



The University of  
**Nottingham**

School of Computer Science

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Research Council

**asap**  
automated  
scheduling  
optimisation  
& planning

# ATM related research at the University of Nottingham



**Dr Jason A D Atkin** and **Professor Edmund K Burke**

Automated Scheduling optimisAtion and Planning (ASAP) group  
School of Computer Science, The University of Nottingham

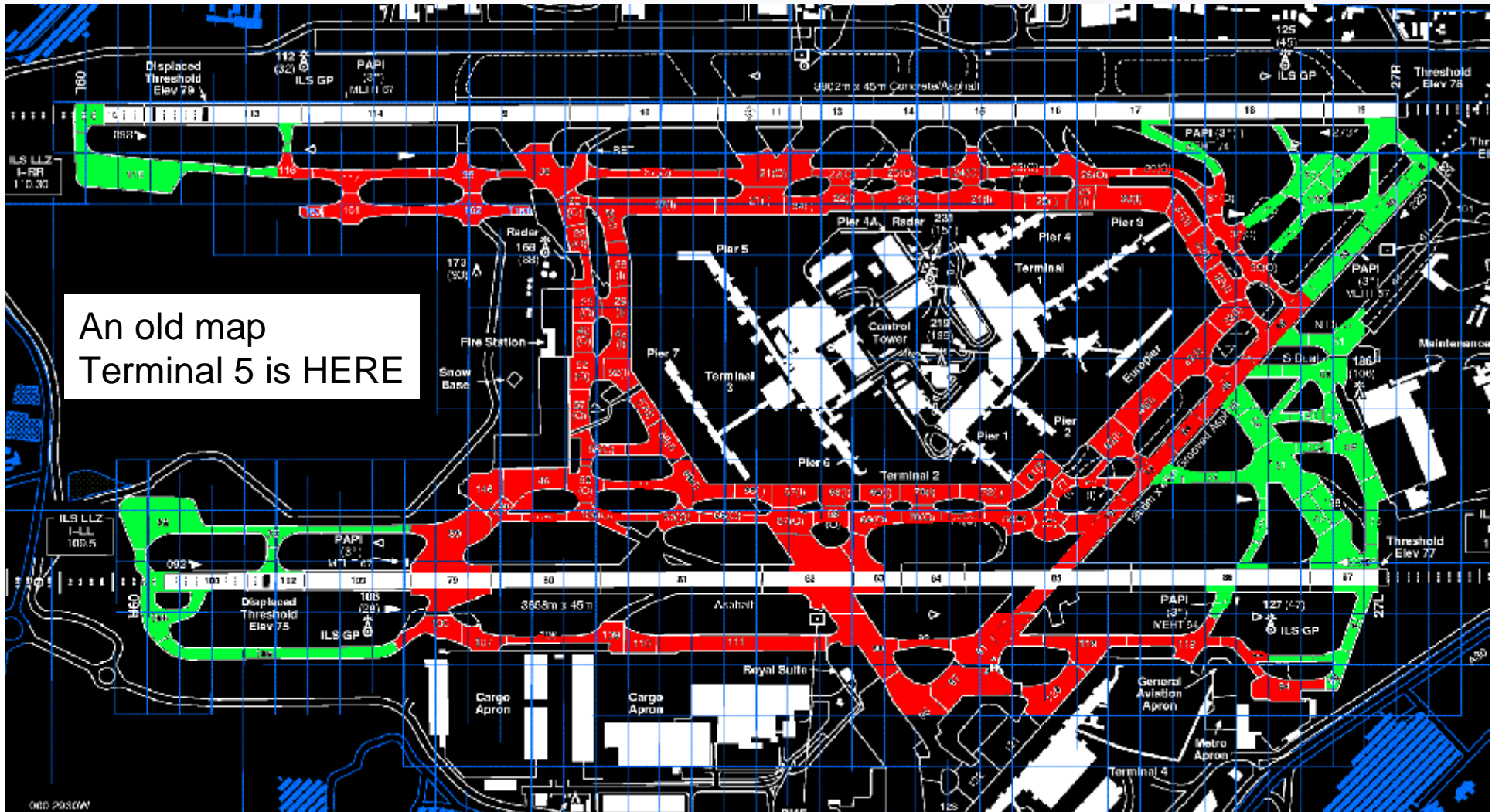


# Overview

- Problem 1: Take-off sequencing within the holding area (at the end of the runway)
  - Sequencing constraints
  - Holding area structure and aircraft positions
- Problem 2: Target Start-At Time (TSAT) allocation
  - Consideration of the cul-de-sac problem
- Other current work: Robust airline scheduling
- Future work (starting soon):
  - The arrival sequencing problem
  - Ground operations
- Other work from Nottingham: Human factors
  - Projects with NATS, BAE systems, Lockheed Martin, ...



# London Heathrow Airport



Problem 1: at the holding area (in green)

Problem 2: at the stands (around the white terminals)

