Analysis of Air Transportation Systems

Descriptions of Airport and Airspace Simulation Models

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Material Presented in this Section

- Review of current large-scale simulation models
- Review some of their strengths and weaknesses
- Provide you with some information to better understand various large-scale airport and airspace simulation models

Basics on Airport and Airspace Simulation Models

- These models mimic the behavior of aircraft in complex airspace and airport systems
- Typically these models use a discrete event simulation approach (see another handout on this) to move aircraft among airport and airspace resources
- Airport and airspace resources are considered objects like runways, taxiways, gates and airspace links
- These models employ some sort of link-node structure to move aircraft entities between resources

Sample Airport and Airspace Simulation Models

SIMMOD - the FAA airport and airspace simulation model

RAMS - Eurocontrol’s reorganized mathematical simulator model

TAAM - Australian developed simulation model (the Preston Group is now part of the Boeing Company)

Several in-house simulation models exist (VPI_asim)

Common Goals of Large-Scale Airport Simulation Models

- To estimate airport measures of effectiveness to estimate delays curves for an airport subject to some airport schedule (or demand) scenario
- Delays are usually defined as the difference between unimpeded and actual travel times
- Estimate utilization of airport resources (such as gates, runways, taxiways, etc.)
- NOTE: These models do not measure capacity directly. **Capacity is a non observable variable** in an airport system (can be estimated measuring delay)

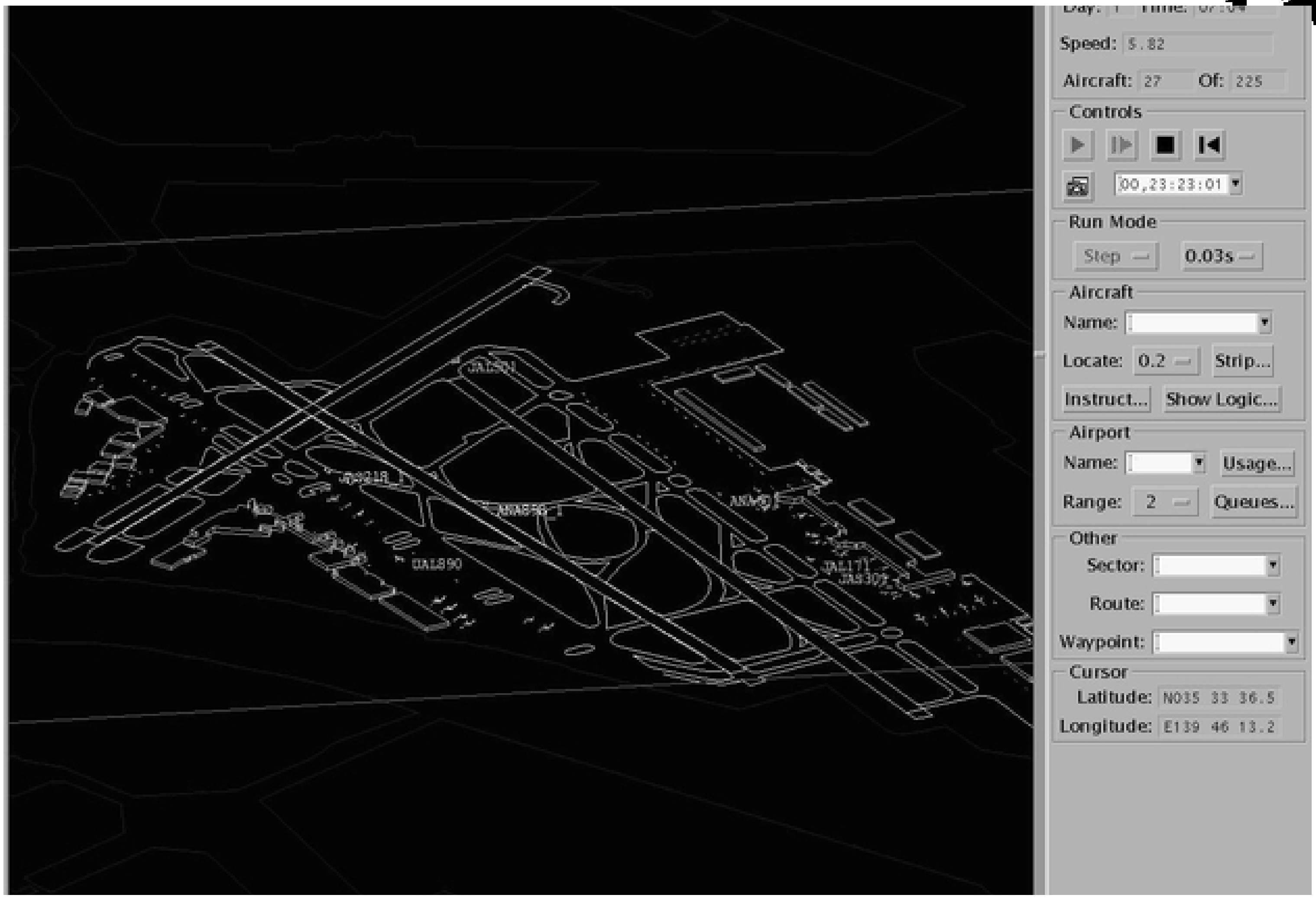
SIMMOD

- An airspace and airfield simulation model developed by the FAA in the last two decades
- Good airfield and airspace logic
- Gate-to-Gate simulator (important for some applications)
- 2D graphics (except for workstation version)
- Validated in the period 1985-1991
- Cost: $5,900 per copy for SIMMOD Plus! version 5.0
- Large learning curve (in general for SIMMOD)

TAAM

- An airspace and airfield simulation model developed by the Preston Group (Australia) - a Boeing Company
- Good airfield and airspace logic
- Gate-to-Gate simulator (important for some applications)
- Excellent graphics
- Not validated although in use by many airlines and research organizations
- Cost: $300,000 per copy
- Large learning curve

TAAM Model



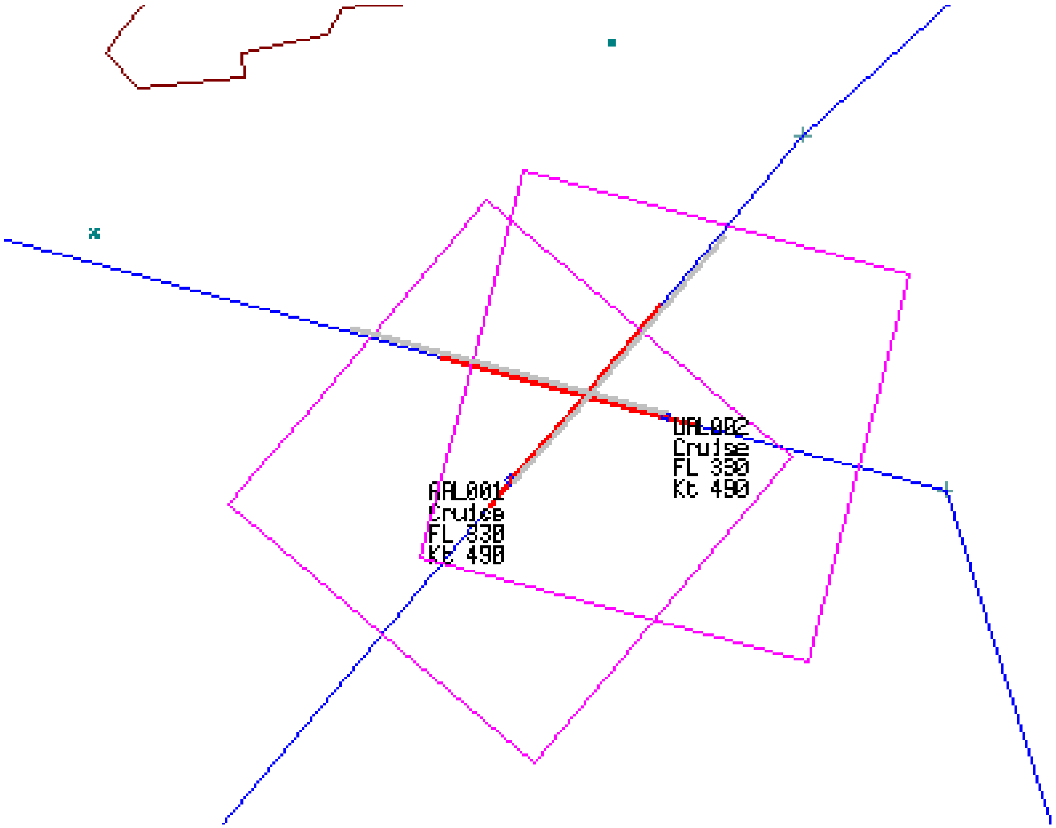
Speed: 5.82
Aircraft: 27 Of: 225
Controls
00,23:23:01
Run Mode
Step
0.03s
Aircraft
Name:
Locate: 0.2
Strip...
Instruct...
Show Logic...
Airport
Name:
Usage...
Range: 2
Queues...
Other
Sector:
Route:
Waypoint:
Cursor
Latitude: N035 33 36.5
Longitude: E139 46 13.2
UAL890

RAMS

- An airspace simulation model developed by Eurocontrol (equivalent of FAA ar traffic services in the US)
- Only airspace simulation
- Developed using MODSIM - a simulation language developed by CACI
- Good aircraft conflict detection and resolution
- Price is around $7,500 Euros (v. 3.0 version)
- Large learning curve

Sample Screen of RAMS

The figure illustrates the conflict detection and resolution in RAMS



Principles of Discrete-Event Simulation (Applies to all three models)

- The simulation moves from one scheduled event to the next one
- Keeps track of simulation events in an orderly fashion
- Many internal events are generated for each external event.
- The simulation clock is based on the current event's scheduled initiation, not elapsed clock time
- Events that are simultaneous, I.e., events with the same initiation times, are processed sequentially but there is no time change to the simulation clock.

Typical SIMMOD/TAAM Studies

- Runway closure impacts
- Analysis and delays of airfield ground operations
- Taxiway closures and upgrades
- Cargo and passenger terminal impact studies
- Pavement management
- Terminal traffic analysis
- Arrival/departure terminal operations
- New in-trail aircraft separation procedures
- Multi-airport interactions

Description of SIMMOD/TAAM

SIMMOD and TAAM are computer modes used in airport operations and planning

Simulates airport airside operations (i.e., airfield and airside)

Estimates capacity, travel time, delay and fuel consumption resulting from aircraft operations

Allows the investigation of causal links between airport technological improvements, aircraft operational procedures and their effect on aircraft delay

Justification of Large-Scale Models

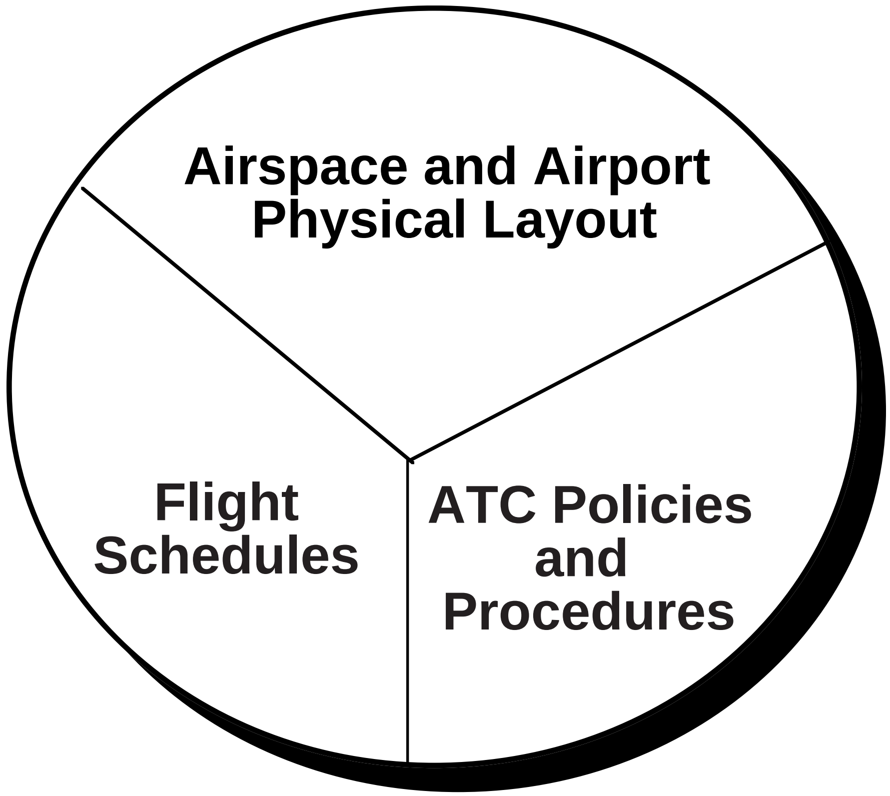
Computer models are:

- Safe in ascertaining the impact of operational changes
- Inexpensive to use
- Flexible to account for special airport/airspace conditions
- Provide answers to airspace and airport operational analysts
- Help to understand complex operational phenomena
- Improve decision-making ability

SIMMOD's History

- Development of the Airport/Airspace Delay Model (ADM)(1978-1979)
- Development of SIMMOD fuel consumption post-processors (1983)
- Validation of the SIMMOD Simulation Model (1985-1991)
- IBM and Compatible version 1.2 available in late1992
- Virginia Tech implements runway and HS runway exit logic changes (1995)
- SIMMOD Plus! from the ATAC Corporation

Large Scale Model as Decision Analysis Tools



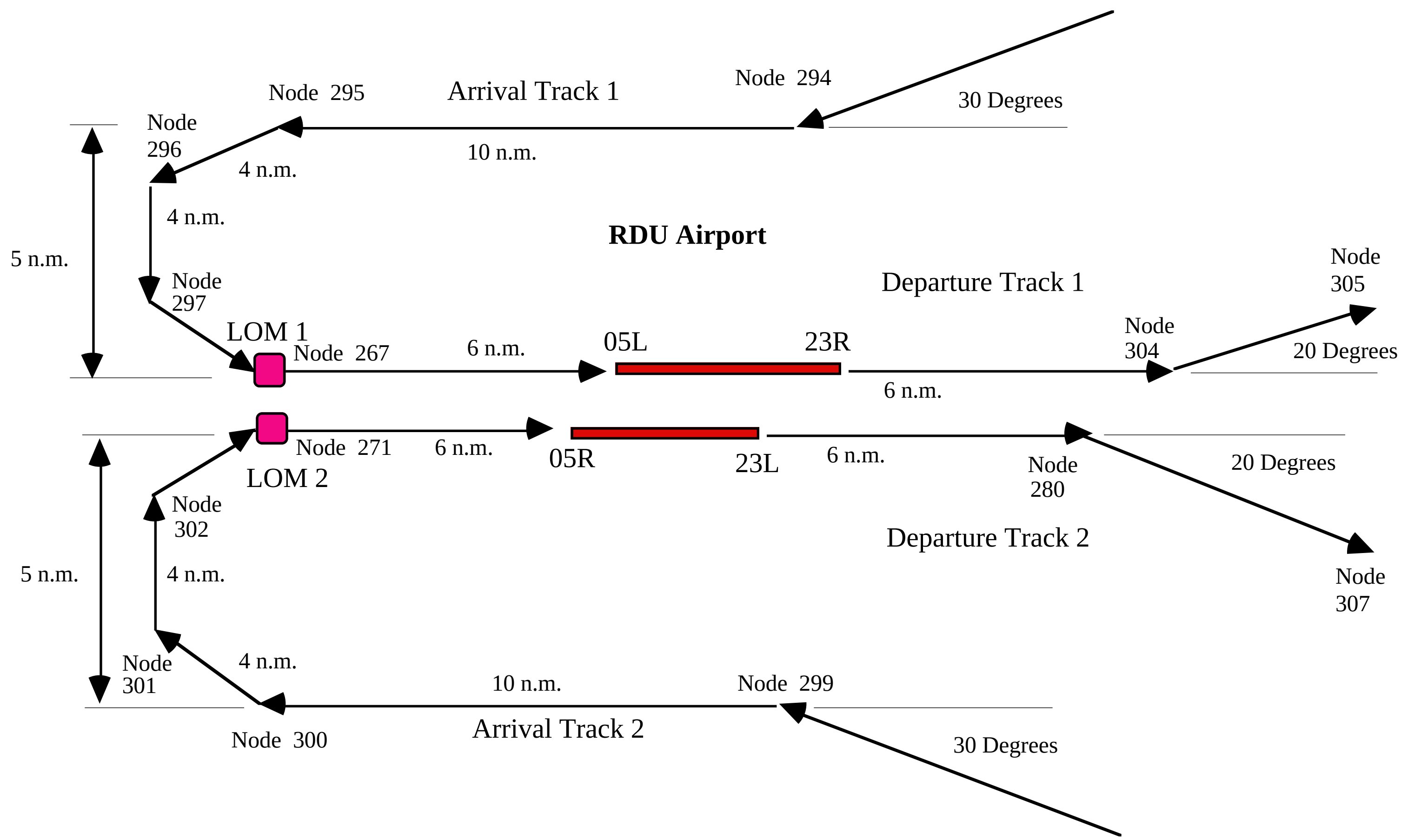
How SIMMOD/TAAM and Work

- Builds airspace and airports from inputs that describe the physical layout.
- Simulates all flights plane-by-plane.
- Uses external data to initiate flights.
- Resolves all conflicts.
- Monitors time and fuel consumed along each segment.
- Generates reports of some of the following: Statistical Summaries, Graphics and Animation

