Proceedings of the 2000 Winter Simulation Conference
J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick, eds.

SIMAIR: A STOCHASTIC MODEL OF AIRLINE OPERATIONS

Jay M. Rosenberger
Andrew J. Schaefer
David Goldsman
Ellis L. Johnson
Anton J. Kleywegt
George L. Nemhauser

School of Industrial and Systems Engineering
Georgia Institute of Technology
Atlanta, GA 30332, U.S.A.

ABSTRACT

Airline transportation systems are inherently random. However, airline planning models do not explicitly consider stochasticity in operations. Because of this, there is often a notable discrepancy between a schedule's planned and actual performance. SimAir is a modular airline simulation that simulates the daily operations of a domestic airline. Its primary purpose is to evaluate plans, such as crew schedules, as well as recovery policies in a random environment. We describe the structure of SimAir, and we give future directions for the study of airline planning under uncertainty.

1 INTRODUCTION

There is a significant amount of randomness within airline transportation systems. The most familiar examples of randomness are weather and mechanical failures, which can disrupt the planned schedule. A *disruption* is an event which prohibits the airline from operating as scheduled. Anecdotal evidence suggests that major domestic carriers almost never experience a day without disruptions. However, current airline planning models do not explicitly consider disruptions in operations. As a result, a schedule's actual performance can be quite different from the planned performance.

Traditional airline planning models assume that every flight takes off and lands as planned. Since this scenario rarely occurs, a better measure of the quality of a plan is its performance in *operations*, when the plan is executed. It is not easy to determine the performance of a plan in operations a priori due to random disruptions.

One difficulty in evaluating the performance of a given plan in operations is recovery. *Recovery* is how an airline reacts to a disruption. Flights may be delayed or cancelled, and pilots or planes may be rescheduled. Different recovery policies will give different performance results.

SimAir is a modular simulation that simulates the daily operations of a domestic airline. Its primary purpose is to evaluate plans and recovery policies. Because of SimAir's flexible framework, the user can test a plan's sensitivity to disruptions and integrate different recovery policies.

Section 2 summarizes some of the literature on airline simulations. Section 3 defines some terminology used in this paper. Section 4 describes the structure of SimAir. Section 5 presents sources of airline delays. Section 6 discusses how SimAir maintains and implements recovery policies in the simulation environment. Section 7 describes the measurements SimAir uses for evaluation. Section 8 gives directions for the further study of airline planning and recovery under uncertainty.

2 RELATED LITERATURE

Carson et al. (1997) discuss using simulation within logistics and transportation to validate optimization techniques. They do not discuss the importance of recovery. Yang et al. (1991) implement an airline simulation for aircraft reliability. Their implementation does not explicitly consider crews or passengers, and their recovery policy for flight cancellations is simpler than that of SimAir. Haeme, Huttinger, and Shore (1988) develop an airline simulation which considers crews and passengers to assist in schedule development. Their implementation uses a recovery policy similar to the default recovery policy for SimAir, but it does not support more sophisticated recoveries. Yau (1991) describes a simulation within an airline planning decision support system. The focus of his decision support system is for short-term airline planning; it does not describe crew recovery and long-term scheduling.

3 AIRLINE TERMINOLOGY

Before we describe SimAir, we define several terms in airline planning and operations. A *station* refers to an airport that an airline serves. A *flight* consists of an origin station, a destination station, a departure time, and an arrival time. The *block time* of a flight is the time from when the plane leaves the gate at the departure station until it arrives at the gate of the arrival station. *Ground time* of a flight is the time from when the plane and crew are ready until the departure of the flight. When planes experience mechanical problems in operations, they receive *unscheduled maintenance*.

4 STRUCTURE OF SIMAIR

We developed SimAir in a flexible modular environment. SimAir has three modules. The Controller Module determines when a disruption prevents the flights from flying as scheduled. When this occurs, the Controller activates the Recovery Module. Then the Recovery Module proposes a revised schedule, and the Controller can either accept the revisions or request a different recovery proposal. The user can customize the Recovery Module to support alternate recovery procedures (see Section 6).

The Event Generator Module generates random ground time delays, additional block time delays, and unscheduled maintenance delays (see Section 5). The user can easily update the Event Generator to include alternate delay distributions.

Figure 1 gives a schematic representation of the structure of SimAir.