Red: taxiways

Two runways, shown in white

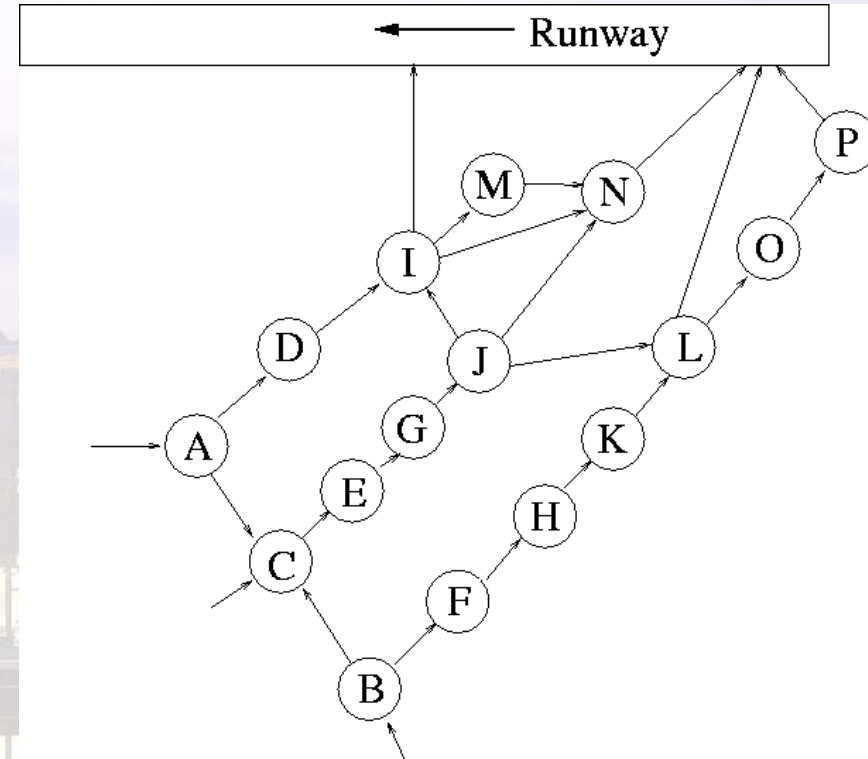


# Problem 1: Take-off sequencing

- My PhD work, co-supervised by John Greenwood (NATS)
- Develop the decision making element for a decision support tool for the runway controller
- Must always maintain required (safe) separations
  - Separations are sequence dependent
  - Changing sequence can alter separations, throughput and (consequent) delay
  - Wake vortex, SID/speed, MDI
- Must adhere to (15 minute) CTOT time slots (if present)
  - Use as few 5 minute extensions as possible
- Aim: reduce delay for aircraft
- But also: control inequity (very important)
  - Positional delay and inequitable delay times
- Consider the real problem!
  - Must be EASILY possible within holding area
  - Must be achievable in the way that controllers work
  - Must allow for pre-flight checks time
  - Must allow aircraft to easily reach runway on time



# A Holding Area (27R)



Example good routes: ADIN, CEGJN, BFHKL

Slower (but good) routes: ADIMN, BFHKLOP

Short-cuts, if necessary: ADI, CEGJI



# Simulation

- Decision Support System Inputs:
  - Positions of any aircraft in the holding area
  - Predicted arrival time/place for aircraft on taxiways
  - Knowledge of currently planned take-off order
- Decision Support System Output:
  - Suggested take-off order
  - For simulation only:
    - Predicted positions of aircraft, and allocated paths
- Simulation loop:
  - Create problem, solve problem (under 1 second), advance time 1 minute, add new aircraft, re-solve