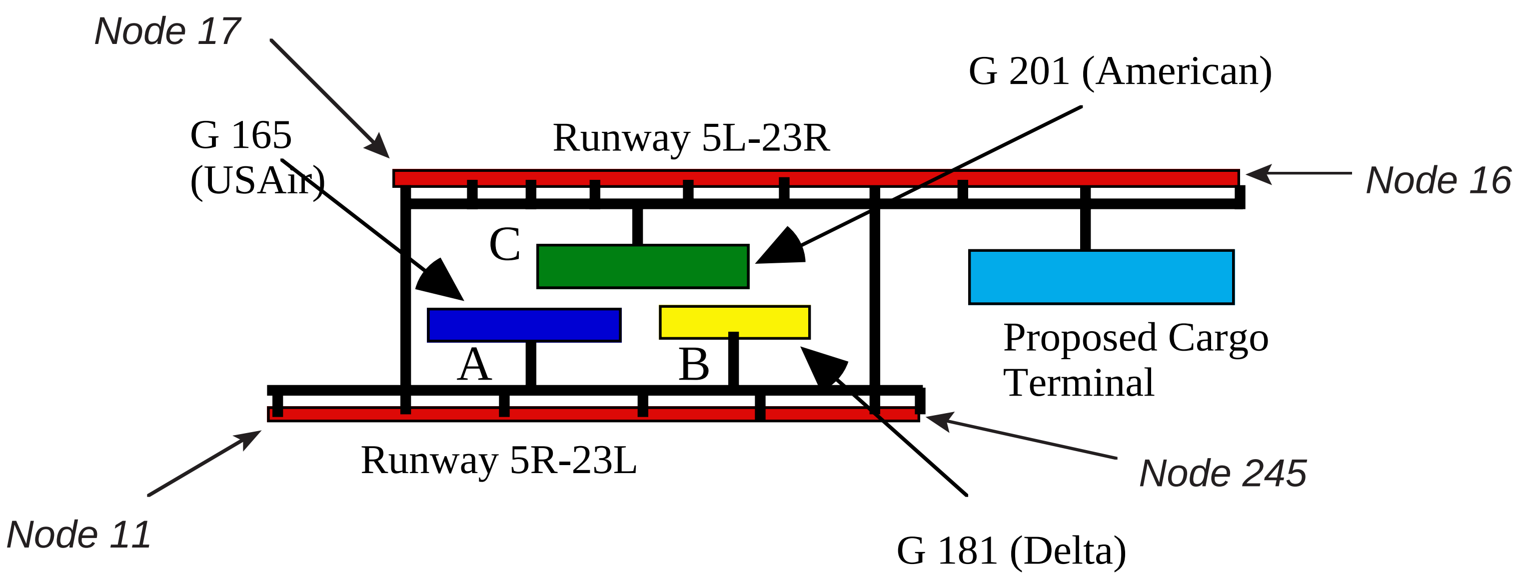
Sample Application (SIMMOD)

- Raleigh-Durham International Airport (RDU) in North Carolina represents a typical example of a medium size hub airport in the US
- Given a baseline aircraft demand during a two hour peak period you will be asked to modify the airspace and run some baseline simulations

Graphical Description of RDU Terminal Airspace



Graphical Depiction of RDU Airfield Configuration



RDU Airport with Supergates Shown

Gate Capacities

Concourse A	**- 15 aircraft**	**Concourse B**	**- 10 aircraft**
Concourse C	**- 30 aircraft**	**Cargo Complex**	**- 30 aircraft**

RDU Baseline Input Parameters (Aircraft Demands during a Two Hour Peak Hour)

	Flight	Type of Aircraft	Departure Time (hours + decimal)	Gate
1	AA 231	B 727-200	7.15	G 201
2	AA 450	B 727-200	7.20	G 201
3	AA 120	B 737-200	7.23	G 201
4	AA 003	F28 MK 2000	7.24	G 201
5	AA 052	F28 MK 2000	7.26	G 201
6	AA 2231	DC9-30-50	7.32	G 201
7	AA 123	B 727-200	7.41	G 201
8	DEL 200	F28 MK 4000	7.45	G 181
9	USA 125	F28 MK 4000	7.50	G 165
10	AA 454	B 727-200	7.52	G 201
11	DEL 560	F28 MK 4000	7.55	G 181
12	AA 320	B 727-200	7.58	G 201
13	USA 178	F28 MK 4000	7.60	G 165
14	DEL 678	F28 MK 4000	7.62	G 187
15	AA 2311	DC9-30-50	7.64	G 201
16	AA 2323	DC9-30-50	7.65	G 201
17	AA 2345	DC9-30-50	7.66	G 201
18	USA 780	B 727-200	7.70	G 165
19	AA 356	DC-10-10	7.79	G 201
20	AA 430	B 727-200	7.82	G 201

Aircraft Demands during a Two Hour Peak Hour - Continuation

	Flight	Type of Aircraft	Departure Time (hours + decimal)	Gate
21	AA 579	B 727-200	7.83	G 201
22	AA 122	A 300-600	7.85	G 201
23	AA 065	A 300-600	7.88	G 201
24	DEL 032	F 28 MK 4000	7.90	G 181
25	AA 012	DC-10-10	7.93	G 201
26	USA 005	F 28 MK 4000	8.00	G 165
27	AA 4543	B 727-200	8.13	G 201
28	DEL 563	F 28 MK 4000	8.20	G 181
29	AA 3200	B 727-200	8.24	G 201
30	USA 103	F 28 MK 2000	8.30	G 165
31	DEL 6782	F 28 Mk 4000	8.32	G 187
32	AA 2314	DC9-50	8.40	G 201
33	AA 2327	DC9-50	8.43	G 201
34	AA 2305	DC9-50	8.52	G 201
35	USA 781	B 727-200	8.56	G 165
36	AA 357	DC-10-10	8.70	G 201
37	AA 5784	B 727-200	8.75	G 201
38	AA 053	B 727-200	8.80	G 201
39	AA 1222	A 300-600	8.84	G 201
40	AA 865	A 300-600	8.92	G 201

RDU Input Aircraft Schedule (Departures During Two Hour Peak Period)

	Flight	Type of Aircraft	Departure Time (hours + decimal)	Gate
1	AA 002	B 727-200 (29)	6.68	G 201
2	AA 087	B 737-200 (45)	6.73	G 201
3	AA 149	B 737-200 (45)	6.76	G 201
4	DEL 096	F 28 MK 2000 (38)	6.80	G 201
5	AA 3290	DC9-50 (46)	6.85	G 201
6	AA 4670	DC9-50 (46)	6.88	G 201
7	AA 274	B 727-200 (29)	7.03	G 201
8	DEL 466	F 28 MK 4000 (39)	7.11	G 181
9	USA 102	F 28 MK 2000 (38)	7.27	G 165
10	AA 338	B 727-200 (29)	7.45	G 201

Numbers in Parenthesis are the aircraft number according to SIMMOD

SIMMOD Aircraft Number Equivalents
Partial List

Aircraft	SIMMOD Number	Aircraft Engine
Airbus A 300	31	GE CF6-50C
Boeing 727-200	29	PW JT8D-15QN
Boeing 737-200	45	PW JT8D-9QN
Boeing 747-200	2	PW JT9D-FL
Boeing 747-100	1	PW JT9D-BD
Boeing 757-200	52	PW 2037
MD-83	50	PW JT8D-219
Douglas DC9-50	46	PW JT8D-17
Douglas DC10-10	19	GE CF6-6D
Fokker F28 MK 2000	38	RR 183-2
Fokker F28 MK 4000	39	RR 183-2P
Saab SF 340	72	GE CT7-5
Canadair CL 600	58	ALF 502L
Cessna 500	57	PW JTD15-1
GASEPV	74	Generic

IFR Aircraft Intrail Separation Matrix

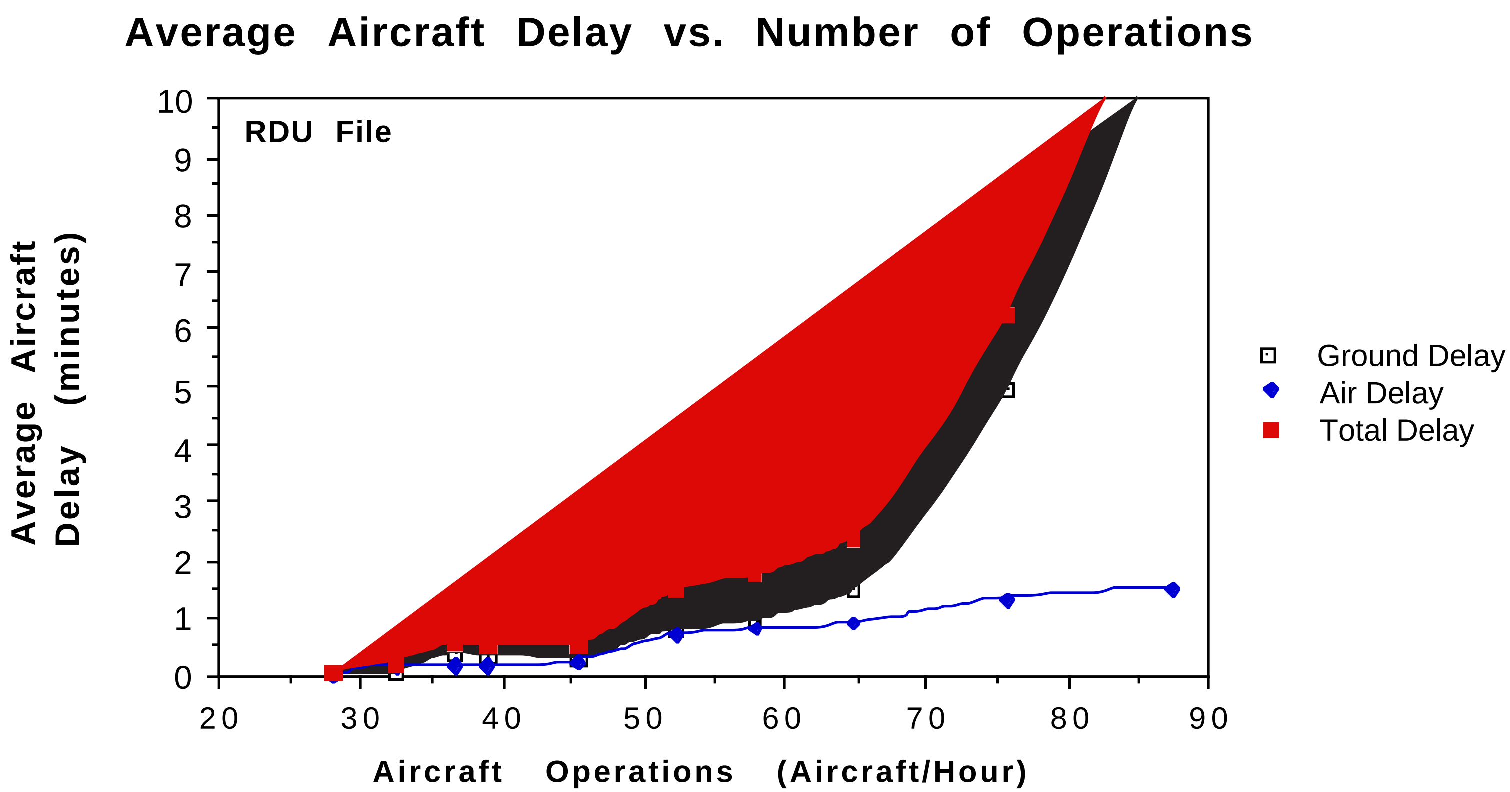
	Leading Aircraft			
Aircraft Group	1	2	3	4
1	3.0	4.0	5.0	6.0
2	3.0	3.0	4.0	5.0
3	3.0	3.0	3.0	4.0
4	3.0	3.0	3.0	3.0

Use the following parameters to estimate actual (stochastic separations)

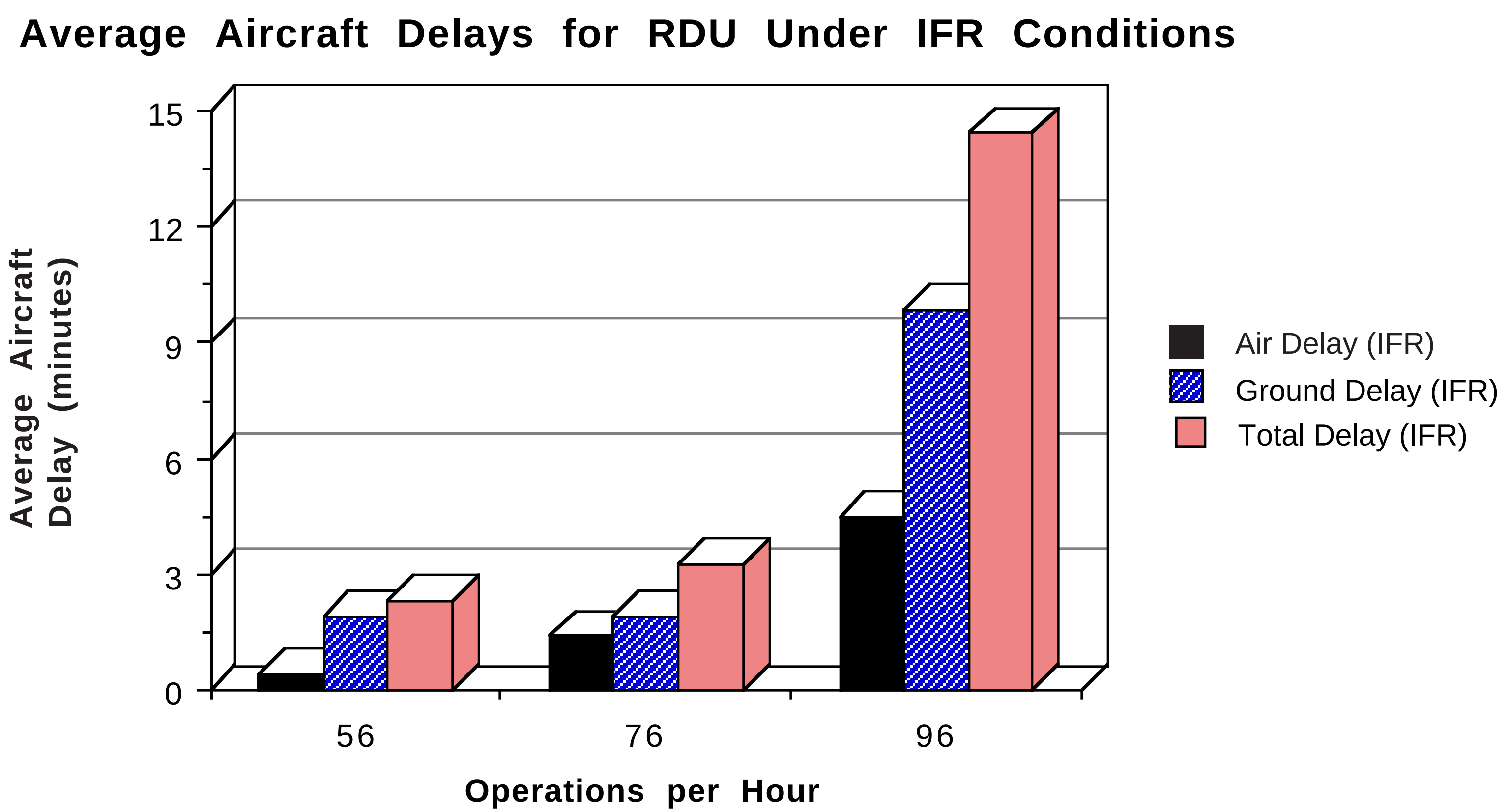
$\sigma_0 = 18$ Standard deviation of intrail delivery error (seconds) for manual ATC

$q_v = 1.65$ Value of cumulative standard normal at $P_v = 5\%$ (prob. of violations)

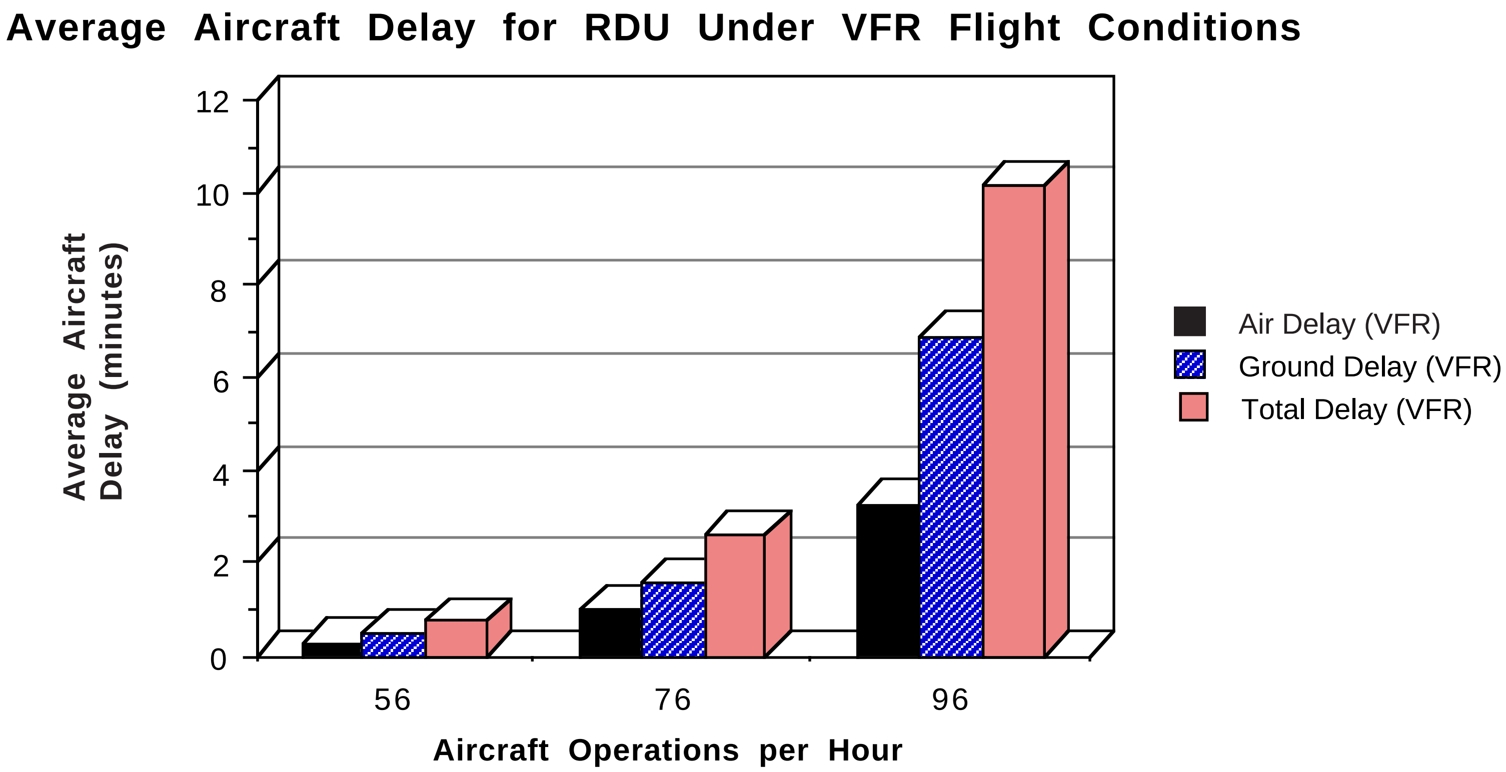
Sample Results (RDU)



