Aircraft Arrival Sequencing:
Creating order from disorder

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Objective

Increasing volume of air-traffic demand has escalated the problems for the air traffic control systems including the Air Traffic Control Towers (hereafter ATCT) at the airport, which among its other jobs has to determine the landing sequence for the aircrafts. The amount of traffic that can land at a given airport is influenced by factors such as the number of runways, taxiways, angle they are making with the runway, weather, etc. This process typically requires between one and four minutes (more in bad weather) for each aircraft [1]. Problems begin when airlines schedule more arrivals into an airport than can be physically handled, or when delays elsewhere cause groups of aircraft that would otherwise be separated in time to arrive simultaneously. Aircraft must then be delayed in the air by holding over specified locations until they may be safely sequenced to the runway. The predominant landing sequencing policy currently in use is FCFS (First Come First Served). However, this does not always lead to the best system performance. System performance is measured by parameters such as aircraft throughput, passenger throughput and passenger waiting time. The system can be thought of as a composition of individual aircrafts, passengers, airlines, crews and the airport. Each stakeholder has his own utility function. The system's utility function as a whole is a function of these individual utilities.

Our objective is to understand the equity of stakeholders for different arrival sequencing policy, based on which we can come up with an *optimal sequencing policy* that maximizes the 'system utility' from the point of view of the involved stakeholders.

[1] http://www.silverstateatc.com/Pages-Operations/center_ops.htm

Assumptions

We will be focusing our study on a single airport (possibly Detroit because of availability of data) where a group of aircraft is already queued for landing under the supervision of the ATCT of the airport. It should be noted that this assumption isolates an airport and therefore rules out effects like network propagation of delay, cost, etc.

Preliminary requirements

Obtaining the sample data for landing queues will be one important aspect of our project. We could get it directly from the Air Traffic Control towers. However, in case we are unable to do so, there is a secondary and less desirable source.
The Center of Air Transportation Research (CATSR) already has multilateration data from Detroit Airport. Since we are only concerned with landings, our initial job will be to eliminate non-landing data from this set. At the end of this process we will have a much smaller data set. Thereafter we will need to design an algorithm to construct landing queues out of this smaller data set. These landing queues would serve as inputs to our model.

The landing queue discipline currently in use at the airports also needs to be studied. We learned the following from Dr. Lance Sherry:

- If the aircraft is not affected by Ground Delay Program (GDP), then the discipline used is FCFS, but
- If the aircraft is affected by GDP then:
  (a) For commercial aircrafts the discipline is sequence by schedule.
  (b) For General Aviation (GA) aircrafts the discipline is FCFS.

Safety is of prime importance to the air traffic control system. The impact of various landing sequences on overall safety requires investigation. It is known that a smaller aircraft following a larger aircraft is potentially more hazardous than the reverse, assuming the same separation-distance in both the cases. We need to determine if for safety reasons the smaller aircraft should receive priority over the larger one and what sequence improves system performance.
One of the prime factors influencing aircraft safety is the wake-vortex hazard. A starting point of this project would be studying the wake-vortex separation matrix, which contains the required separation for each pair of aircraft categories.

Technical approach

Problem statement
For simplicity, the landing queue is divided to two sub queues, a front queue and rear queue. Aircrafts in the front queue are ready to land, and their sequence cannot be changed. Aircrafts in rear queue have to wait for a while to land and their sequence can be altered. New arrival aircraft are placed at the end of rear queue, where they remain until advancing to the front queue. In the rear queue aircraft may experience several sequence changes. In this study, we will investigate the policy by which these sequence changes are made to maximize the system utility.

Problem formulation
The objective is to solve a multi-objective optimization problem so as to maximize the system utility function, which is a function of the utilities of various stakeholders, including the airport, airlines and passengers.
The airport authority seeks to maximize throughput of aircrafts and passengers.
Airlines want to minimize air waiting time to save fuel consumption and crew workload. Airlines also have some preference with regard to the delay of different flights. For example, if an airline has ten flights in a morning bank, the airline would rather let the first flight be delayed than the last one so the probability of disrupted flights is minimized.
Passengers want to arrive at their destination on time. Greater delay leads to more passenger disappointment and impatience.

Constraints in the problem include a limit on the number of landing slots due to airport capacity. Air waiting time is limited by fuel tank capacity. The number of aircraft on hold is limited by available airspace.

The decision variables in this problem are the landing sequence positions given to aircraft.

Modeling
There are two ways to approach the problem.
First, optimize the rear queue sequence and update the solution whenever a new arrival aircraft shows up at the end of rear queue.
Second, choose the aircraft to move from the rear queue to front queue whenever one aircraft lands at the airport, thereby filling the vacancy. In this approach, the rear queue is never sequenced and is simply treated as a pool of entities. The decision of which aircraft in the pool should enter the front queue is executed at every landing event.

Tools
Using this approach, MPL and CPLEX can be used to solve the problem sequentially. If the sequential solving becomes an issue, or other factors such as wake vortex constraints are introduced, the problem can be solved using a general computer language such as Java or C/C++. The use of custom software would be feasible since the search space required is small, especially for the second approach.

Expected Results

Sequential solutions will be combined to arrive at a final arrival sequence, thereby yielding an objective function value or system utility. Historical data will be used as a baseline for comparison. Objective function values will be compared to determine optimal sequencing policies. Other metrics, including average flight delay, flight delay distribution, average passenger delay, passenger delay distribution, total fuel burn will also be compared. We may also study the correlation of different utility functions with each other.

Overall we expect to gain a better view of the system component interactions. This will allow us to explore which components compete most heavily for system resources and which resources are the bottlenecks in the system. Additionally, we will be able to study effects and influences of the various stakeholders.

Challenges

The cyclical nature of the economy, and the strong correlation between the strength of the economy and the demand for air travel, results in an airline industry that can be described as a "very dynamic system" [2]. The combination of this dynamic property and stochastic factors including weather and congestion delays, lead to uncertain actual arrival time. Hence, in order to ensure real-time usage of the results of our project we need to design a fast and reliable tool.

[2] http://web.mit.edu/airlines/www/research-themes/research-themes-2.htm

Initial Project Plan

- Research the current landing sequencing strategy being used. Study the research that has already been done in this area and avoid redundancy. Study various queuing disciplines and their advantages.
- Try to obtain the landing queue data directly from the Center of Air Transportation Research at GMU. In parallel, begin extracting the landing data from the multilateration data already available for Detroit Airport.
- Study the system in detail. This includes studying the safety requirements (wake-vortex, runway arrival capacity, etc), uncertainty due to weather, utility function of various stakeholders including the airport, airlines, passengers, crew and landing infrastructure.
- Divide the various system components into groups and make sure that the individual components are not double-counted so as to avoid bias in the system.
- Study various constraints on the system: economic, safety, contractual. Try to assimilate these constraints into our model using as much detail as possible.
- Design the model. We can begin by assuming that the airport uses only one runway for landing.
- Test the model with various inputs and compare its performance with existing sequencing techniques. Do sensitivity analysis.
- Suggest future development.