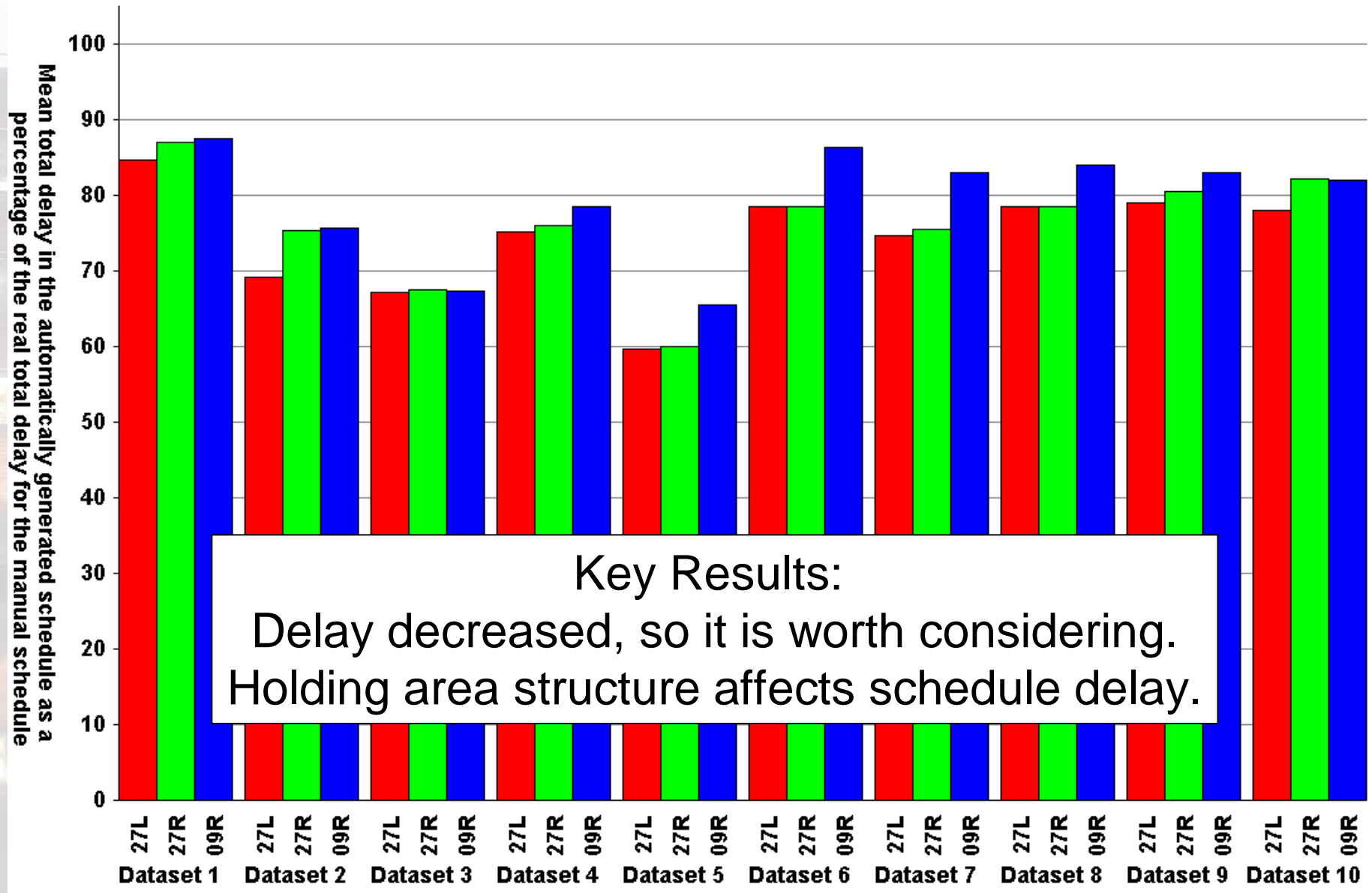


# Solution Method

- Take-off sequence is key
  - But must be achievable – easily!
- Search through take-off sequences
  - Heuristic search (good guess, no guarantees)
  - Some final checks (provide some guarantees)
- Within search: evaluate each sequence
  - Heuristic path allocation
    - According to overtaking required
  - Is it achievable? (How to achieve it?)
  - How early can aircraft take off?
  - What is the delay, CTOT compliance, equity?