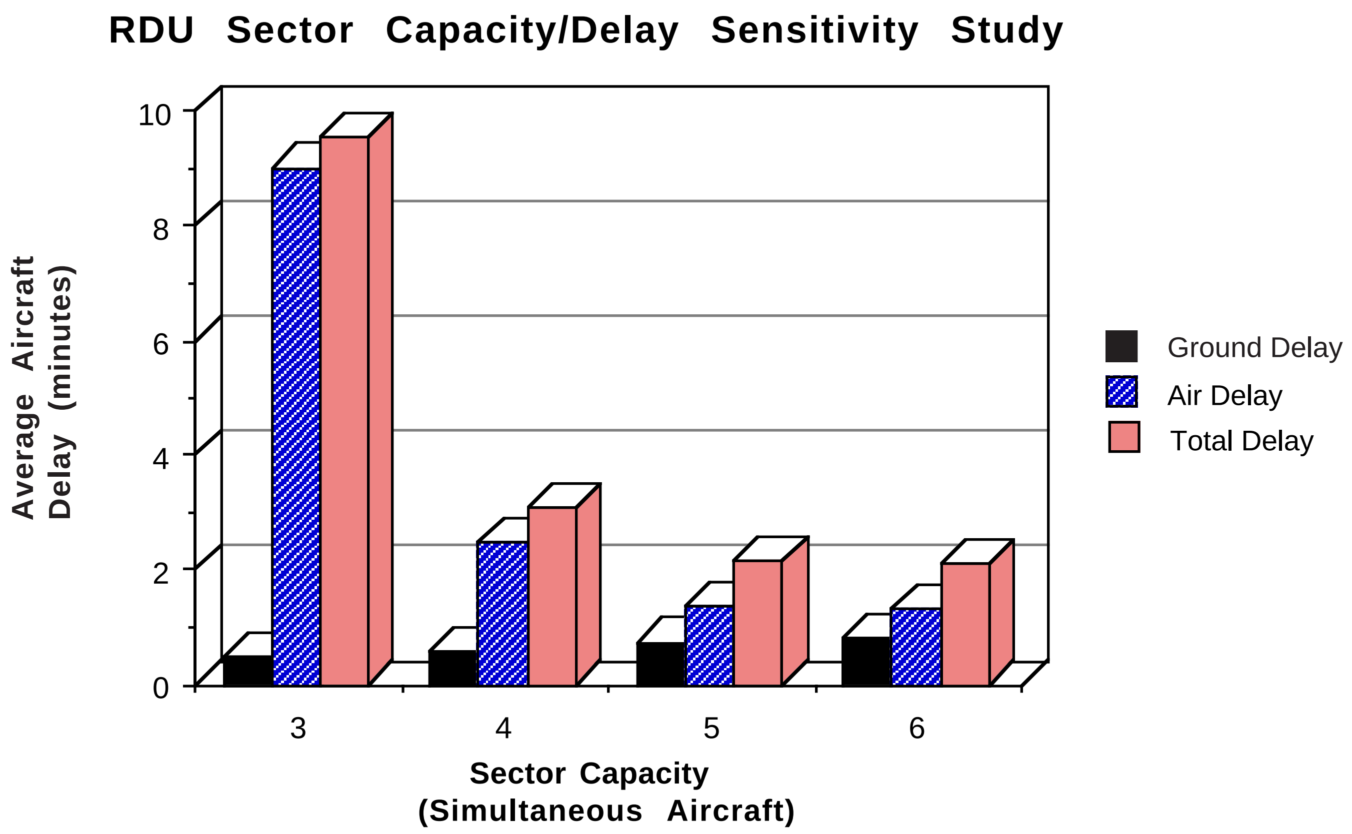
Sample Results for RDU (IFR Weather Conditions)



Sample Results for RDU (VFR Weather Conditions)



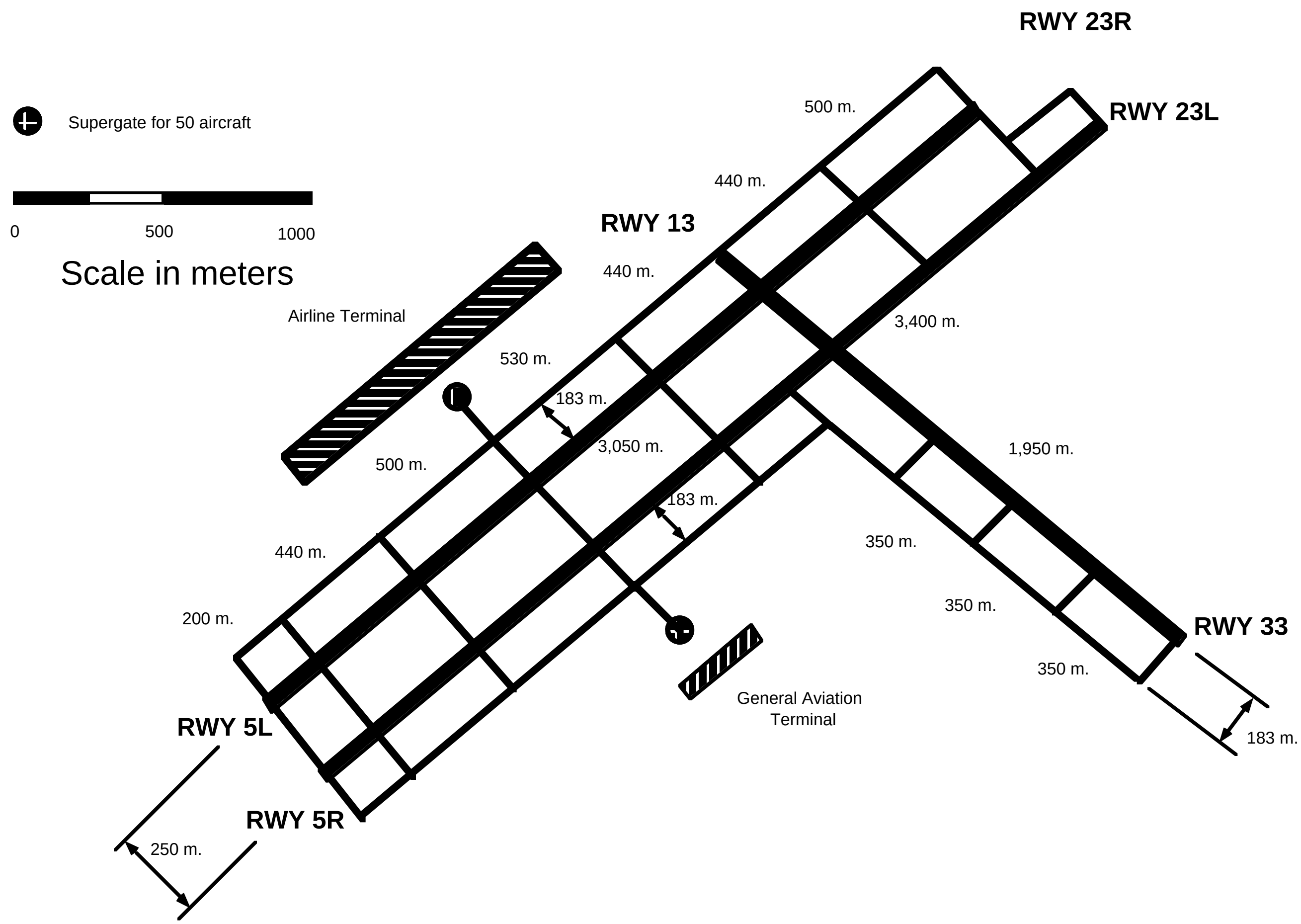
Sample Results for RDU and ATC Sector Study



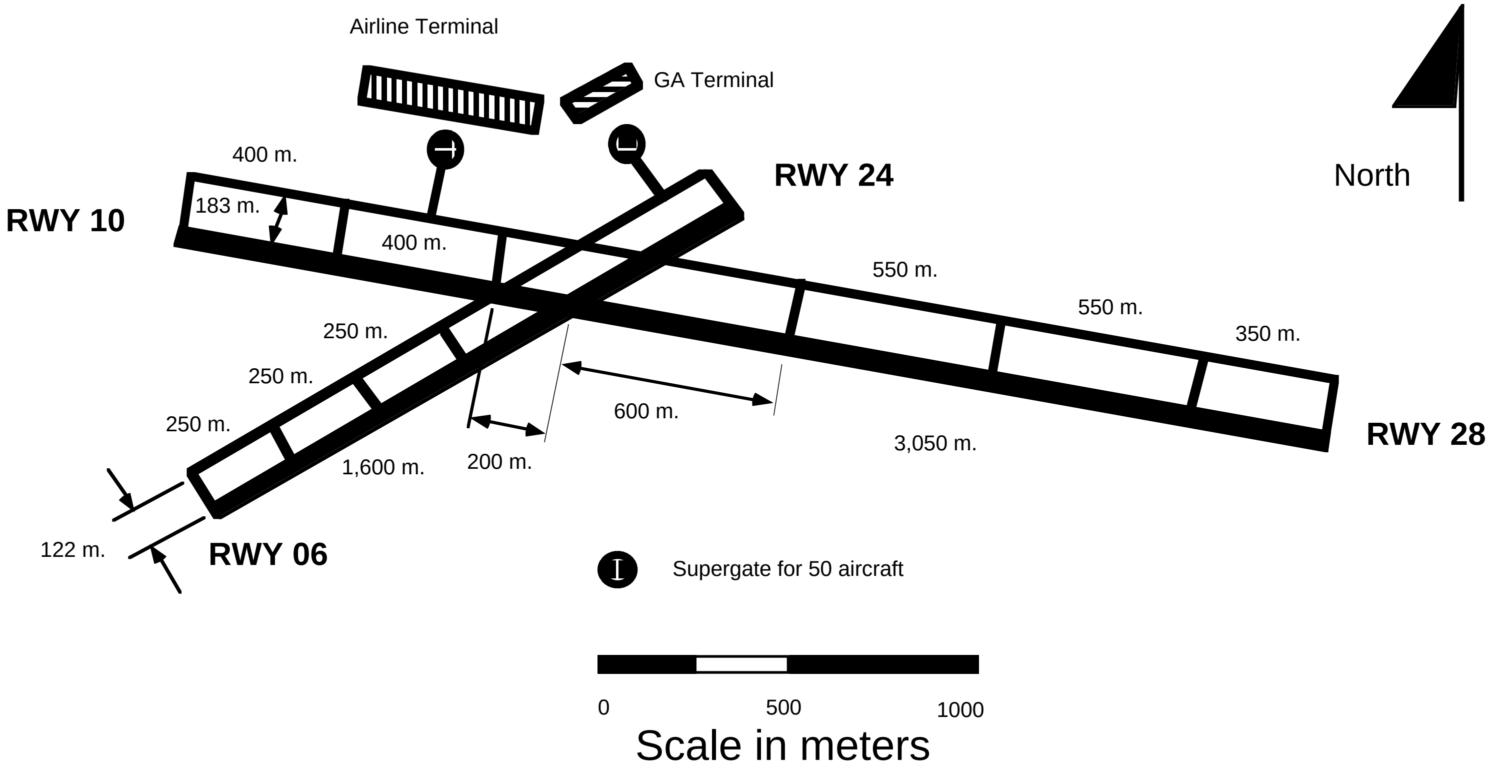
Creating Application with Multiple Airports

- All large-scale simulation models allow the creation of scenarios with multiple airports
- Discuss the implications of multiple airport analysis in airport engineering and planning
  - Airport interfences
  - Airspace planning studies
  - Traffic issues

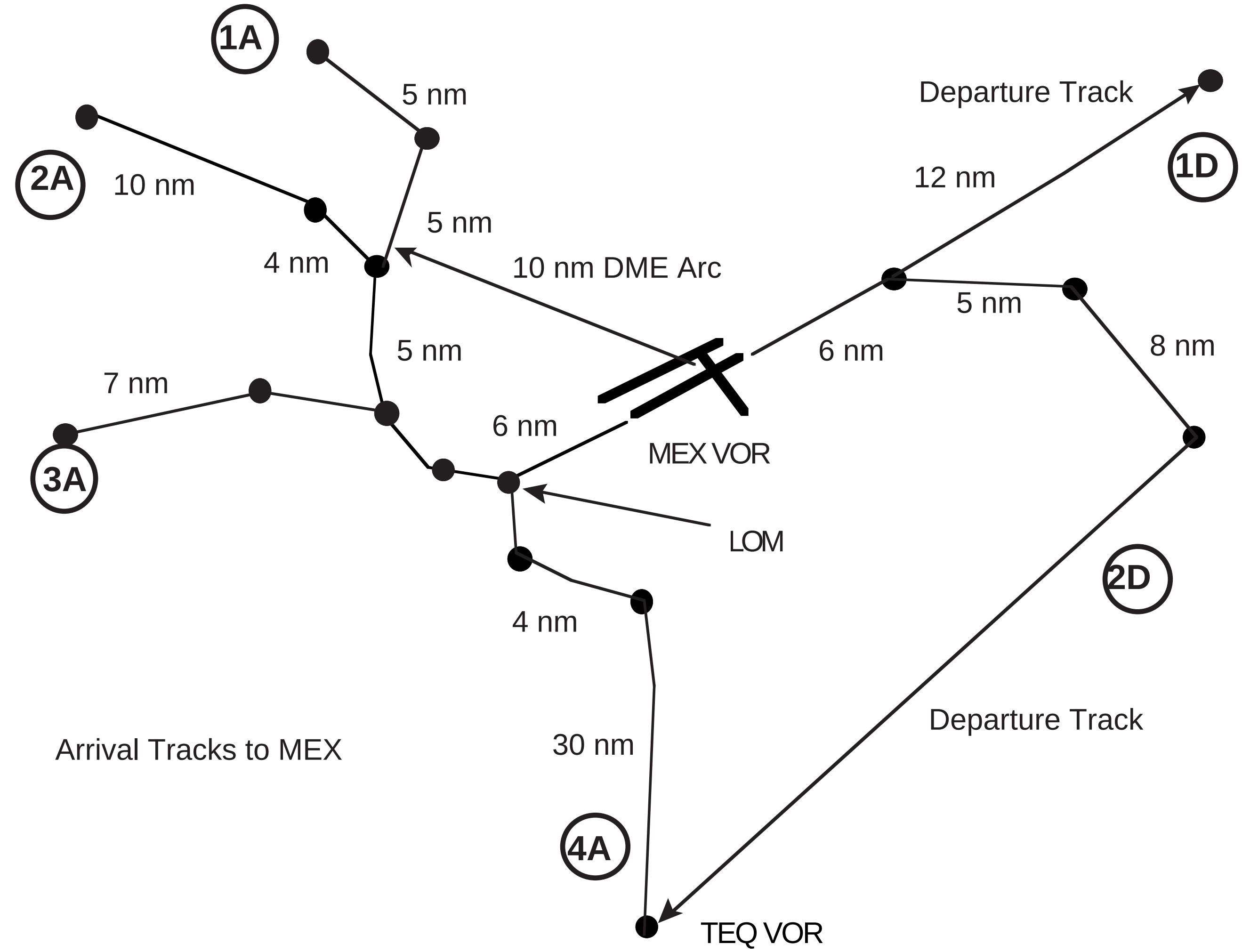
México City International Airport (México)



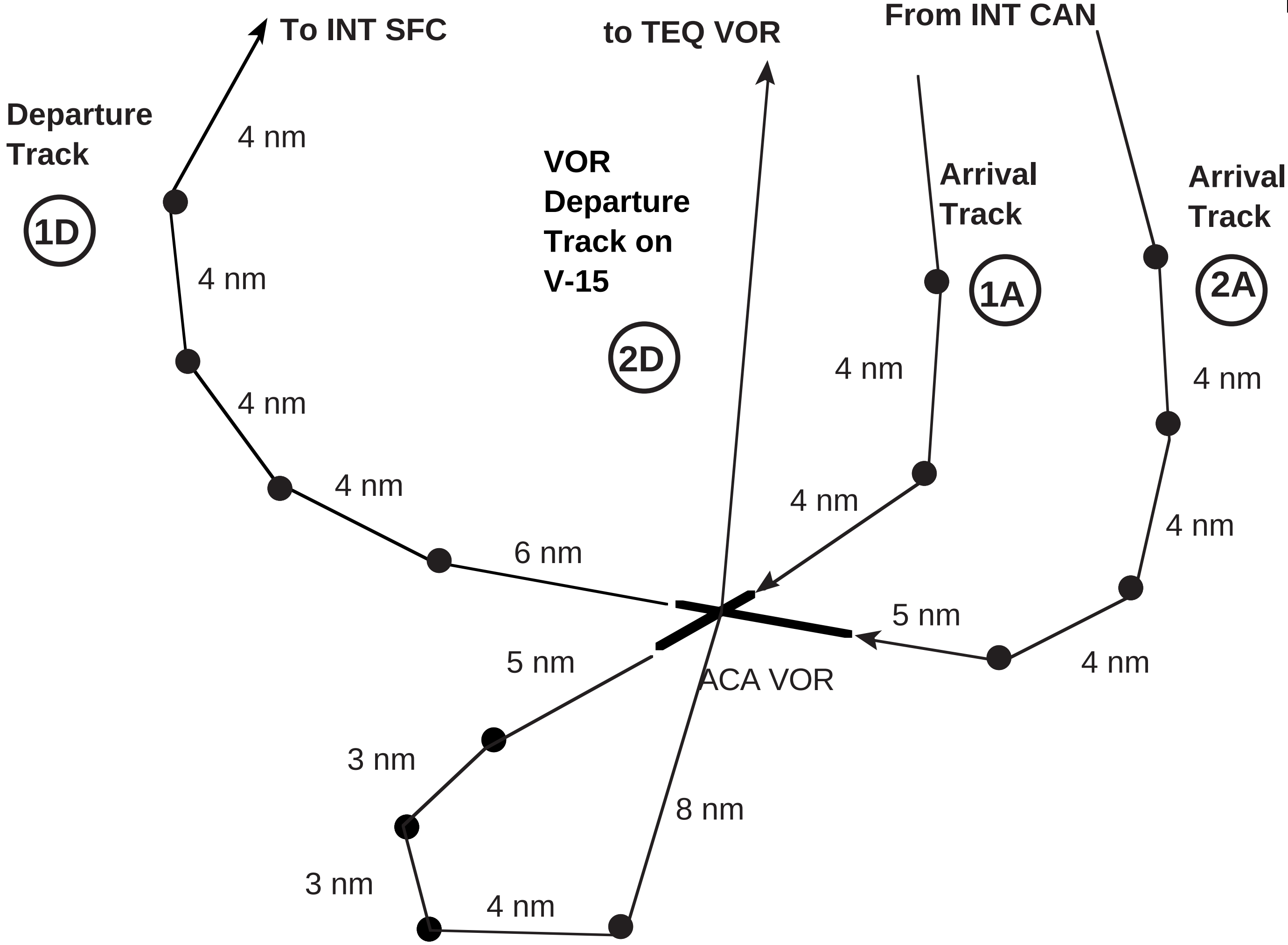
Acapulco International Airport (Mexico)