4.1 Event Queue

SimAir uses a *simulation clock* and a time-sorted *event queue*. There are two types of events—arrivals and departures. The simulation clock is the time currently being simulated. The events in the queue drive the simulation. In particular, SimAir keeps track of the first event, the last event, and the most recently added event in the queue. Upon an event occurrence, SimAir removes the first event from the event queue and updates the simulation clock. SimAir can also insert an event into the queue. For example, if the first event were a departure event, then SimAir would update its simulation clock to the departure time and add an arrival event for the corresponding flight to the event queue. SimAir can also delete events from the event queue. The purpose for deleting events is recovery.

4.2 Departure Event

When a departure event occurs, SimAir updates the simulation clock and the state of the simulation. If SimAir expects that the arrival of the flight will be later than scheduled, it invokes the Recovery Module. SimAir then schedules an arrival event for the flight. The time of the arrival event is based upon the flight's block time; that is, the arrival event is scheduled for the time of the departure event plus the block time of the flight.

4.3 Arrival Event

Upon an arrival event, SimAir updates the simulation clock and the state of the simulation and creates a list of departures to schedule. If the Controller knows when a flight's crew and plane will be available for the flight's departure, the flight's departure is *determined*. The Event Generator then samples an unscheduled maintenance delay for the aircraft, and the Controller determines if there is a reason to invoke the Recovery Module. With the assistance of the Recovery Module, the Controller selects the determined departures. For example, the Controller may select the next flight of the arrival crew and the next flight of the arrival plane.

For each flight in the list of determined departures, SimAir schedules a departure event. The flight will depart at the maximum time of the crew's ready time, the plane's ready time, and the original schedule departure time plus a random ground time.

5 THE EVENT GENERATOR

5.1 Sources of Delays

Sources of ground and block delays include many elements, such as airport congestion, luggage loading, connecting passengers, weather, etc. Because SimAir does not explicitly consider the sources of these delays, it is unnecessary to simulate them individually. Instead, the Event Generator uses aggregate distributions for additional block time and ground time. A block time disruption changes the number of minutes a crew flies, but a ground time disruption does not.

5.1.1 Block Time Distribution

SimAir requests a realization from the block time distribution from the Event Generator when it is scheduling an arrival event. The block time distribution may depend on several characteristics of the flight. For example, a flight with a long scheduled block time may experience more variance in its actual block time than a flight with a short scheduled block time. Airports are more congested during certain times of day, and this may affect the block time. A block time may also be dependent on the departure station or the arrival station.