# Simulation Results: Delay

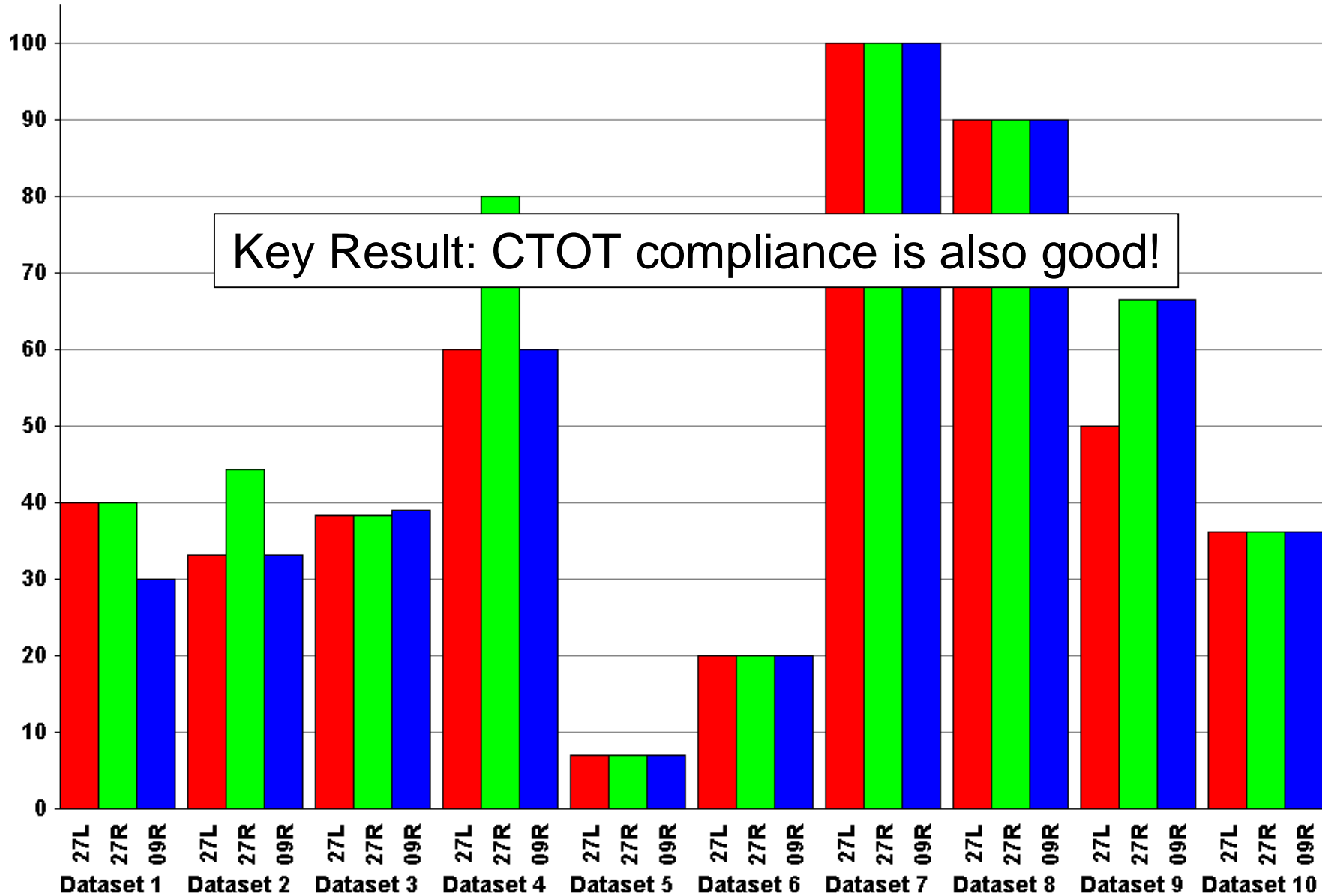


**Key Results:**  
Delay decreased, so it is worth considering.  
Holding area structure affects schedule delay.



# Results: CTOT compliance

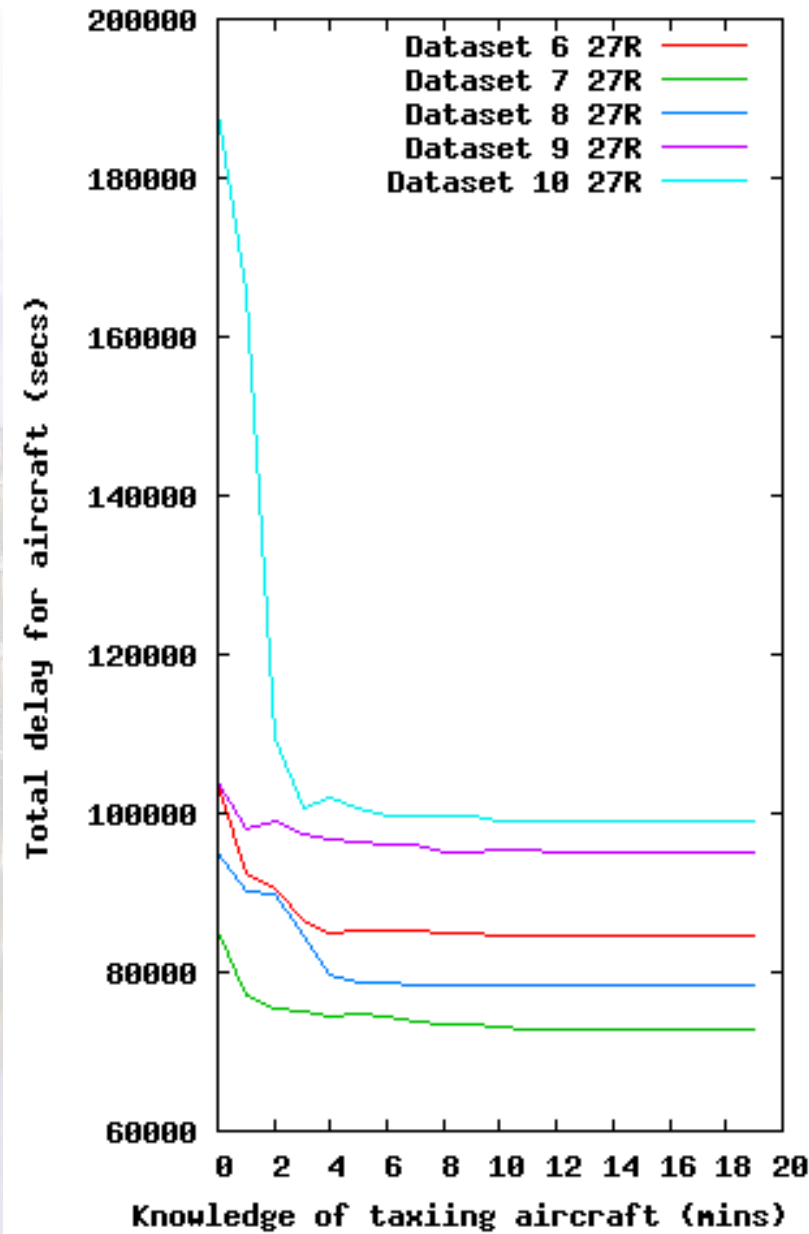
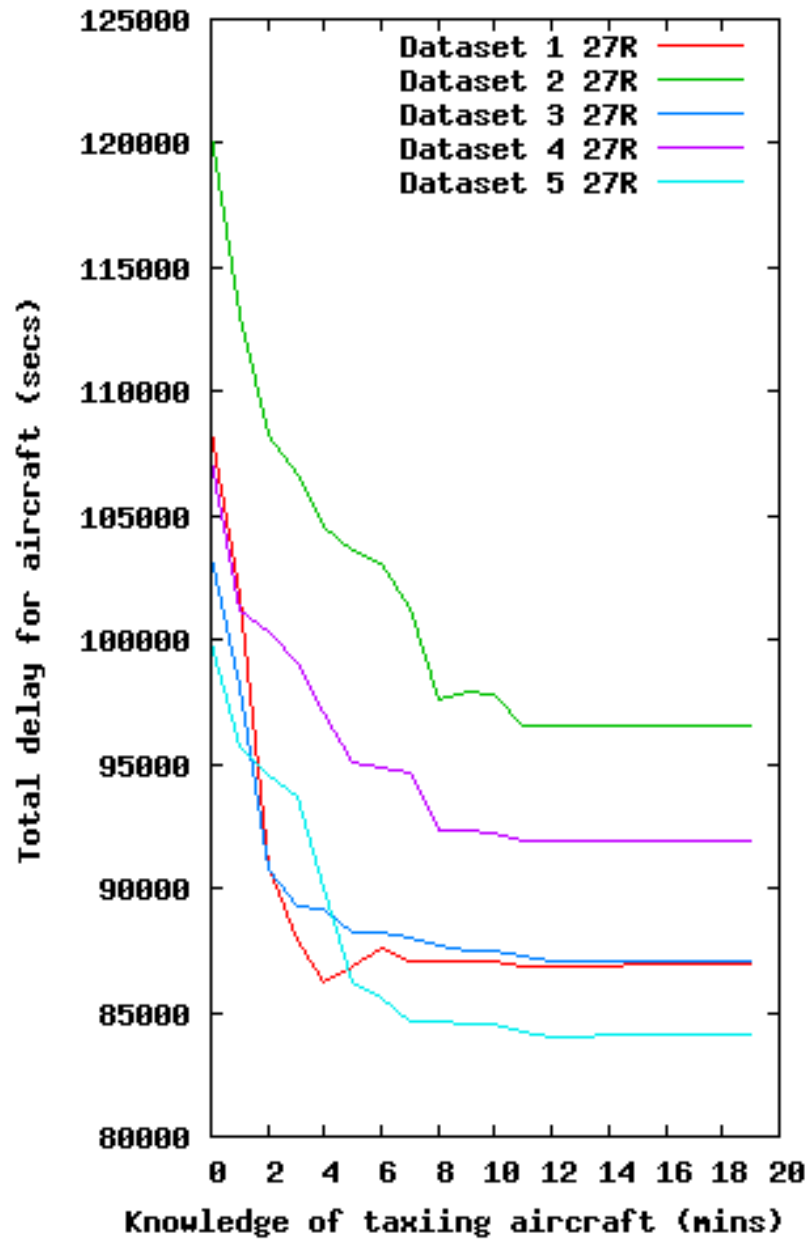
Mean number of CTOT time-slots missed in the automatically generated schedules, as a percentage of the real number missed



Key Result: CTOT compliance is also good!