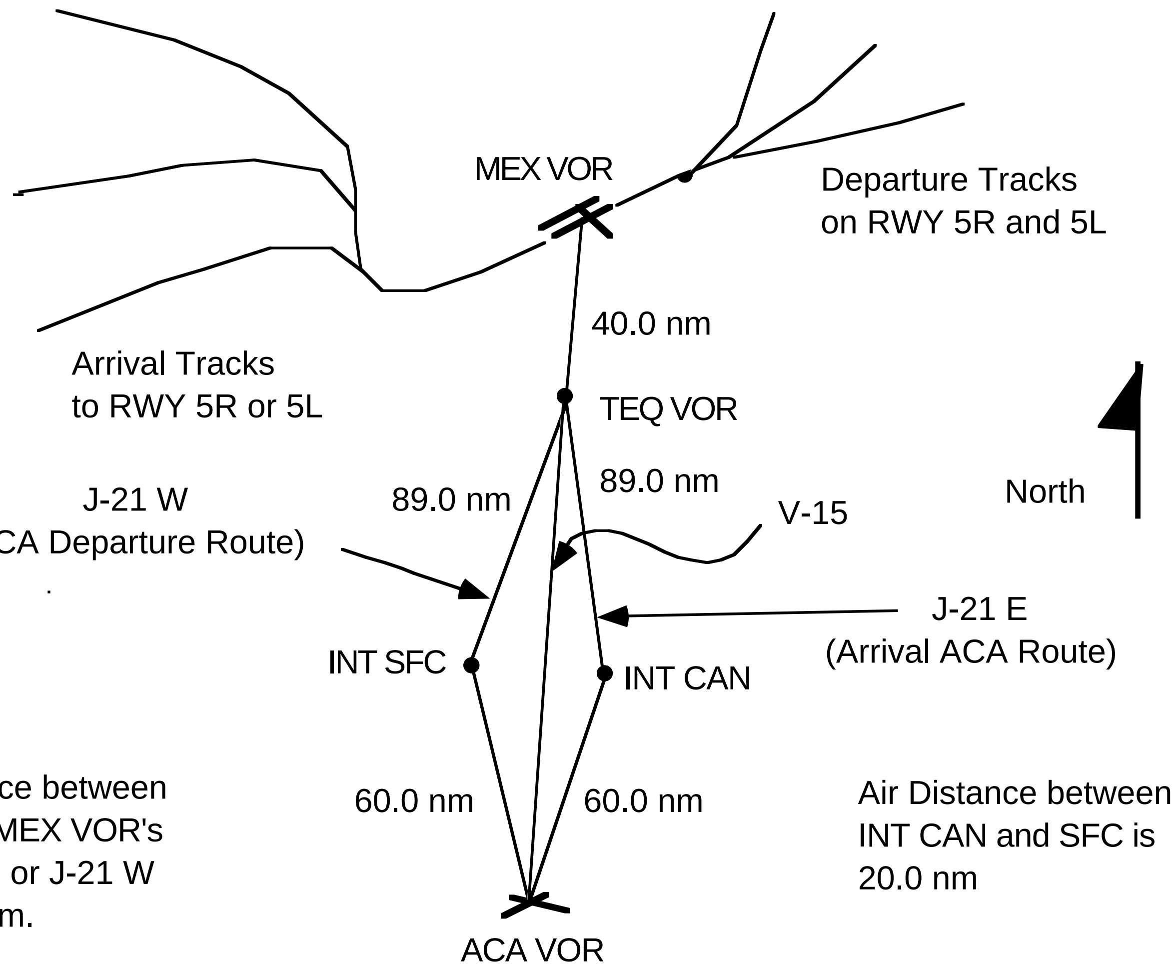
México City Terminal Area (Sketch)



Acapulco Airport Terminal Area (Sketch)



MEX-ACA Airway System



Air Distance between ACA and MEX VOR's via J-21 E or J-21 W is 189.0 nm.

Air Distance between INT CAN and SFC is 20.0 nm

Large-Scale Model Inputs (Typical)

- Airspace files (link and node structures)
- Airfield files (link and node structures)
- Aircraft file (demand or schedule files)
- Ancilliary files (for other tasks like fuel consumption etc.)

Large-Scale Model Outputs (Typical)

- Aircraft delays (in the airfield and in the airspace)
- Fuel consumption (TAAM and RAMS)
- Arrivals vs. Departures
- Runway utilization patterns
- Travel times and delays (air and ground)
- Hourly delay metrics
- Animation of aircraft operations (a selling point to show decision makers what will happen)

Use of Animation in Airport Modeling and Simulation

- Serves to identify potential airspace/runway logic problems
- Analysts can examine the simulation in real time or faster
- Identifies visually potential queueing problems at various airfield spots
- Helps non-technical people to understand airport operations (specially good for airport facilities with community complaints)

Aircraft Move Checks (Ground and Airspace)

Scheduled at a node by the following:

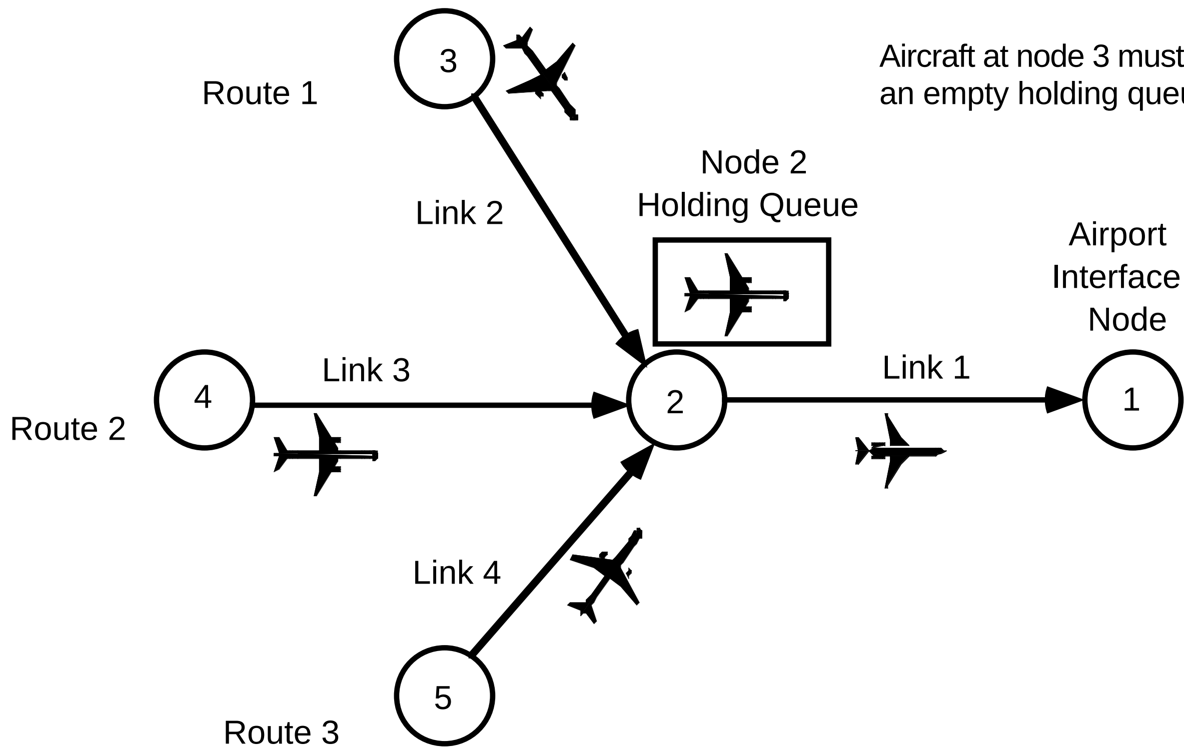
- Aircraft arriving at current node
- Aircraft departing from current node
- Estimated release time for aircraft in holding queue at the current node
- Aircraft departing from an approaching node to current node
- Aircraft leaving holding queue from an approaching node to current node

Sample SIMMOD Airspace Logic

Description:

Aircraft holding at node 2.

Aircraft at node 3 must hold until node 2 has an empty holding queue.



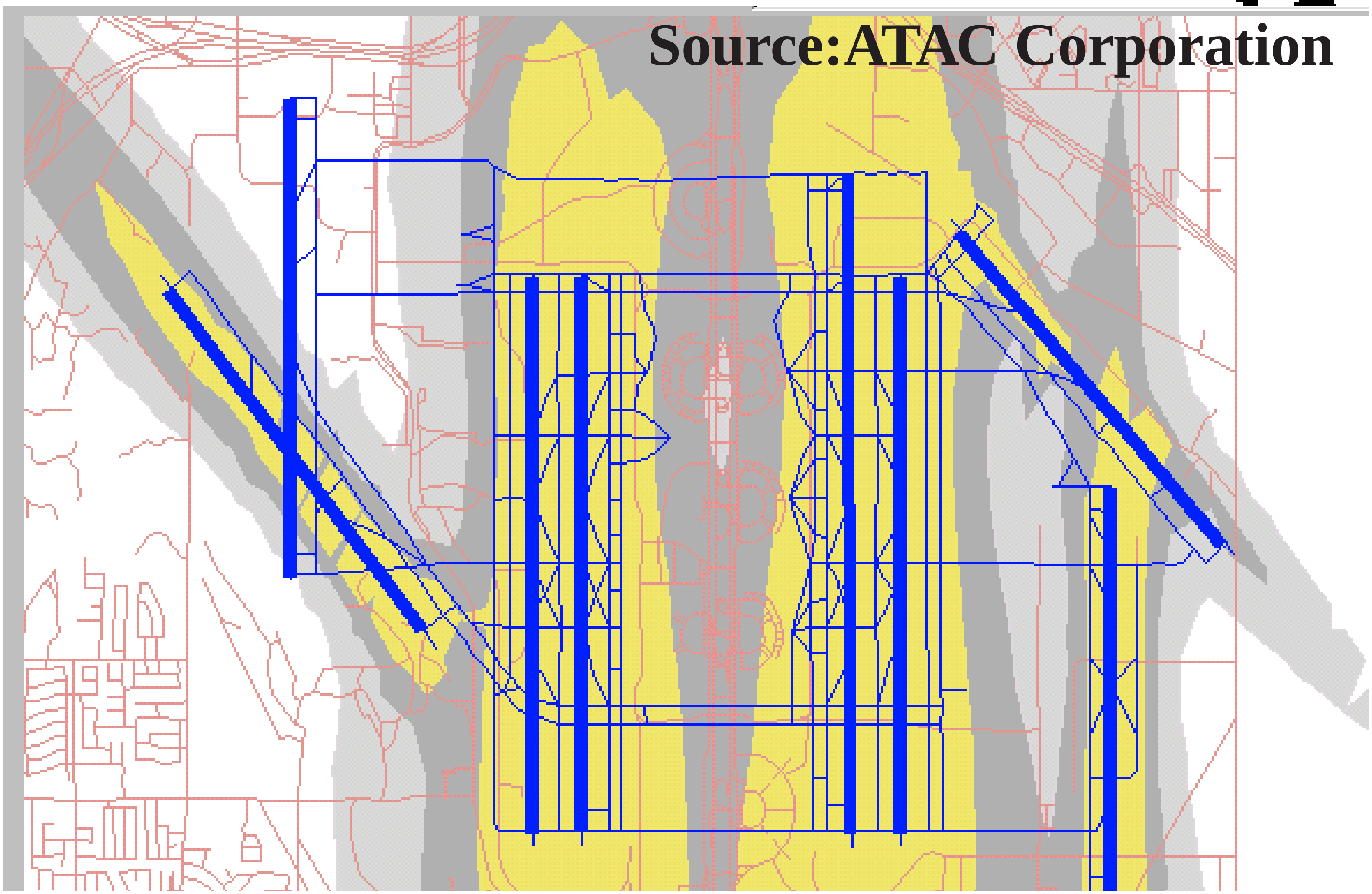
Order of Actions to Impose Delays (SIMMOD)

- Reduce aircraft speed based on node strategy (i.e., ATC speed change request)
- Vectors where wake turbulence on link is not a consideration..
- System cannot track wake during vectoring (ATC responsibility)
- Vector time must be specified for each link
- Hold at node

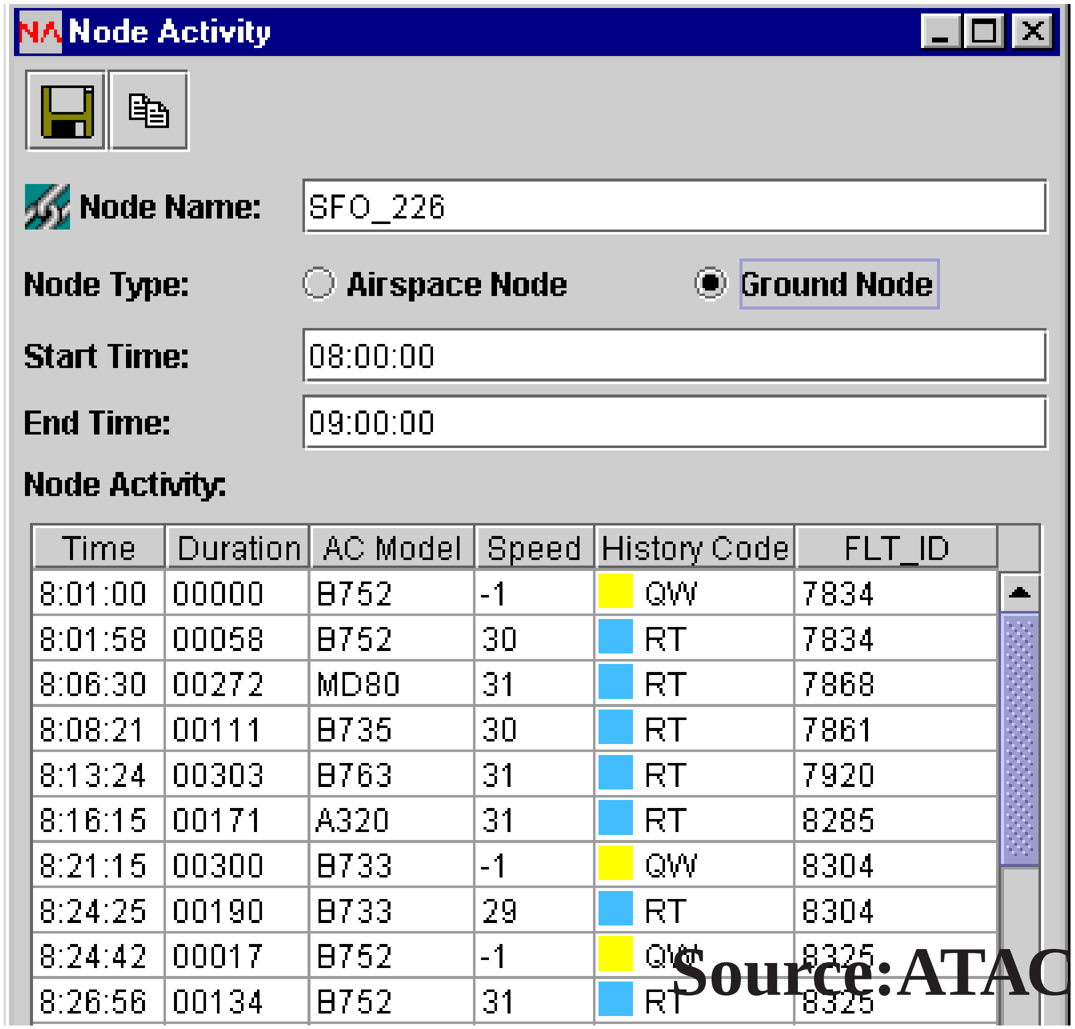
New SIMMOD Interface (SIMMOD Plus 5.0)

- Two version of SIMMOD have been developed by the ATAC Corporation (SIMMOD systems integrator for FAA):
  - SIMMOD Plus! 5.0
  - SIMMOD Pro (based on work done for the Navy)
- The new version of SIMMOD Plus! 5.0 has a very detailed Java-based interface

Sample SIMMOD Plus! (Builder GUI)