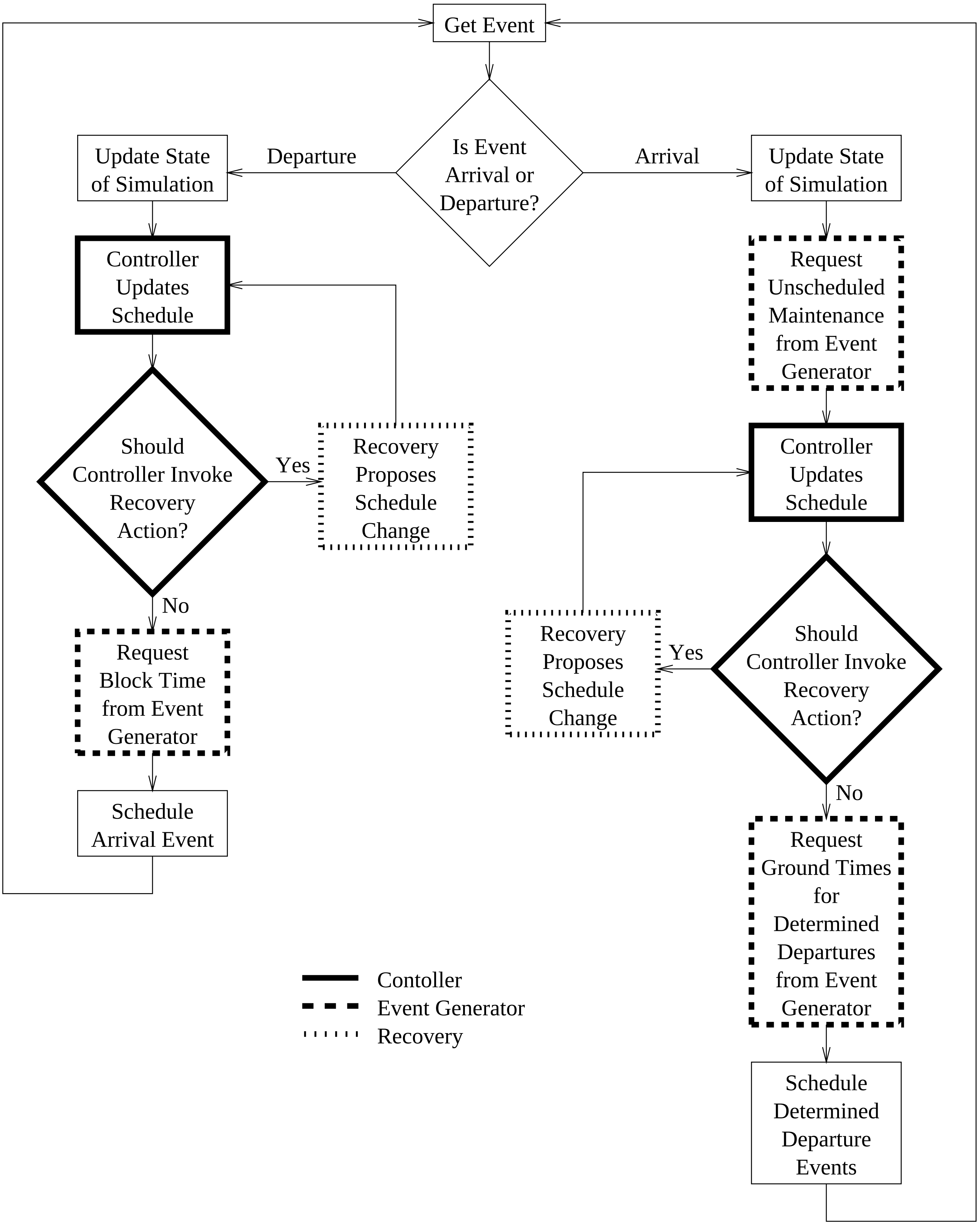

Figure 1: The Structure of SimAir

5.1.2 Ground Time Distribution

SimAir requests a ground time realization when it is scheduling the departure of a flight. The ground time distribution is an aggregate of several distributions, such as weather and passenger delays. The random ground time depends on the location and the time of day of the departure event.

5.2 Unscheduled Maintenance

The Event Generator generates two random variables for unscheduled maintenance for an aircraft. The first random variable determines whether there is a maintenance delay. If there is a delay, then a second random variable is generated which determines the length of the delay. Both random variables depend on the aircraft.

6 CONTROLLER AND RECOVERY MODULES

SimAir's Controller Module recognizes disruptions and implements recovery policies. The Controller maintains the planned flight schedule of SimAir. It determines whether there is a disruption in the current plan and when to invoke the Recovery Module. The Recovery Module proposes a solution to the disrupted plan. The Controller updates the plan and determines whether to continue to invoke the Recovery Module.

6.1 Push-Back Recovery

When a flight is delayed, the Recovery Module needs to find a recovery action to respond to the delay. The Recovery Module may use a simple routine which waits for the scheduled planes and crews regardless of their tardiness. We refer to this recovery as *push-back*. Consider an arrival event. The Recovery Module calculates the plane's ready time for the plane's next flight and the crew's ready time for the crew's next flight. The plane's ready time for the plane's next flight is the arrival time of the current flight plus a turn time plus any unscheduled maintenance delay the plane incurs. The crew's ready time for the crew's next flight is the arrival time of the current flight plus the turn time of the crew. If a flight has both a known crew time and a known plane time, then the Recovery Module proposes adding the flight to the list of determined departures.

7 PERFORMANCE EVALUATION

There are many criteria that can be used to evaluate the quality of a schedule. SimAir provides several performance measures of a schedule in operations. For crews, SimAir can calculate crew cost and the number of reserve crews called per day. SimAir can tabulate statistics in operations such as on-time performance and the number of cancelled flights per day. It also finds the percentage of passengers who miss their connections.