# Planning Horizon





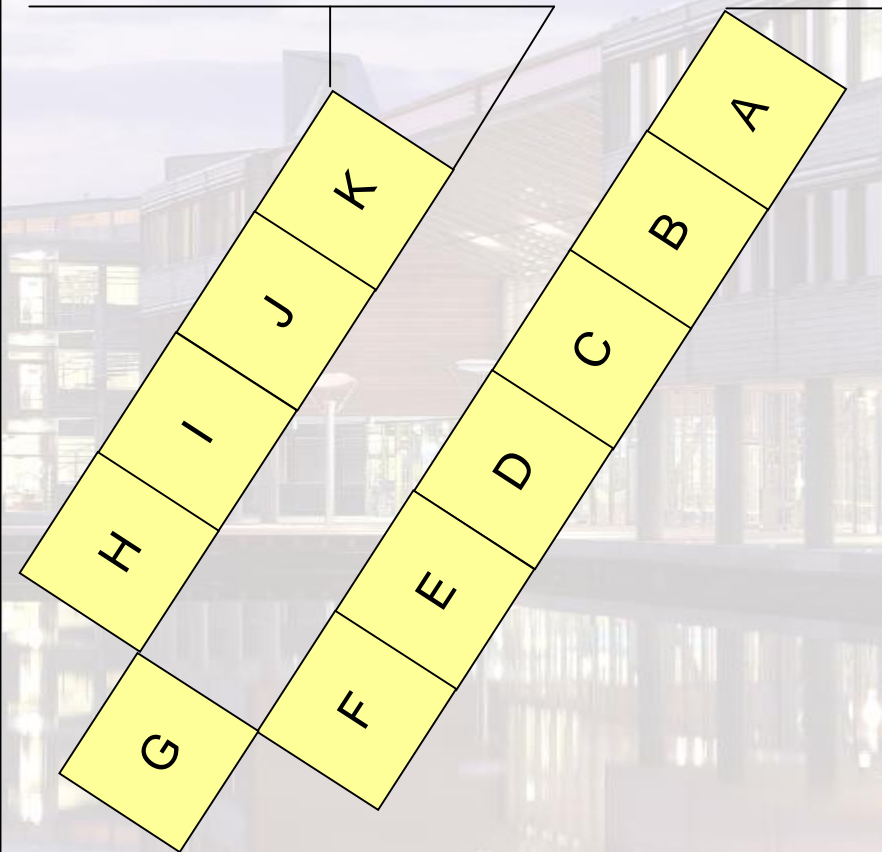
# Problem 2: TSAT allocation

- Aim: Absorb some of the necessary delay at the stand, instead of at the holding area
  - Before engines are started (fuel/pollution savings)
- How: Allocate Target Start-At Times
  - A time for each aircraft at which to commence pushback and then start engines
  - Predict a good take-off sequence and take-off times
  - Determine total delay from predicted take-off times
  - Determine ideal pushback time (from 'ideal' runway hold)
    - Ideal runway hold includes slack for robustness
    - and provides failover sequences
  - Consider contention around the stands