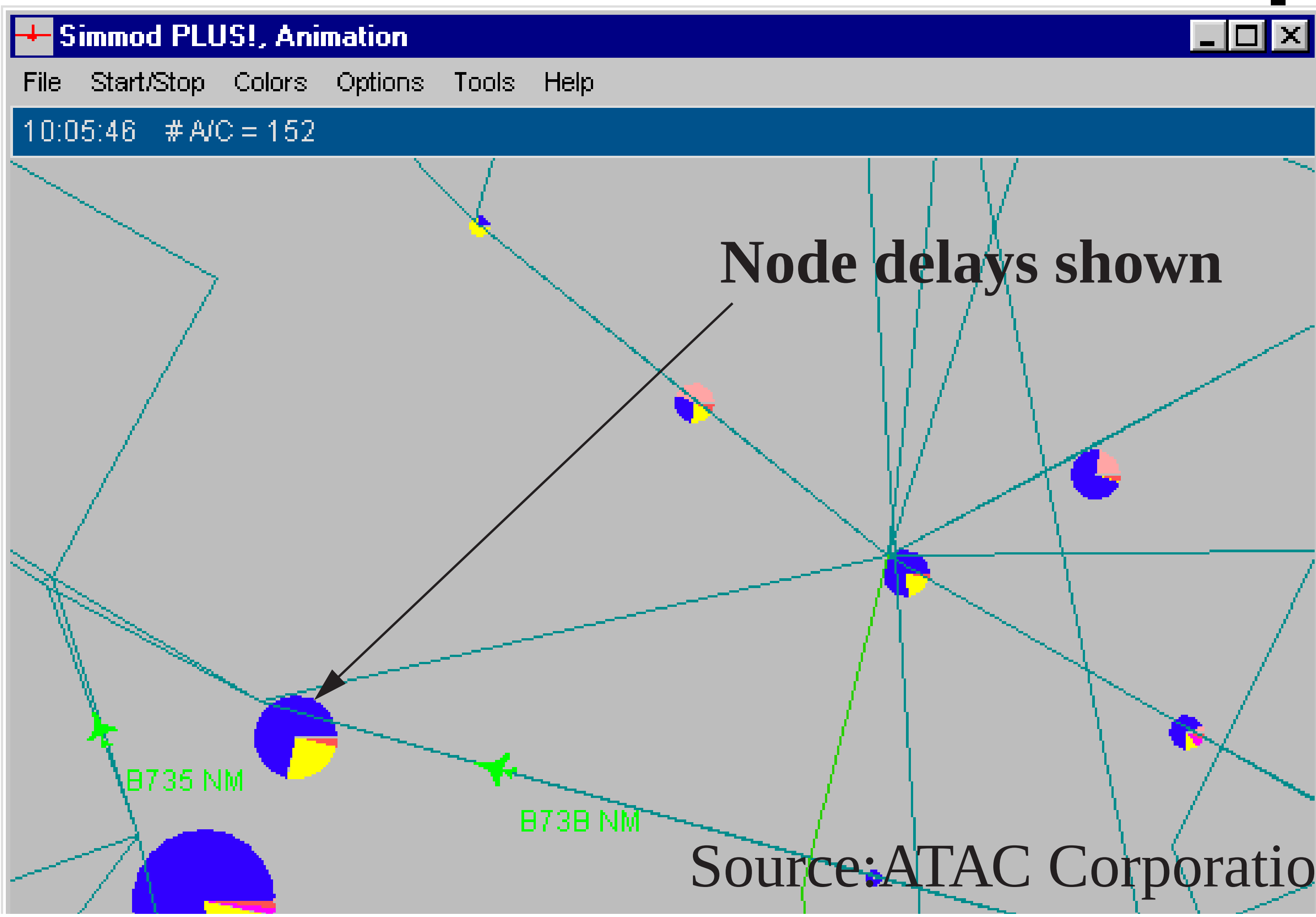
Sample SIMMOD Plus! Interface



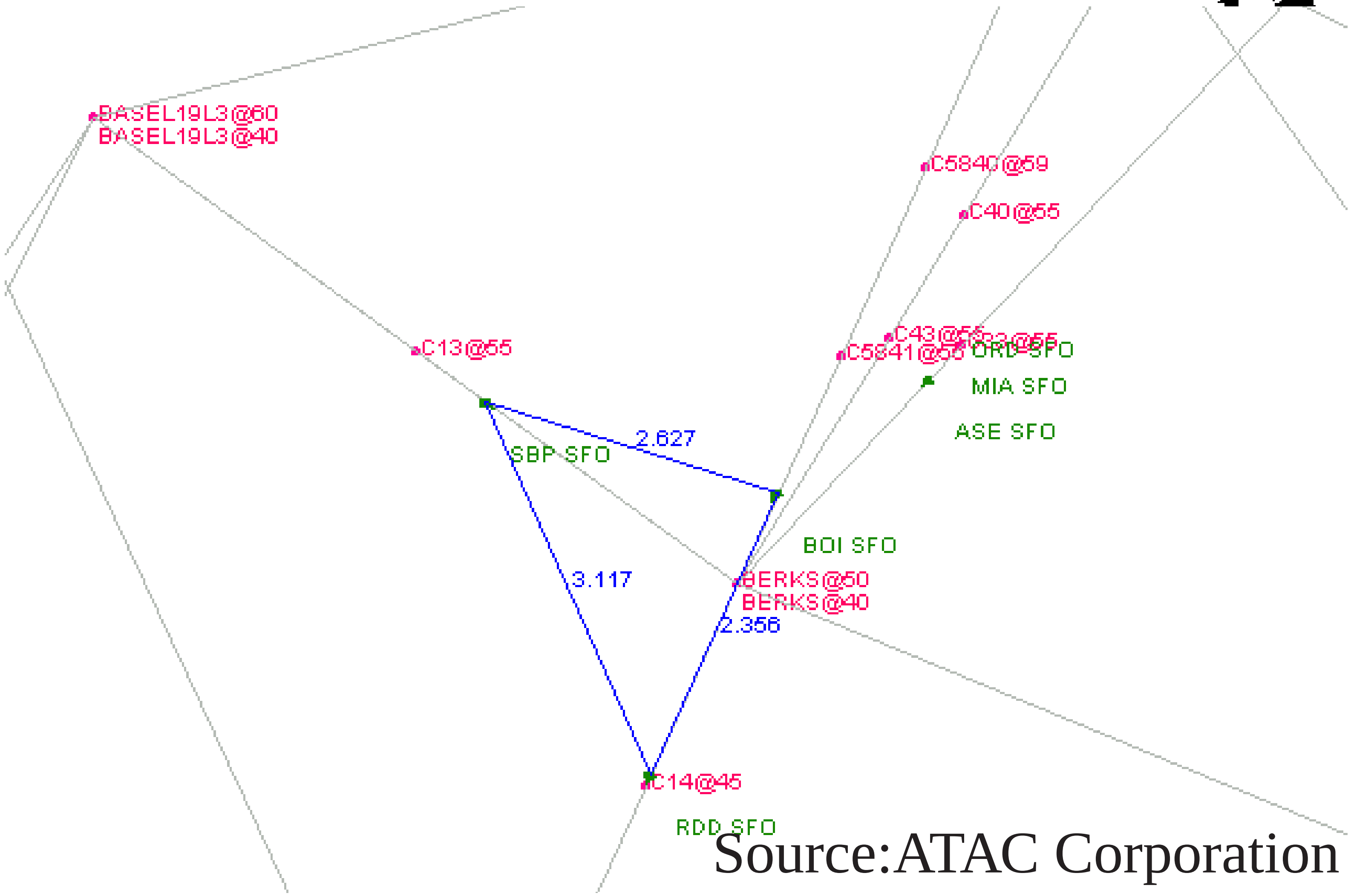
Time	Duration	AC Model	Speed	History Code	FLT_ID
8:01:00	00000	B752	-1	QW	7834
8:01:58	00058	B752	30	RT	7834
8:06:30	00272	MD80	31	RT	7868
8:08:21	00111	B735	30	RT	7861
8:13:24	00303	B763	31	RT	7920
8:16:15	00171	A320	31	RT	8285
8:21:15	00300	B733	-1	QW	8304
8:24:25	00190	B733	29	RT	8304
8:24:42	00017	B752	-1	QW	8325
8:26:56	00134	B752	31	RT	8325

Source:ATAC Corporation

Sample SIMMOD Plus! (Animation)



SIMMOD Plus! Aircraft Monitor



Source:ATAC Corporation

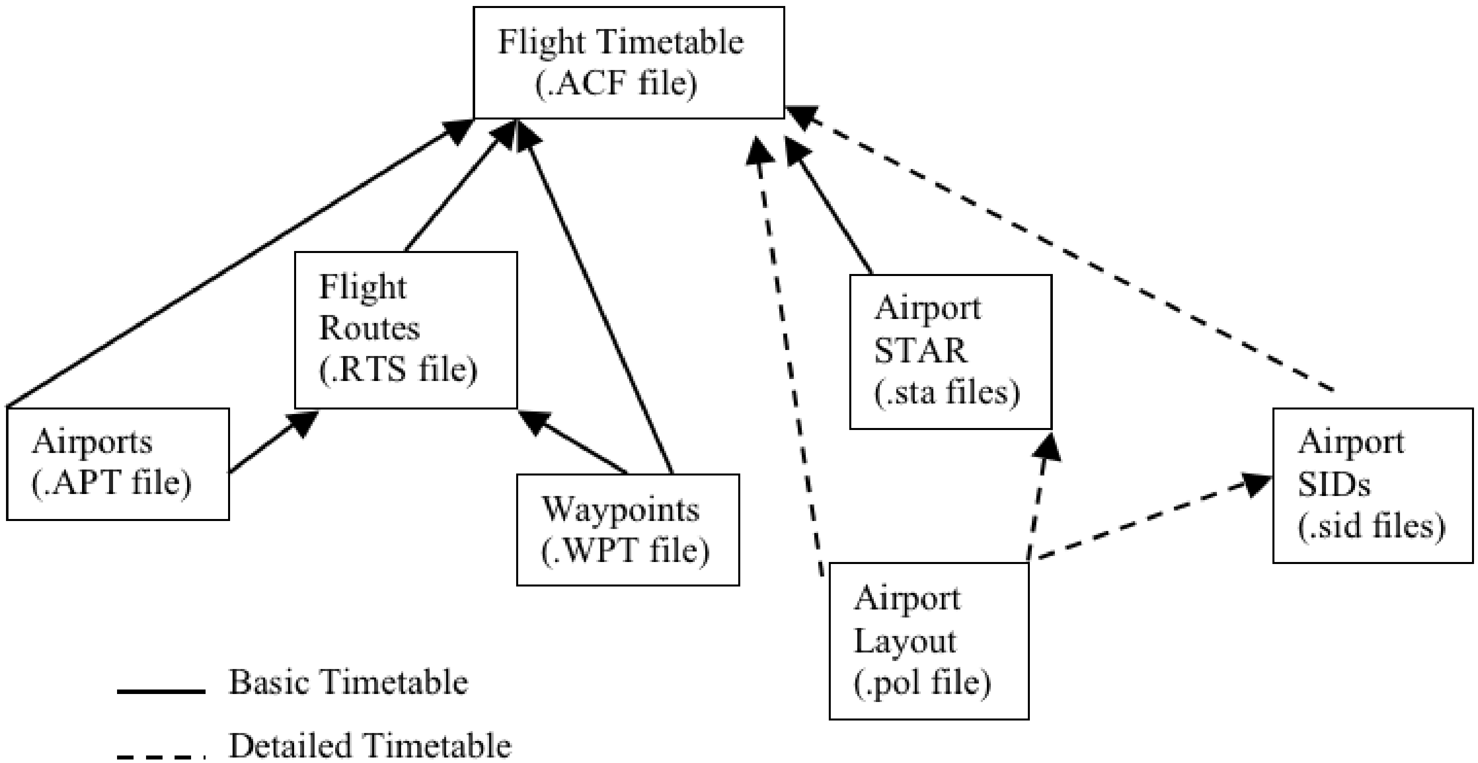
Sample Airspace Study in RAMS (CSSI)

RAMS Atlanta Airspace Study

TAAM

- An airspace and airfield simulation model developed by the Preston Group (Australia) - a Boeing Company
- Good airfield and airspace logic
- Gate-to-Gate simulator (important for some applications)
- Excellent graphics
- Large learning curve
- Limited stochastic behavior (only the aircraft performance is somewhat stochastic in this model)

TAAM Data Directory Organization



TAAM Relation to Aircraft Performance

- TAAM uses table functions to approximate the performance of aircraft in the airspace and on the ground
- Currently, 60 aircraft are included in the TAAM database (version 1.2 under Solaris 2.8)
- Transport aircraft and GA vehicles are included in the database
- Technically, it is not difficult to add an aircraft to the TAAM aircraft definition file

Sample TAAM Aircraft Data

57 # SUPER KING AIR -SHORT/LONG -
BE20 S 4 4 M M # Type, Haul, Wake Turb.Cat., Classif., Performance Cat (SID, STAR)
030 280 350 # Preferable levels (Low, High), Ceiling (FL)

015 104 114 126 0.0 0.0 0.0 12 # Below level... Min,Norm,Max Climb.IAS(kt) Mach, Fuel C.
030 110 160 210 0.0 0.0 0.0 12
050 110 160 200 0.0 0.0 0.0 12
100 110 160 195 0.0 0.0 0.0 12
150 110 140 190 0.0 0.0 0.0 12
190 110 140 190 0.0 0.0 0.0 12
230 110 130 180 0.0 0.0 0.0 12
260 110 130 160 0.0 0.0 0.0 12
310 110 120 140 0.0 0.0 0.0 10
350 110 120 120 0.0 0.0 0.0 10

TAAM Studies

- Berlin multi-airport and airspace simulation
- Delta Airlines Atlanta simulation
- FEDEX cargo hub modeling
- FAA ARTCC modeling (Kansas City)
- FAA Super TRACON modeling (Potomac metroplex study)
- NASA Ames studies of advanced ATM concepts
- VPI SATS enroute analysis
- GMU SATS enroute analysis

DFS Case Study

- Optimization of a complex airspace structure and arrival/departure procedures for the approach control unit serving the three airports of Berlin (Germany)
- Developed a new airspace sectorization scheme with departure routes representing more optimal flight profiles
- This resulted in a reduction of the controllers' coordination “workload” by almost 35%
- Shorter arrival routes and optimized descent profiles
- Reduced fuel burn (due to shorter flying time).

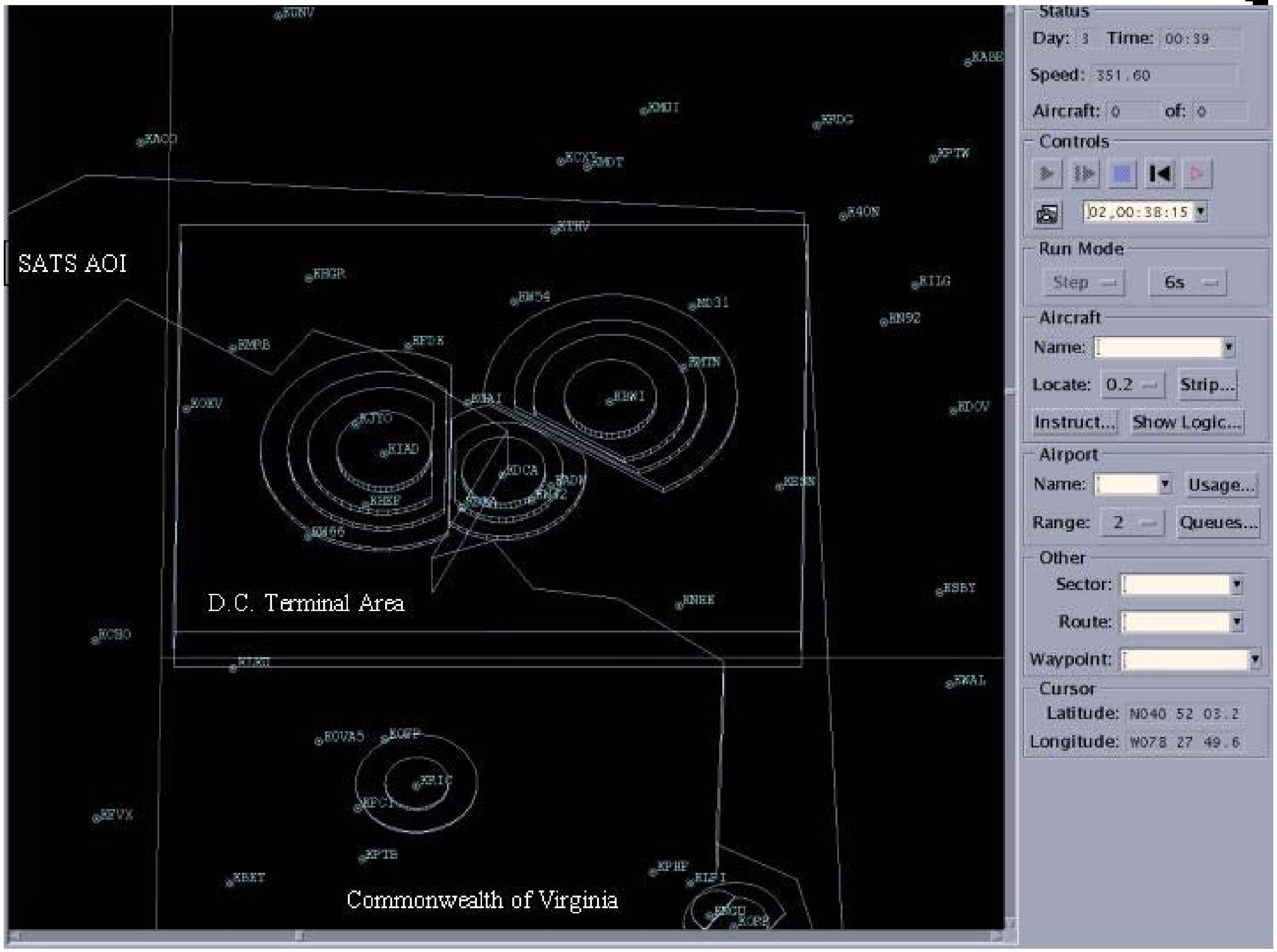
FEDEX Use of TAAM

- Construction work at Memphis (FEDEX Hub) runways required a change of operating procedures and forced the use of an alternate runway.
- TAAM simulation showed that a 30% delay reduction could be achieved through the use of a new parking plan and departure order
- Revised departure plan produced estimated annual savings in fuel costs of $5 - $10 million for two projects.

