obligations of participants together with strategies that the agents can follow during the negotiation [14]. Our task as evaluators of the concept of operations is to design a solid protocol and then evaluate a range of strategies. Airspace users will ultimately develop sophisticated strategies tuned to their business models; our goal is just to ensure that such strategies are readily developed and the protocol ensures a fair and level playing field.

NEGOTIATION PROTOCOL DESIGN

Figure 1 presents our protocol design. It is derived from the agent-based communities standards body (FIPA) body's work [16] and has been enhanced for this application domain.

The protocol begins with the issues and impact assessment results of the first two phases being distributed by the ATSP to the airspace users. The users are then invited to participate in the forthcoming negotiation on each. Users electing to not participate will still be given equal access to the airspace by the ATSP but will not have their preferences considered.

Negotiation begins with the airspace users first looking for other users willing to discuss complementary problems or "*need giving pairs*" as we term them as agents typically have a need in one part of their airspace for which they are willing to give up something in another part. Once a pair is found, the agents begin a negotiation conversation seeking a mutually beneficial agreement.

AGENT NEGOTIATION STRATEGIES

Our agent negotiation strategies are derived from the work of Fatima et. al. [15]. The users formulate an initial and a reserve position on each issue in the NAS. The reserve position denotes the maximum amount that a user is prepared to give up on an issue. In this domain this may correspond to the number of flights a user can accept being delayed. The initial position denotes the agent's starting offer position on an issue. This may be much less

than the reserve position. As the negotiation progresses, airspace users increase their offers from the initial position until either an agreement is found or the reserve position is reached.

The approach an agent takes in moving between these two positions denotes its negotiation strategy. There are two extremes. A *conceding* strategy will immediately move to its reserve position. A *hold out* strategy will wait until the time period for the negotiation is almost over before increasing its offer from the initial to the reserve position. In the middle, a *linear* strategy will increase the amount offered on an issue linearly throughout the negotiation time window.

EXPERIMENT DESIGN

We are in the process of designing experiments to answer the following question:

- *Will inter airline negotiation alleviate the congestion problem in the NAS?*

We have broken this into several sub questions for empirical investigation

- Can airlines find the solutions?
- Will the solutions be optimal or at least better than the current ATSP's?
- Is negotiation sensitive to the mix of airline types and the type of airspace problem?
- What airline negotiation strategies will emerge?
- How long will the negotiation take?
- Will airspace users be able to manipulate the system?
- How do you design the mechanisms to prevent manipulation?

CONCLUSION

We have described our approach to evaluating a concept of operations designed to improve user involvement in the design and implementation of solutions to demand and capability imbalances. We detailed ABMS technologies applicable to evaluating each phase of the concept of operations and detailed a research plan for evaluating the use of negotiation technologies in the flow-planning phase.

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The Brahms system maybe downloaded from

<http://www.agentisolutions.com/>

DEFINITIONS, ACRONYMS, ABBREVIATIONS

ABMS: Agent-Based Modeling and Simulation

ATM: Air Traffic Management

ATSP: Air Traffic Service Provider

BDI: Belief-Desire-Intention

Brahms: multiagent tool kit developed at NASA

CCFP: Collaborative Convective Forecast Product

FACET: Future ATM Concepts Evaluation Tool

TMI: Traffic Management Initiative