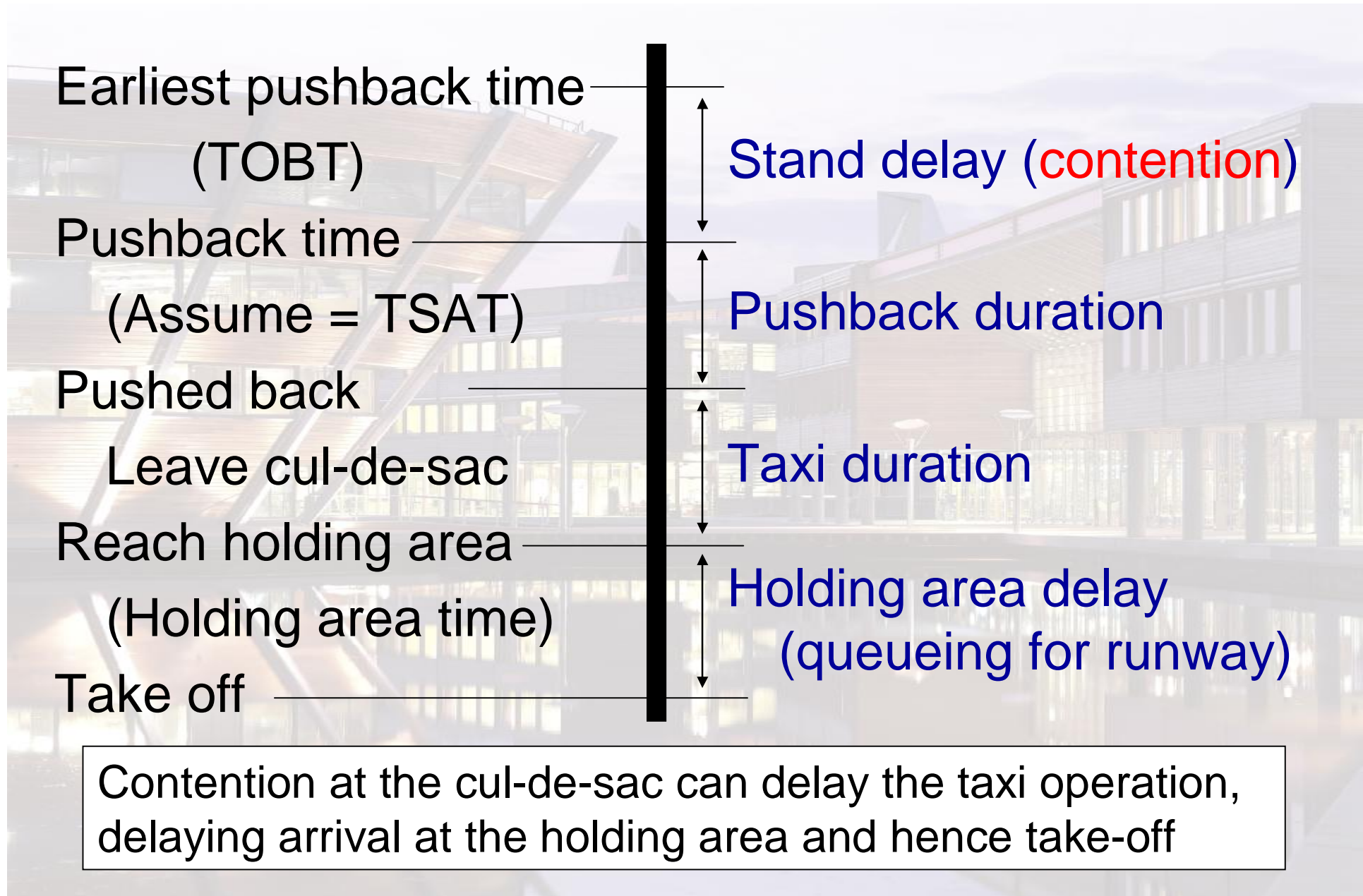
# Cul-de-sac Contention

- Two types of contention:
  1. Blocked from pushing back while another aircraft is pushing back
  2. Blocked from leaving cul-de-sac until an aircraft nearer to the end does so
    - Either nearer one does not start pushback until farther one has gone
    - Or farther one cannot leave until nearer one leaves





# Departure system



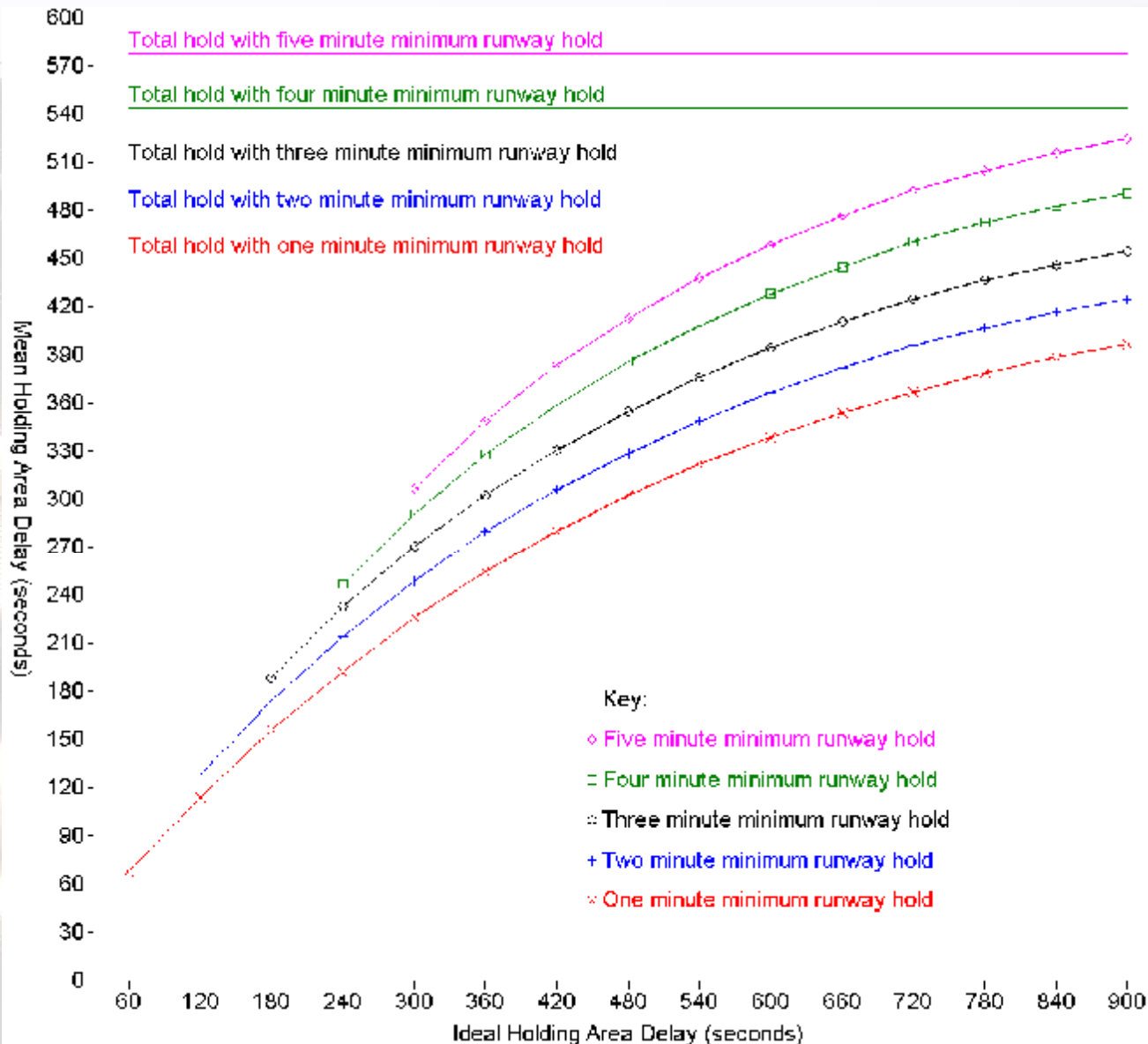


# Solving the problem

- Best take-off sequence depends upon earliest take-off times for aircraft
- Earliest take-off times depend upon the delay at the cul-de-sac
  - Which is determined by sequence of leaving
  - Another sequence-dependent separations problem
  - Not always best to leave in take-off order
- Again heuristic solution method necessary
  - Uses branch-and-bound (exact method) within a rolling window through sequence