TAAM Study of SATS Enroute Traffic

- A non-funded study was performed at Virginia Tech to study the impacts of SATS traffic in the enroute airspace above the State of Virginia Boundaries
- SATS = Small Aircraft Transportation System (a NASA langley initiative to bring General Aviation aircraft to the masses)
- Limited study of baseline conditions (no SATS), 5% and 10% enplanements in NAS shifting mode to SATS. (Performed by Baik, Farrell, Trani and Koelling)
- Another more comprehensive study being done by George Mason for the Virginia SATS Alliance with inputs from LMI and Virginia Tech

Scenario Modeled

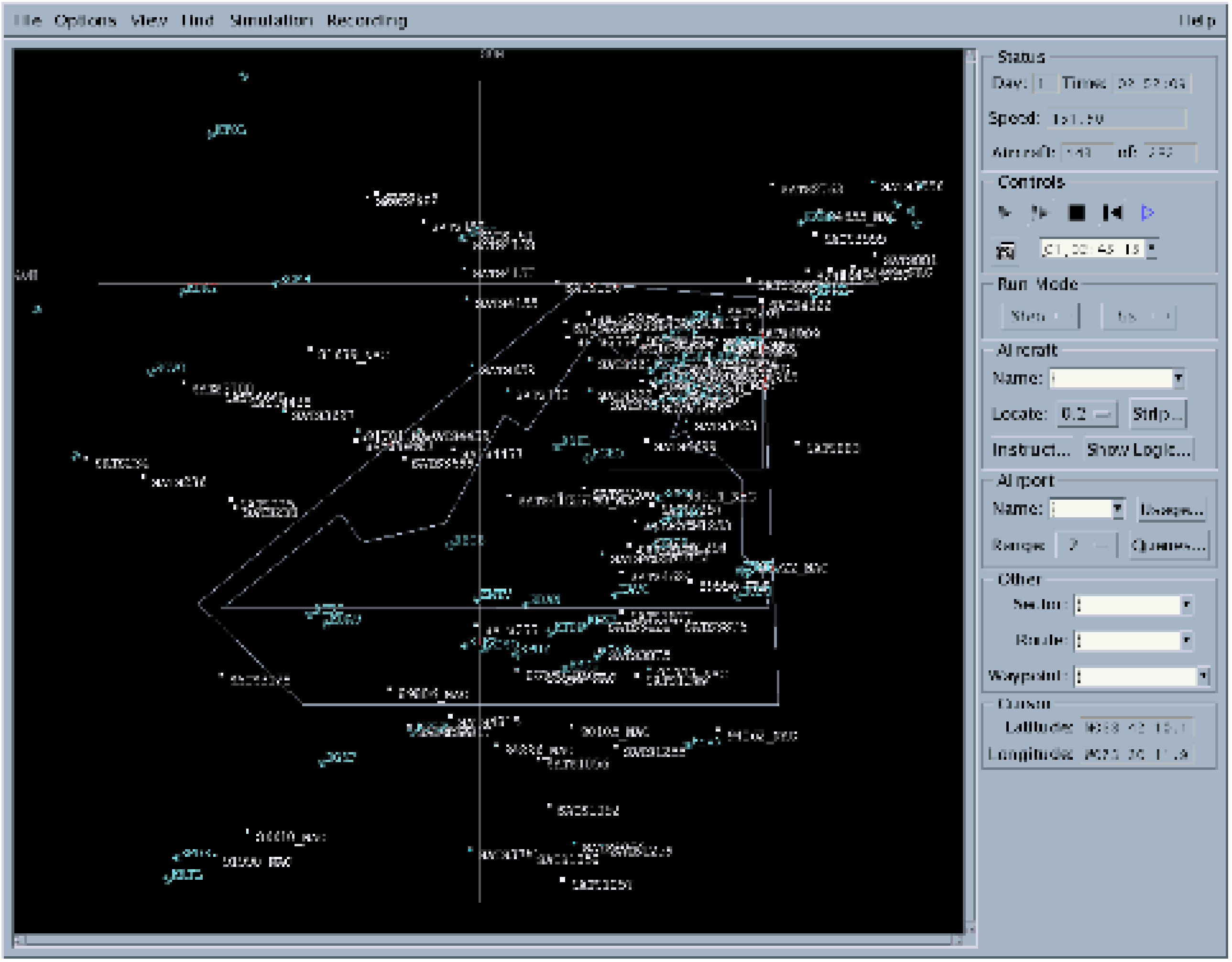


Statistics of Scenario Modeled

SATS Market Penetration	11/12/2000	11/12/2010	11/12/2015
0%	SATS: 0 ETMS: 4299 GA: 1191 Overflights: 2140 Total: 7630	SATS: 0 ETMS: 5353 GA: 1249 Overflights: 2734 Total: 9336	SATS: 0 ETMS: 5569 GA: 1279 Overflights: 2852 Total: 9700
5%	SATS: 5219 ETMS: 4299 GA: 1191 Overflights: 2140 Total: 12849	SATS: 6739 ETMS: 5353 GA: 1249 Overflights: 2734 Total: 16075	SATS: 7021 ETMS: 5569 GA: 1279 Overflights: 2852 Total: 16721
10%	SATS: 8957 ETMS: 4299 GA: 1191 Overflights: 2140 Total: 16587	SATS: 11958 ETMS: 5353 GA: 1249 Overflights: 2734 Total: 21294	SATS: 12455 ETMS: 5569 GA: 1279 Overflights: 2852 Total: 22155

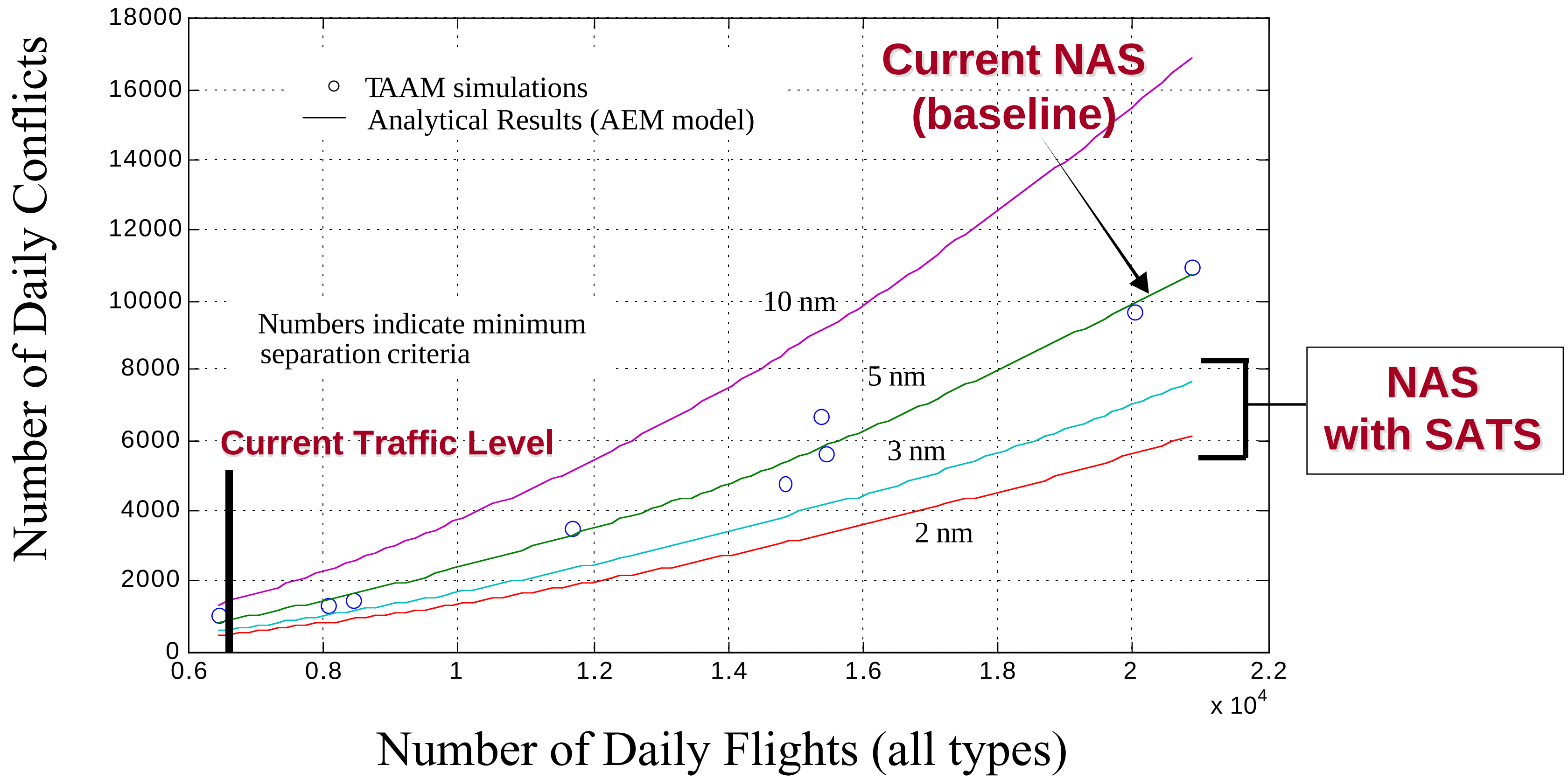
ETMS includes Air Carrier, Air Taxi/Commuter, Charter, Freight, and Military Aircraft)

Modeled Scenario (Part of ZDC)

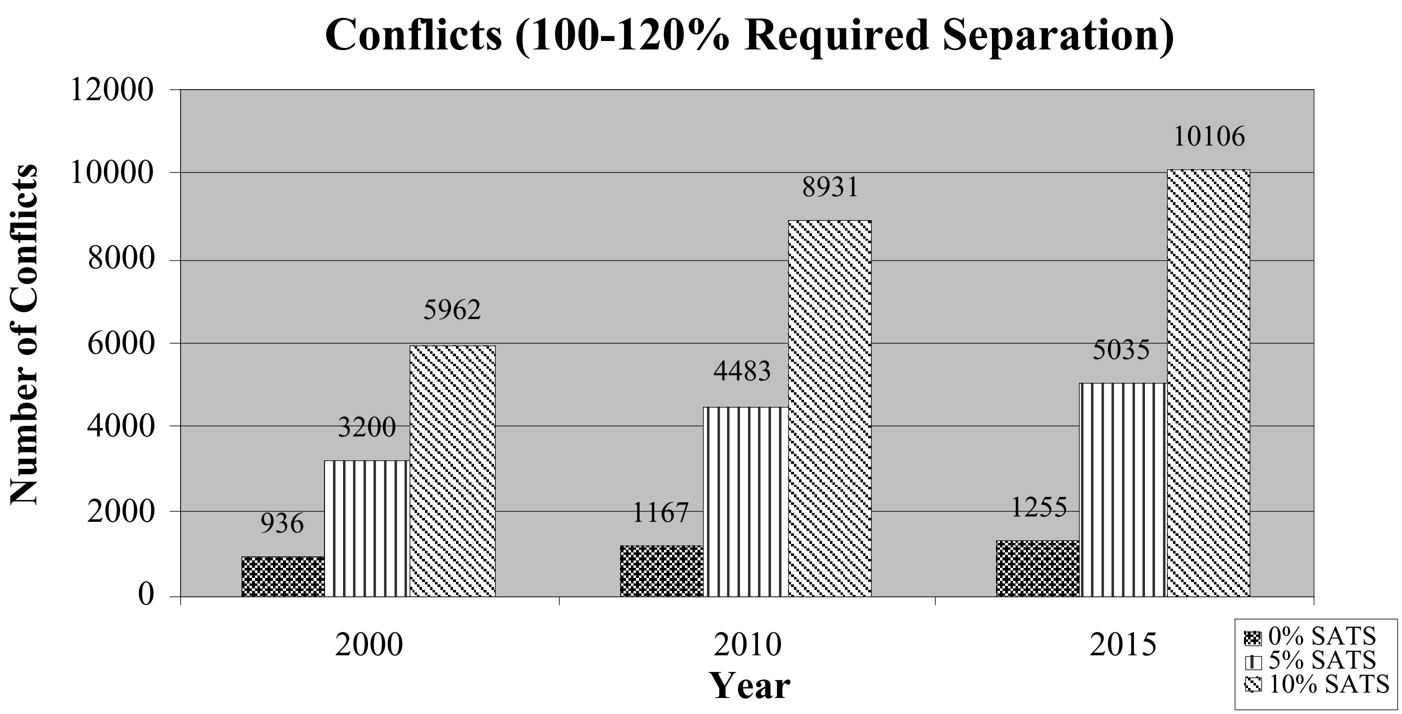


Results of Study (Baik et al., 2002)

Region of Interest = Size of ZDC ARTCC



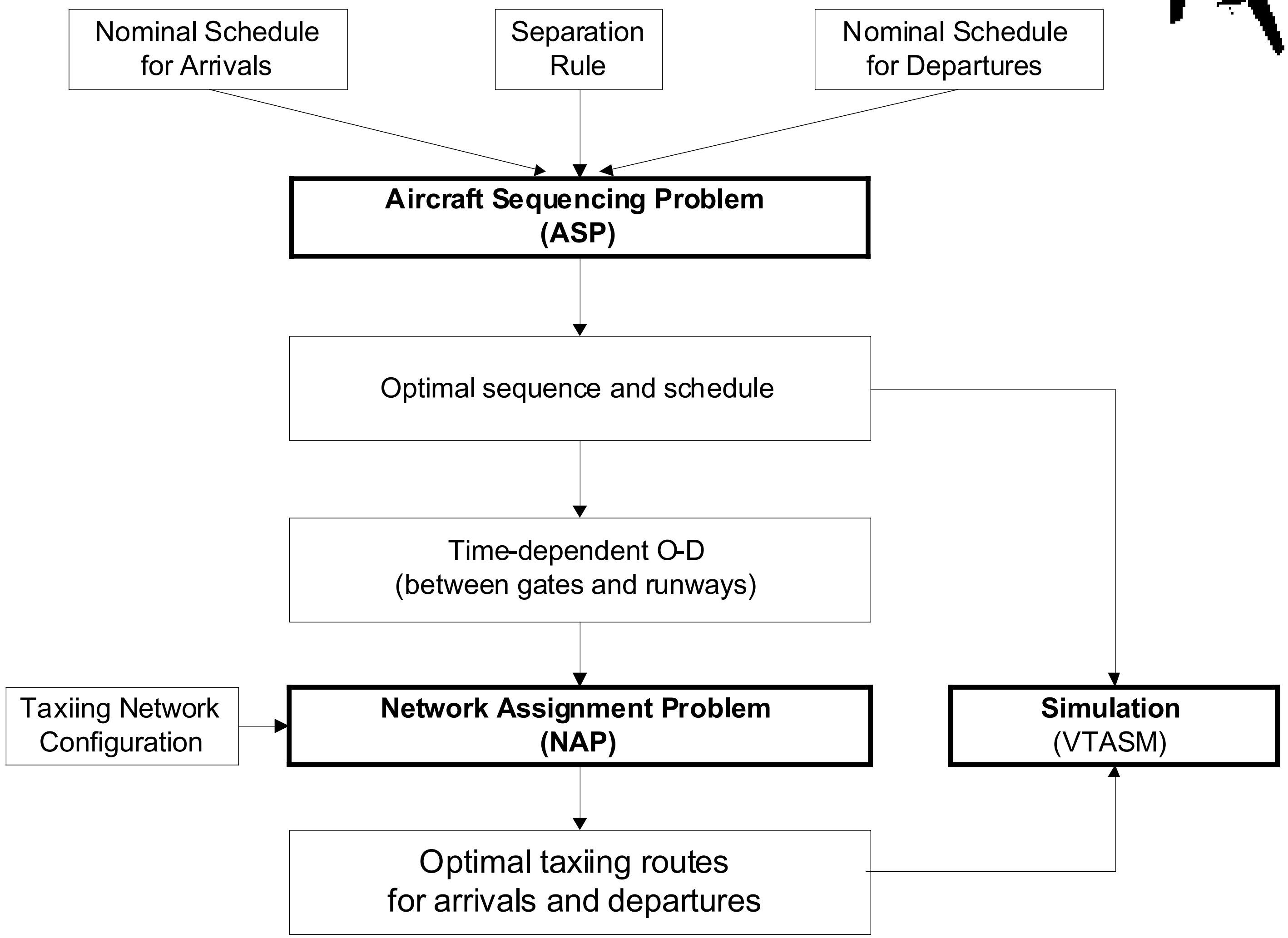
Other Results (Baik et al., 2002)



The Virginia Tech Airport Simulation Model

- Hybrid simulation model
- Microscopic in nature (second-by-second output if required)
- Models aircraft operations around the airport terminal area (includes sequencing)
- Models ATC-pilot interactions explicitly (voice and datalink)
- Dynamic taxiing plans (true dynamic traffic assignment)
- Developed under the auspices of the FAA NEXTOR basic research funding (ATM agenda)

Framework for VTASIM



Development of a Simulation Model: VTASIM

- Existing microscopic simulation models for airport studies:
  - SIMMOD, TAAM (airfield and airspace analyses)
  - Airport Machine (airfield analysis)
  - RAMS (airspace analysis)
- These models are:
  - discrete-event simulation models,
  - less accurate in describing the aircraft movement,
  - do not describe communication process (ATC-pilot).

VTASIM is a Hybrid-type Simulation Model

- A discrete-event simulation model
  - Represents a system by changing the system status at the moments when an event occurs
- A discrete-time simulation model
  - Represents a system checking and changing the system status at every step size (dt).
- VTASIM is a hybrid-type simulation model
  - Movement: represented by discrete-time simulation model
  - Communication: represented by discrete-event simulation model

Entities and State Variables in VTASIM

Entities:

- Two types of controllers (i.e., local and ground controllers),
- Two types of flights (i.e., departing and arriving flights), and
- Facilities including gates, taxiways, runways, etc.

