Airport queuing models for delay prediction

David Lovell, Kleoniki Vlachou

• Develop queuing models to quantify benefits of increased precision in future air traffic processes: e.g., reduced interarrival times, reduced variance in interarrival times
• Employ diffusion approximation to model joint probability density function of queue length and time
  • Permits independent specification of mean and variance for service process – in contrast to typical Poisson models
  • Requires assumption of continuous process: valid when many flights considered

Single airport queue model

• Fokker-Planck equation is governing PDE
  \[ \frac{\partial^2 f}{\partial x^2} + \frac{\partial f}{\partial t} = -\frac{\partial}{\partial x} \left[ \lambda f(x,t) \right] + \mu \left( \frac{1}{2} \frac{\partial^2 f}{\partial x^2} + \frac{\partial f}{\partial x} \right) \]
  • Boundary conditions enforce realism: queue length must be non-negative and must begin the day empty
  • System of coupled partial differential equations solved using Finite Element Method

Model validation and results

• Validate results using Monte Carlo simulation of system and analytic results, where appropriate
  • Uncongested steady state: \( M/M/1 \), \( \mu = 40 \) – Monte Carlo, 1000 runs
  • Time-varying demand, constant service rate

Long-term airport congestion management

David Lovell, Michael Ball, Avijit Mukherjee, Andrew Churchill

• Under nominal conditions, some airports experience demand well in excess of their capacity
• Because increasing capacity is often very difficult, approaches for regulating demand are employed

How many operations should be permitted?

• Target number of operations must be set while accounting for:
  1. Variations in available capacity: if target equal good weather capacity, then delays will be rampant, but if it equals bad weather capacity, the airport will be underutilized
  2. Variations in value: accessing the airport: offering flights during certain hours is clearly more valuable to airlines than offering them during others
• Use stochastic integer program to balance these considerations while hedging against both good and bad capacity outcomes

Regional traffic flow management

Coordinate capacity rationing and dynamic flight rerouting

David Lovell, Michael Ball, Moein Ganji

• Rerouting presents an alternative for offloading flights from congested airspace resources, in place of assigning ground delays
• However, alternative routes are likely longer, increasing travel time and fuel burn
• If disruption clears early, then flights on alternative route may return to nominal route along some hybrid path

Coordinate multiple conflicting traffic management initiatives

David Lovell, Michael Ball, Andrew Churchill

• In practice, capacity rationing occurs independently at each congested resource
• Explicit coordination will guarantee feasibility, improve equity between users, and improve efficiency

Model problem as binary linear program, treating each resource as an assignment problem, apply linking constraints for feasibility

• More complex formulations may consider random capacity variation
• Objective may induce inequities, requiring alternate formulations to control worst-case deviations

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Model problem as binary linear program to make efficient and equitable tradeoffs between ground delay for nominal route and increased cost of using alternative route

Include random end time and movement for disruption

Resource capacity constraint in initial allocation

Objective: Minimize assigned arrival delays

Each flight receives an initial allocation

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