# Results for parameters



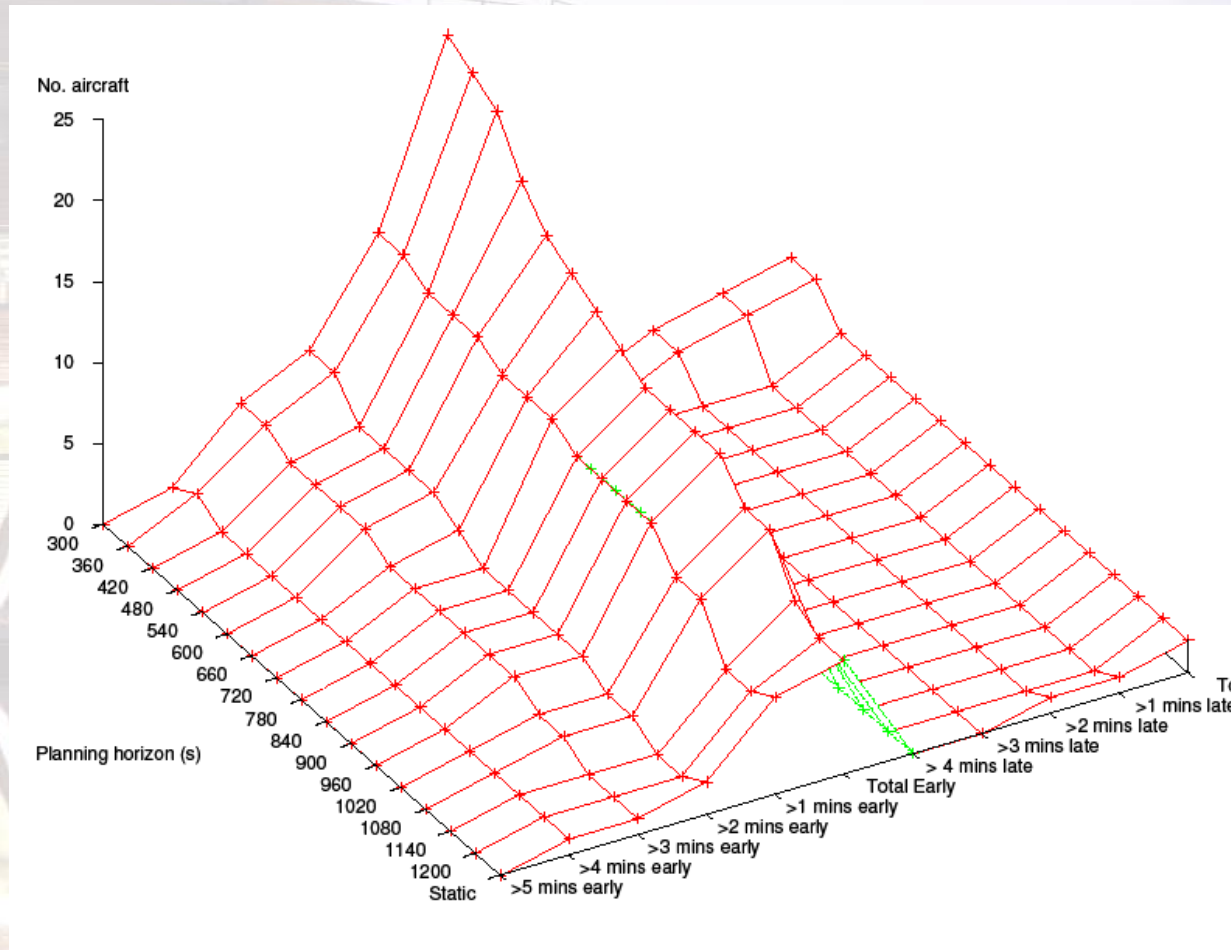
Minimum runway hold affects the total delay in predicted schedule