State Variables:

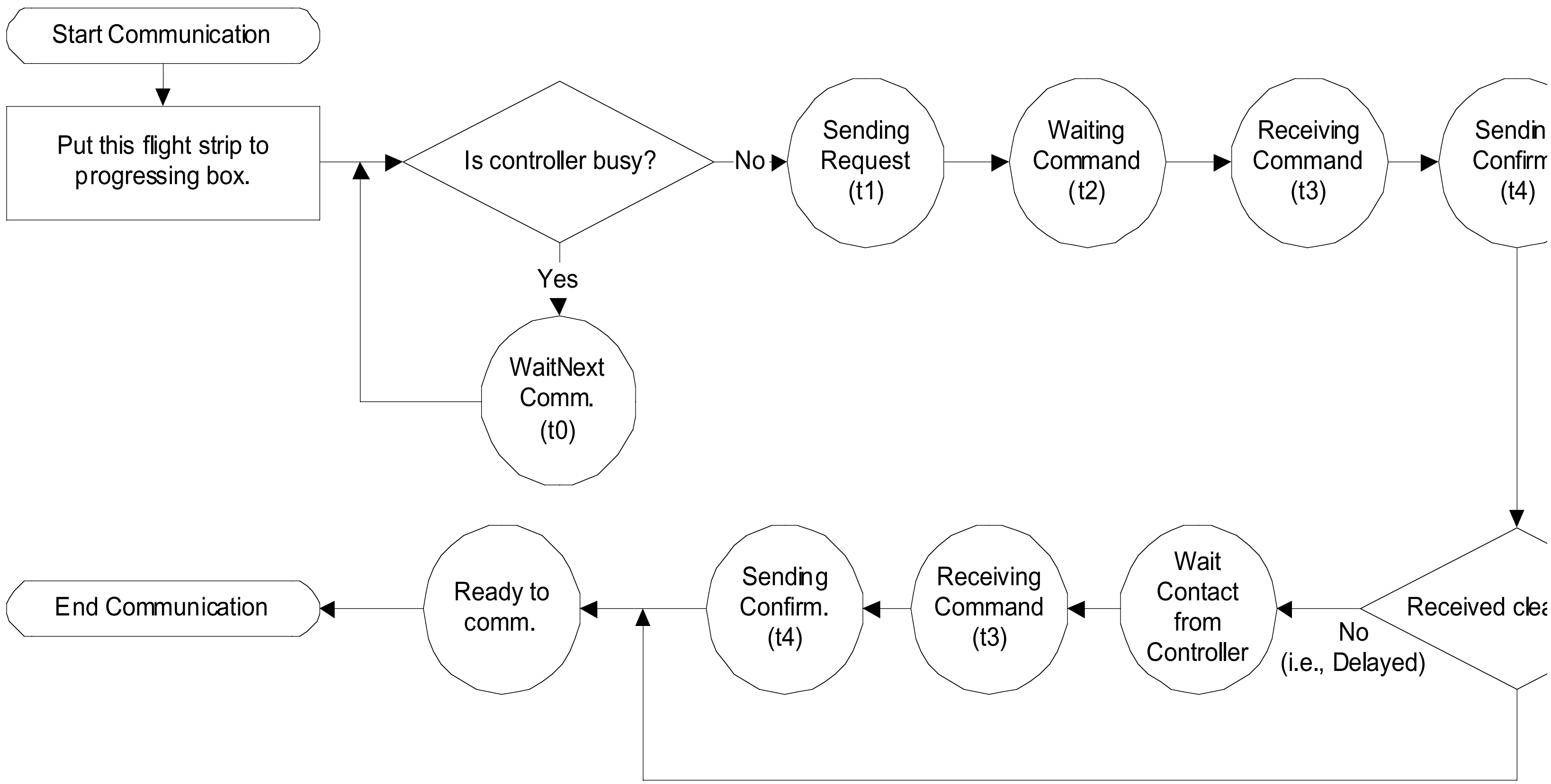
- Controllers: controlling state, next communication time,
- Flights: communication state, next communication time, movement state, next movement time, speed, acceleration, position, etc.,

- Gates, taxiways, runways: current flight(s).

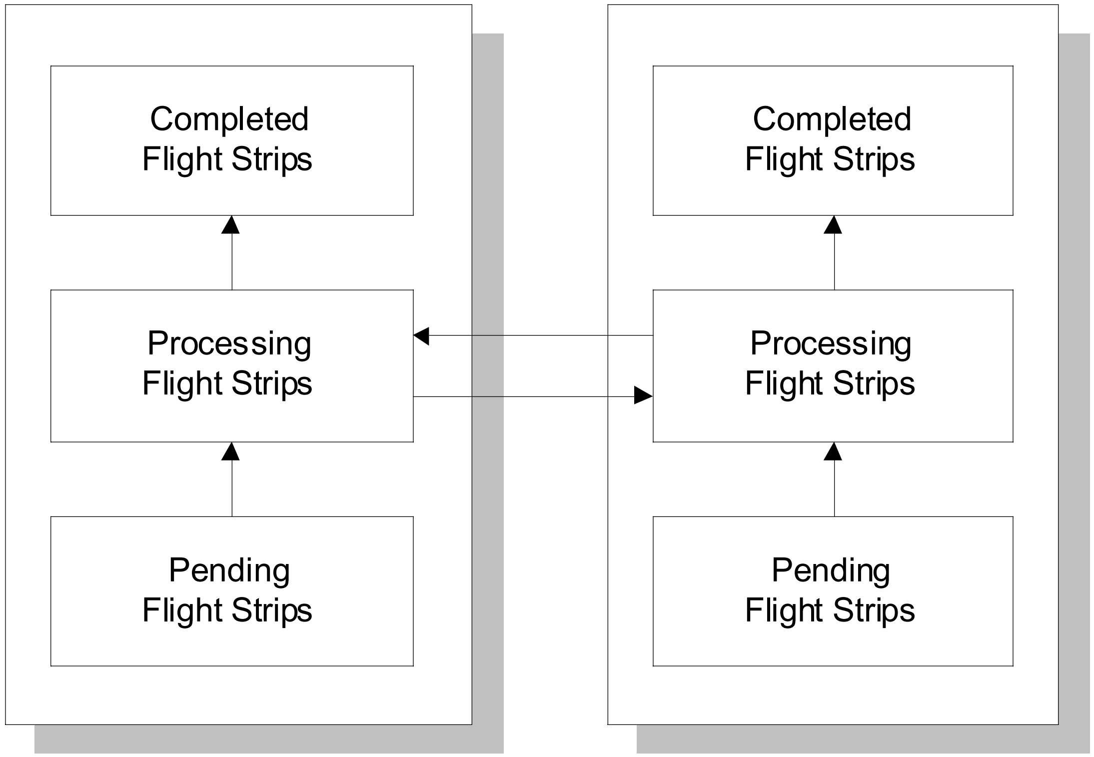
Ground Control Model Features

- Communication interactions between ATC controllers/ data link and each aircraft is explicitly modeled
- Delay analysis. There are two types of delay:
  - Traffic delay due to the traffic congestion on taxiway/ runway
  - Communication delay due to the controller/data link communications
- Dynamic aircraft-following logic
- Static and dynamic route guidance for taxing

State Diagram for COM (Voice Channel)



State Diagram for Controller's Data Strips



Ground controller's flight strip organization

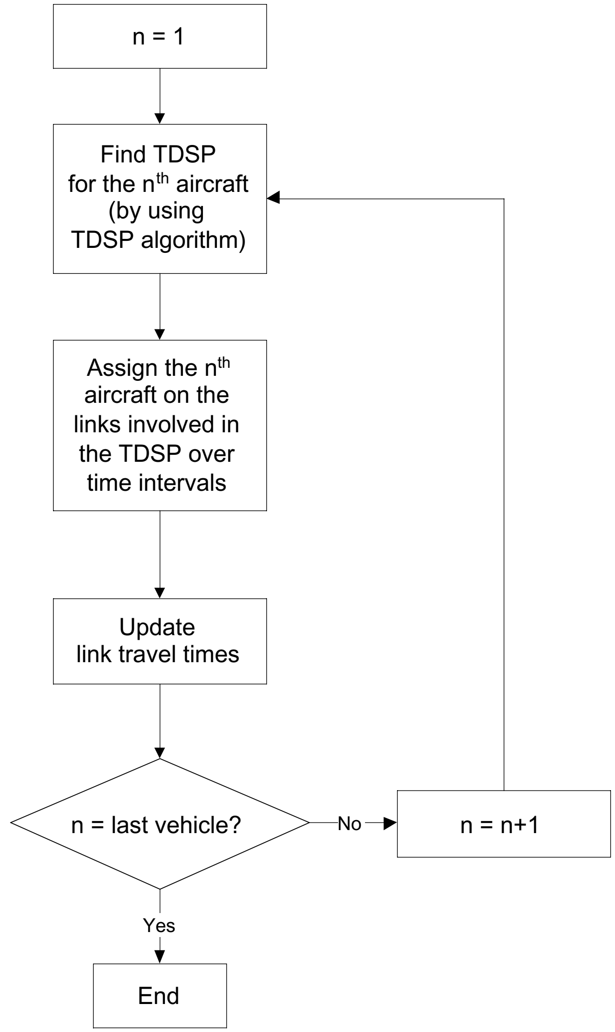
Local controller's flight strip organization

Algorithm: Dynamic Taxiing Route Plan

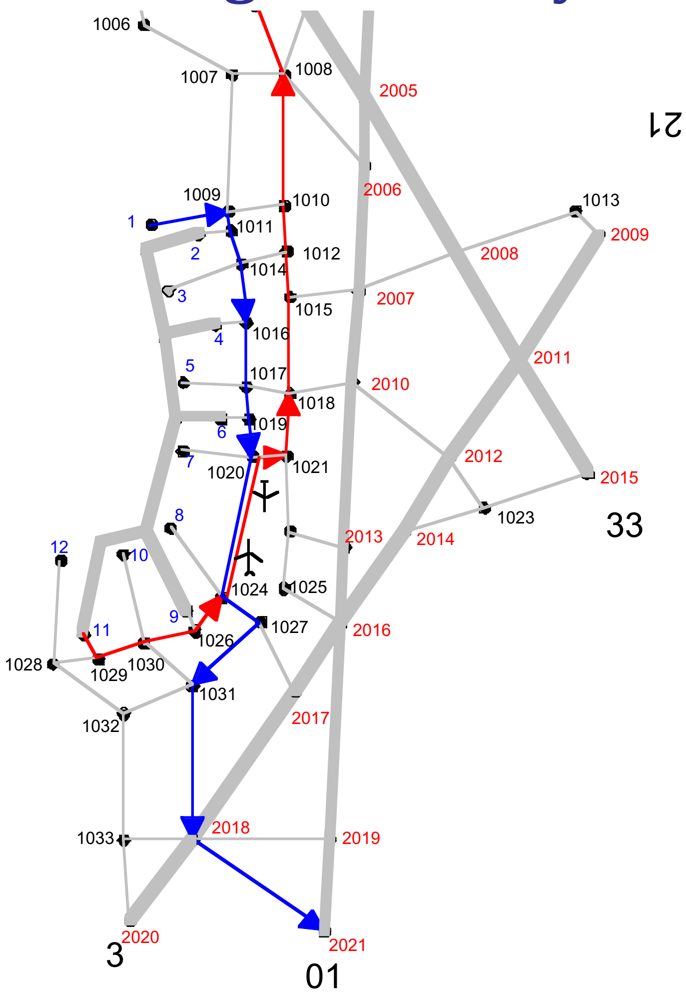
Considers time-dependent network loading

Employs an incremental time-dependent network assignment strategy

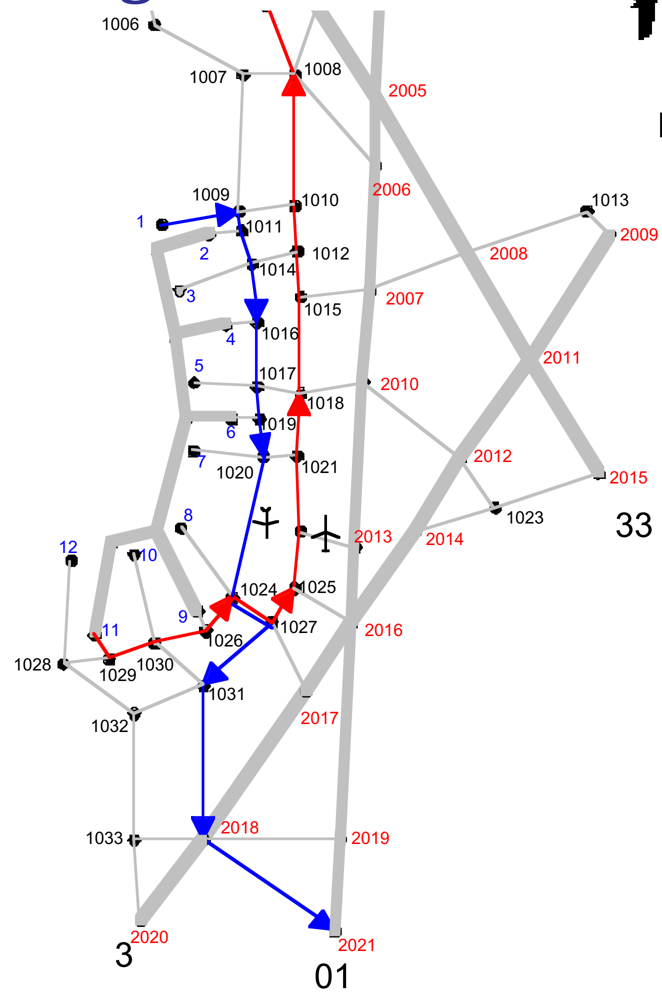
Based on time-dependent shortest path algorithm



Algorithm: Dynamic Taxiing Route Plan

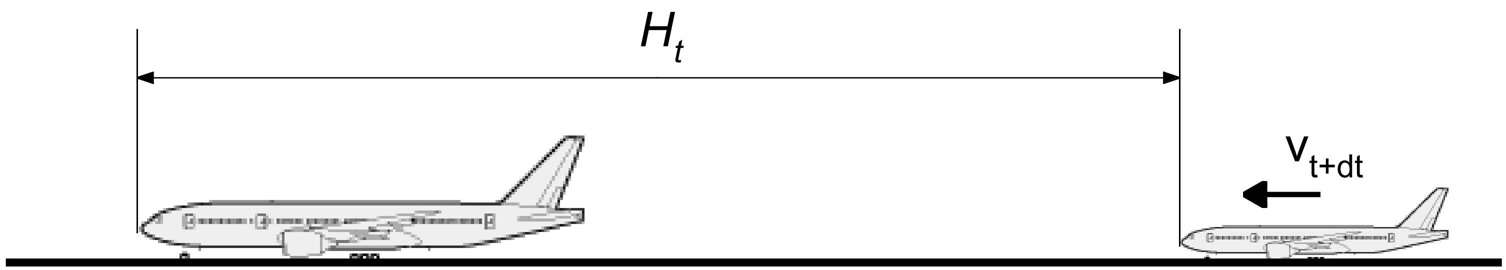


Statically assigned path



Time-dependent assigned path

Aircraft Following Model



Basic equations of motion to characterize the aircraft taxiing following model

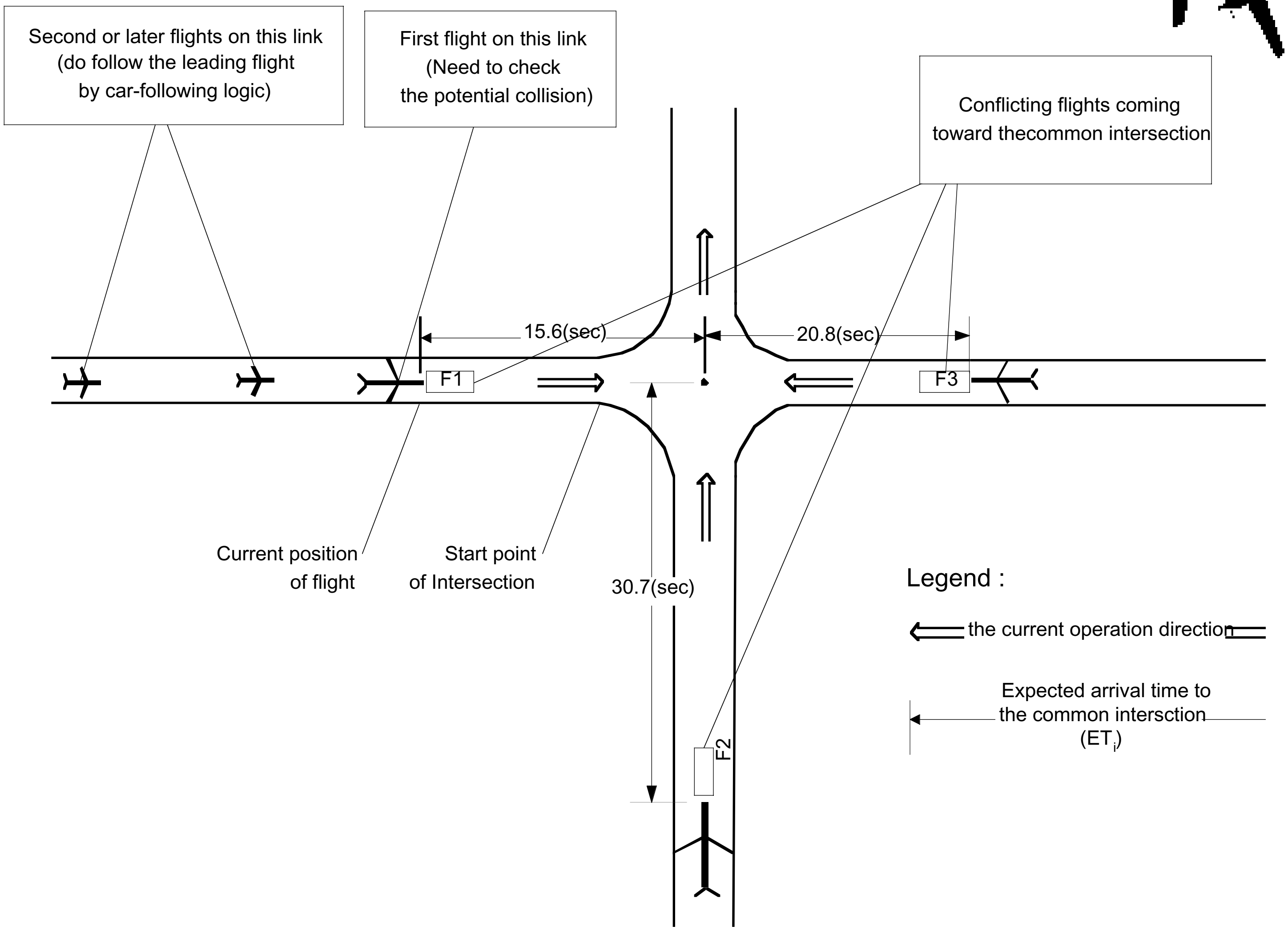
$$v^d_{t+\Delta t} = v^f (1 - \frac{H_j}{H_t})$$