8 FUTURE RESEARCH

SimAir provides a modular environment for the study of recovery policies. The structure of SimAir is flexible to allow easy integration for different recovery policies. Moreover, SimAir can assist in developing airline planning models. Many planning models are solved using optimization methods. Most of these models assume every flight flies as planned. Because airline operations rarely follow the initial plan, the consideration of disruptions may lead to plans that perform better in practice. SimAir provides a more realistic environment to measure the performance of an airline plan in operations.

REFERENCES

J. S. Carson II, M. S. Manivannan, M. Brazier, E. Miller, and H. D. Ratliff. 1997. Panel On Transportation and Logistics Modeling. In *Proceedings of the 1997 Winter Simulation Conference*, ed. S. Andradóttir, K. J. Healy, D. H. Withers, and B. L. Nelson, 1244–1250. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.

R. A. Haeme, J. L. Huttinger, and R. W. Shore. 1988. Airline Performance Modeling to Support Schedule Development: An Application Case Study. In *Proceedings of the 1988 Winter Simulation Conference*, ed. M. A. Adams, P. L. Haigh, and J. C. Comfort, 800–806. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.

W. Yang, Y. Zhu, Q. Tu, and Y. Sheng. 1991. Simulation of Commercial-Aircraft Reliability. In *Proceedings of the Annual Reliability and Maintainability Symposium*, 112–119. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.

C. Yau. 1991. An Interactive Decision Support System for Airline Planning. *IEEE Transactions on Systems, Man, and Cybernetics* 23: 1617–1625.

AUTHOR BIOGRAPHIES

JAY M. ROSENBERGER is a Ph.D. student in the School of Industrial and Systems Engineering at the Georgia Institute of Technology. He received a bachelor's degree in mathematics from Harvey Mudd College, and a master's degree in industrial engineering and operations research at the University of California at Berkeley. His e-mail and web addresses are `<jrosenbe@isye.gatech.edu>` and `<www.isye.gatech.edu/~jrosenbe/>`.

ANDREW J. SCHAEFER is a Ph.D. candidate in the School of Industrial and Systems Engineering at the Georgia Institute of Technology. He received a bachelor's degree in applied mathematics and quantitative economics and a master's degree in computational and applied mathematics from Rice University. His e-mail and web addresses are `<schaefer@isye.gatech.edu>` and `<www.isye.gatech.edu/~schaefer/>.`

DAVID GOLDSMAN is a Professor in the School of Industrial and Systems Engineering at the Georgia Institute of Technology. His research interests include simulation output analysis and ranking and selection. He is the Simulation Department Editor for *IIE Transactions*, and an Associate Editor for *Operations Research Letters*. He was the Program Chair for the 1995 Winter Simulation Conference. His e-mail and web addresses are `<sman@isye.gatech.edu>` and `<www.isye.gatech.edu/~sman/>`.

ELLIS L. JOHNSON is Coca-Cola Professor of Industrial and Systems Engineering at the Georgia Institute of Technology and is resident faculty member in the SABRE Research Group. Through The Logistics Institute at the Georgia Institute of Technology, he currently works with SABRE, United Airlines, and Delta Airlines. Crew scheduling and fleet assignment have been major areas of focus. His e-mail and web addresses are `<ejohnson@isye.gatech.edu>` and `<udaloy.isye.gatech.edu/~ellis/ellis.html>`.

ANTON J. KLEYWEGT is an Assistant Professor in the School of Industrial and Systems Engineering at the Georgia Institute of Technology. He received a bachelor's degree in civil engineering from the University of Pretoria, South Africa, a master's degree in civil engineering from Purdue University, and a Ph.D. degree in industrial engineering from Purdue University. His e-mail and web addresses are `<anton@isye.gatech.edu>` and `<www.isye.gatech.edu/~anton/>`.

GEORGE L. NEMHAUSER is an Institute Professor and holds the A. Russell Chandler Professorship in the School of Industrial and Systems Engineering at the Georgia Institute of Technology. Previously he was on the faculty of Cornell University and Johns Hopkins University. His current research interests are in solving large-scale mixed-integer programming problems and he is actively working on several applications, especially in the airline industry. He is the editor-in-chief of *Operations Research Letters* and co-editor of the *Handbooks in Operations Research and Management Science*. His e-mail and web addresses are `<gnemhaus@isye.gatech.edu>` and `<tli.isye.gatech.edu/faculty/nemhauser.cfm>`.