Ideal runway hold affects how much of this is absorbed as runway hold

Thus it works as expected



# Stand hold distribution



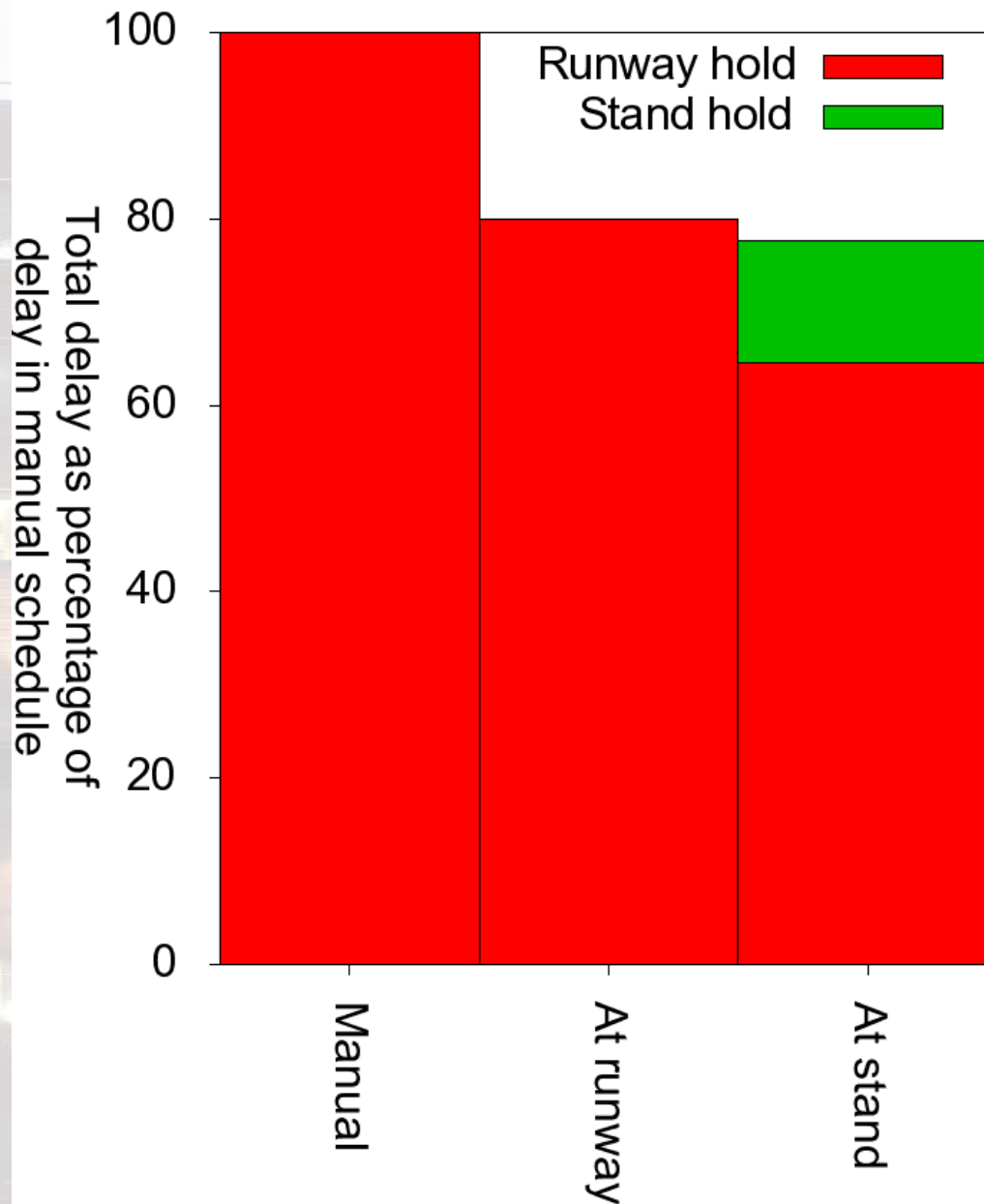
Most aircraft had very close to their ideal runway hold

But significant number were affected by cul-de-sac contention

Number of aircraft whose hold differs from the ideal by specified amounts, as a function of the planning horizon (notice of TOBT prior to TOBT)



# Comparative Results



- Both systems involve some kind of take-off sequencing
- Experimented using the same data
- Sequencing at the runway holding area vs at the stands
- Two systems give similar results
- TSAT allocation system allows further delay to be absorbed at the stand



# Other (ASAP) Work: Strategic robust airline scheduling

- Airline rather than ATC
  - Working with KLM
  - Ongoing (started 2003)
- Investigating robustness of airline schedules
  - Produce more robust airline schedules
    - By understanding, measuring and predicting robustness
  - Or, to determine and use robustness-influencing characteristics:
    - Increase swap opportunities
    - Strategically allocate slack to avoid knock-on delays
  - Currently considers shifting flight timings by a few minutes or re-routing aircraft
- To investigate mutual interaction between airports and airline schedules
  - e.g. Predict the effect on airport of de-banking



# Planned future work (For ASAP)

- Arrival sequencing
  - Linking the arrival sequence and movement to the ground resources and stand allocations
- Ground operations
  - The effects of ground operations and resources upon departure times
- Where can computers help?
  - Considering the benefits of adding automated support for airport services
- Non-ATM optimisation/planning work
  - See brochures



# Human factors

- VIEW of the Future (IST-2001-26089)
  - Aerospace partner: Alenia Spazio
  - 3 year project examining design of visualisation technologies for aerospace and automotive applications
- Autonomous Logistics in Aviation Maintenance
  - With Lockheed Martin and BAE Systems
  - Human factors scoping of issues associated with remote sensing technology and aviation maintenance processes and procedures
- Teamworking
  - With BAE Systems
- Co-Spaces
  - EU Integrated Project with Airbus CIMPA (France)
  - Development and evaluation of innovative collaborative work environments for individuals and teams in design and engineering
- PhD projects:
  - Simon Gill : Aviation and Virtual Reality
  - Steve Shorrock : TRaCER - Error analysis in ATC
  - Gemma Cox : Evaluating ATC - cockpit collaboration

# Human Factors in Aviation: Flightdeck and Air Traffic Collaboration Evaluation (FACE)

- 2 year EPSRC funded programme (completed)
  - Collaboration with NATS and Virgin
- Increasing number aircraft
  - => increasing ATC load
- Technological solutions proposed:
  - Datalink (text or graphics base communication)
  - Freeflight (pilot mediated ATC)
- FACE examined impact of increased automation on collaboration between pilots and ATC
  - Laboratory studies: datalink and freeflight simulations
  - Real world observations of current ATC-pilot communications
- Result: implementation guidance for datalink and freeflight





# Summary

- **ASAP Research Group**
  - Current/Past
    - Take-off sequencing
    - TSAT allocation
    - Airline scheduling
  - New projects (starting soon)
    - Arrivals integration into CDM
    - Group operations integration into CDM
- **Human factors group**
  - Various ATC/airport/airline projects

**Questions/comments?**