Speed equation of motion

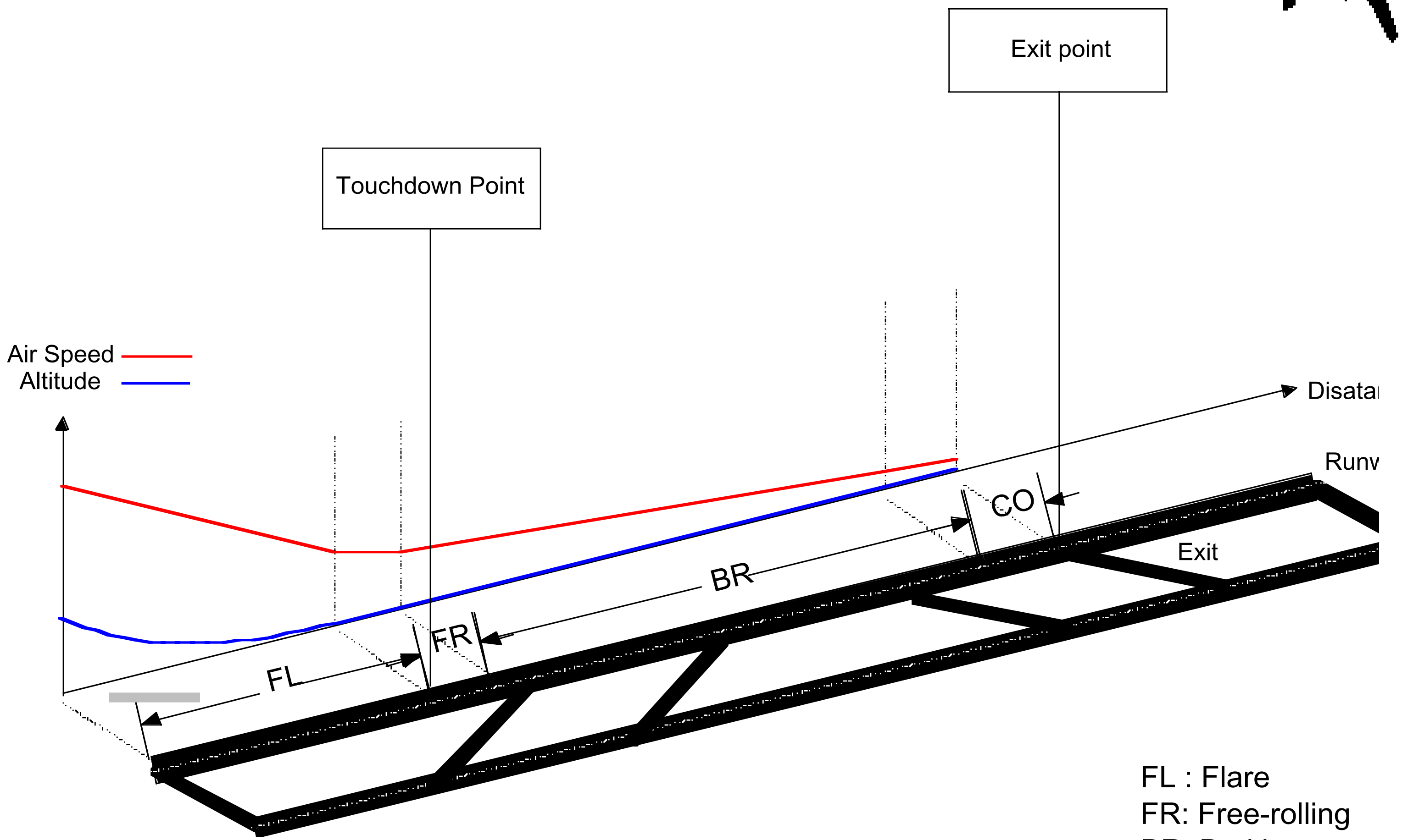
$$a^{t+\Delta t}_{n+1} = (v^d_{t+1} - v_t) / \Delta t$$

Acceleration equation of moti

Conflict Detection and Resolution Model



Four Phases of the Landing Procedure



FL : Flare
FR: Free-rolling
BR: Braking
CO: Coasting

Example of Output File (1): Log File

Second-by-second statistics can be obtained in VTASIM

Time = 320.000

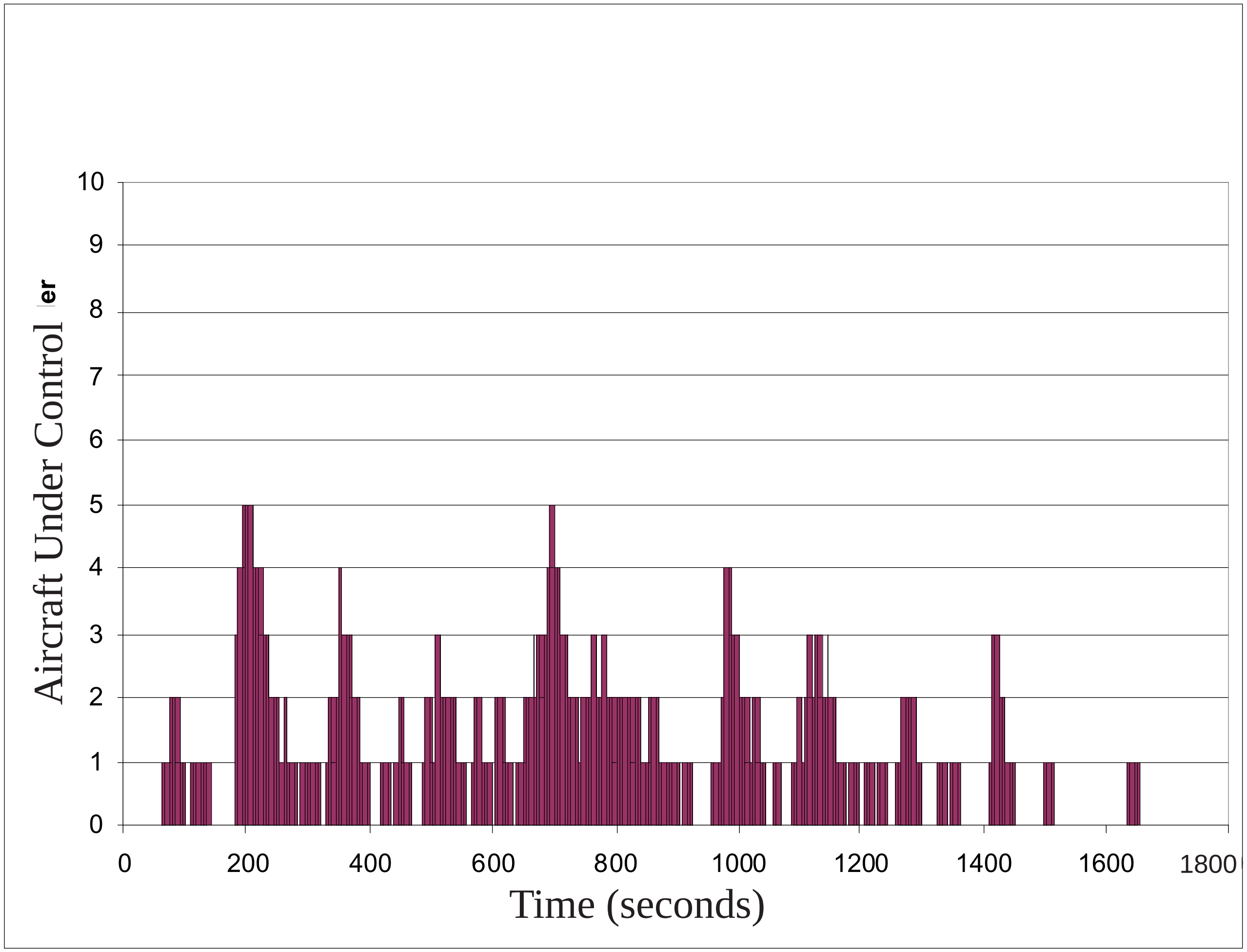
DEP_1 (4.27860, 7.23847)	←	Aircraft ID and Posit
readyToCommunicate	←	Acft. COMM State
clearToTakeOff rolling	←	Acft. Permission
228.557 5.65931 2006 -> 2005	←	Acft. speed, accel. ar
347.582 322.875 8907.85		link information

DEP_2 (3.44770, 3.71363)
readyToCommunicate
clearToTaxi taxiingToDepQue
27.3409 0.000000 1031 -> 2018
782.058 727.237 3832.22

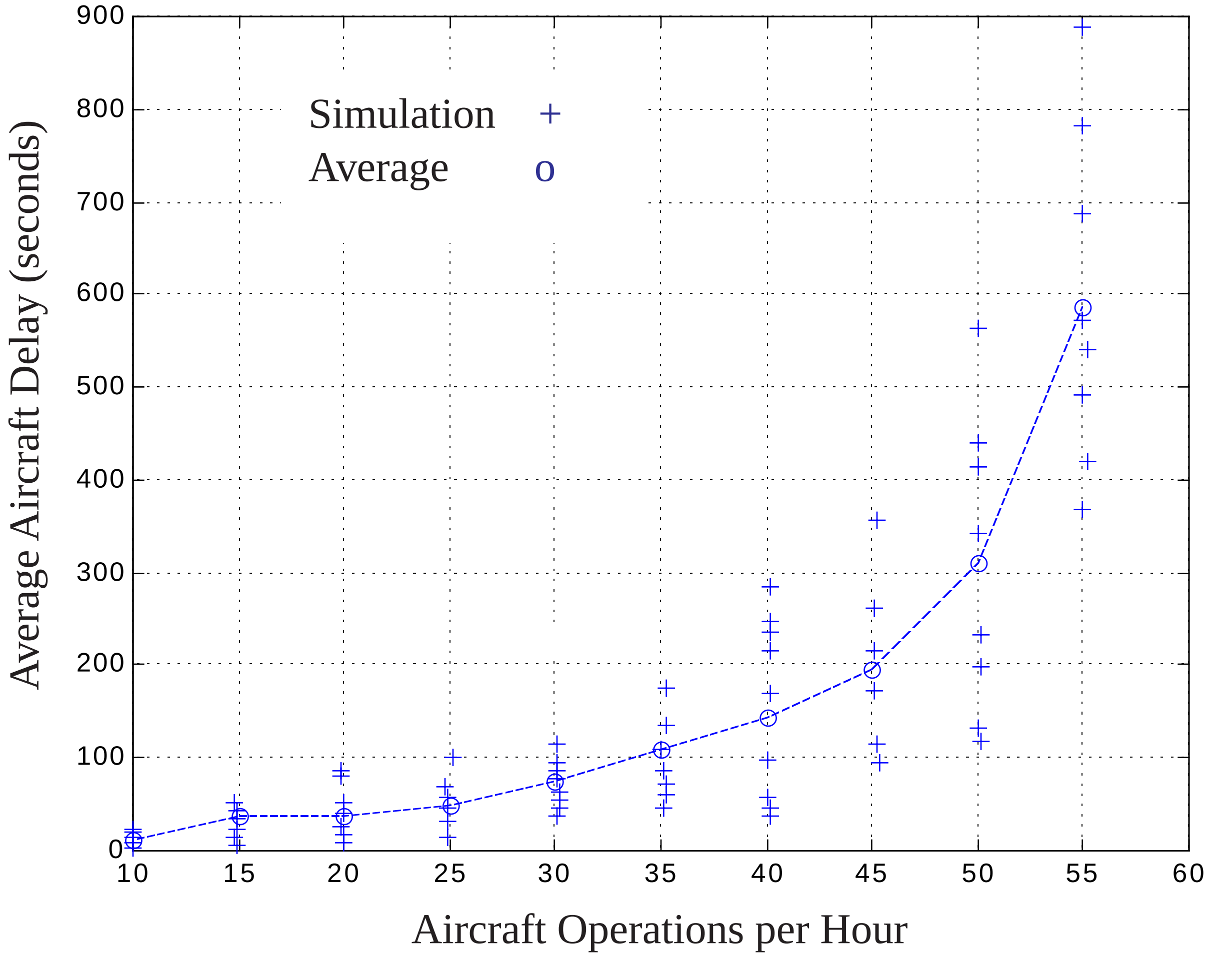
Example of Output File (2): Summary File

```
------------------------------ SUMMARY ------------------------------
Flight (Departure DEP_1, B727-100, Gate 1, Runway 36)
Enters into the simulation at          : 1 sec.
Taxiing Duration                       : 73 - 217
Taxiing Delay                          : 2.22827
Nominal Takeoff Time   (= NTOT)        : 186
Sequenced Takeoff Time (= STOT)        : 268
Actual Takeoff Time    (= ATOT)        : 289
Runway Occupancy Time  (= ROT)         : 289 - 328
Sequenced Delay        (= ATOT - STOT) : 21
Runway Delay           (= ATOT - NTOT) : 103
```

Local Controller Workload Metric

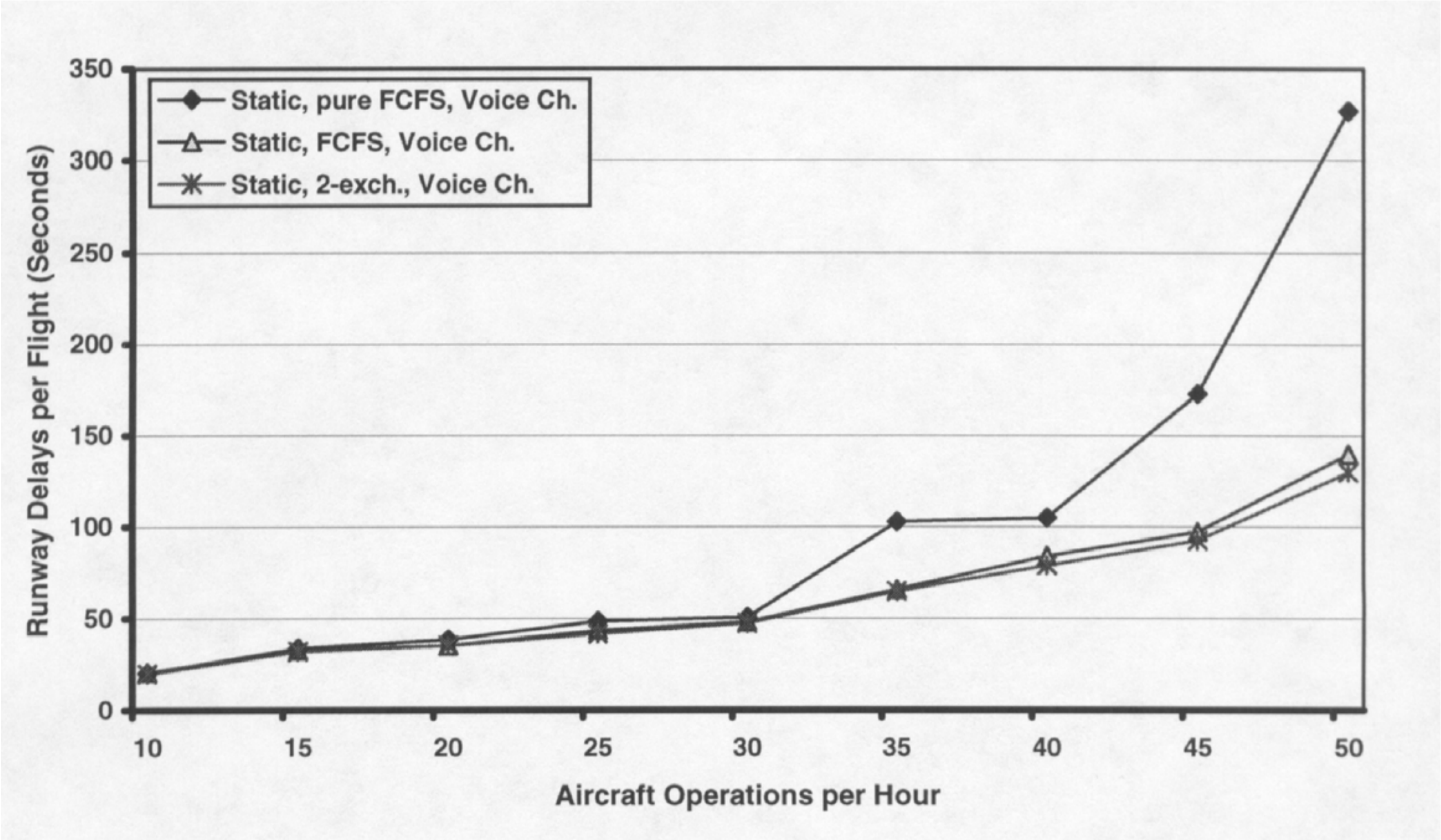


Delay Curves for Mixed Runway Operations



Sample Aircraft Delays Curves

Voice channel - three assignment techniques studied



Sample Delay Curves (datalink analysis)

Datalink active - three assignment techniques studied