Impact of Different Strategies on Route Utilization and Airlines Cost:
Multi-agent Simulation and Evolutionary Computation

Progress Report on:
Parametric Games

Guillermo Calderón-Meza (Ph.D. Student)
Lance Sherry (Ph.D.)

May 2009

Interim Report: NASA NNA07CN32A
Analysis of NGATS Sensitivity to Gaming

CENTER FOR AIR TRANSPORTATION SYSTEMS RESEARCH

GEORGE MASON UNIVERSITY

Acknowledgments

CATSR

NASA (Provided funding NASA NNA07CN32A)

María Consiglio, Brian Baxley, Kurt Neitzke

Sensis

George Hunter, Huina Gao

Flight Profits

Randal Kelly

CATSR/GMU

Maricel Medina-Mora, John Ferguson, Keith Sullivan,

George Donohue, John Shortle, Rajesh Ganesan, Kenneth De Jong

Metron Aviation

Norm Fujisaki, Terry Thompson

FAA

Joe Post, Tony Diana

GEORGE MASON UNIVERSITY

Outline

CATSR

1. Research objectives & observations
2. Context & definitions
3. Previous work
4. Method, behaviors & assumptions
5. Results experiments: #0 (equal strategies), #1 (single objective) & #2 (multi objective)
6. Conclusions
7. Future work

GEORGE MASON UNIVERSITY

Research Objectives

CATSR

- TFM/ATC objectives for *utilization* conflict with airline objective of *profit*

- Evaluate the impact of agent *gaming* in selection of alternate trans-continental routes
  - Cost vs utilization

- *Simulation* vs *optimization* models
  - Gain knowledge about behavior

GEORGE MASON UNIVERSITY

Context

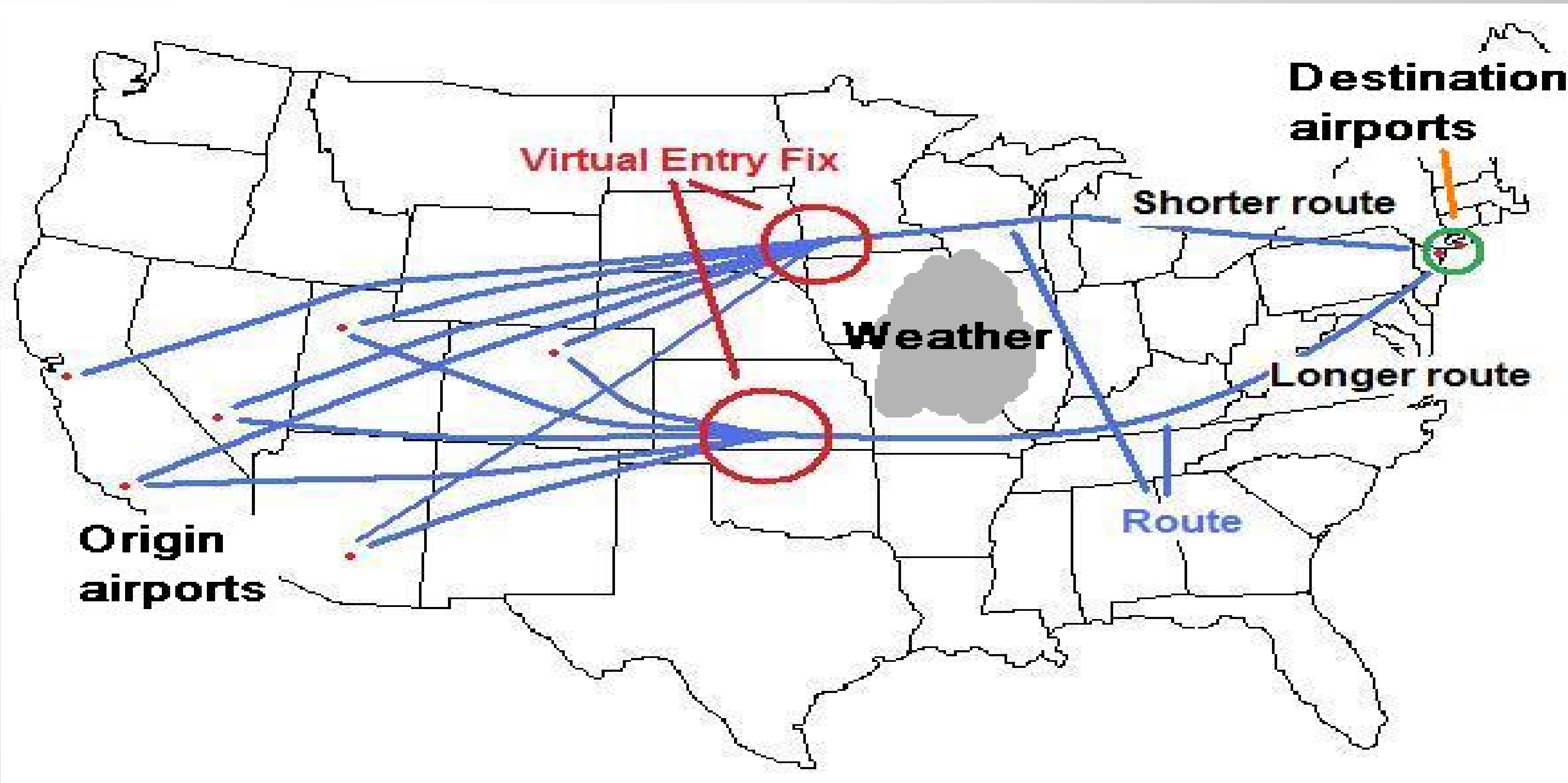
CATSR

- *NextGen* increases capacity & throughput by investing in infrastructure
  - *TFM – SEVEN* – (Klopfenstein, 2007)
  - Re-routing (Wanke & Greenbaum, 2007; Ramamoorthy, Boisvert, Hunter, 2006)
  - System Wide Information Management, *SWIM* (Dieudonne, Crane, Jones, Smith, Remillard, Snead, 2007)
  - *Ribbons* / *Tubes* - (Kopardekar, Bilimoria, Sridhar, 2007; Yousefi, Donohue, Sherry, 2004)
- Re-routing could result in under-utilization
- Impact on investment if airlines "game" the system?
  - Under-utilized resources?

GEORGE MASON UNIVERSITY

Context

CATSR



Will airlines use the resources if provided, or will the resources go unused (due to airline preferences) ?

GEORGE MASON UNIVERSITY

Definitions

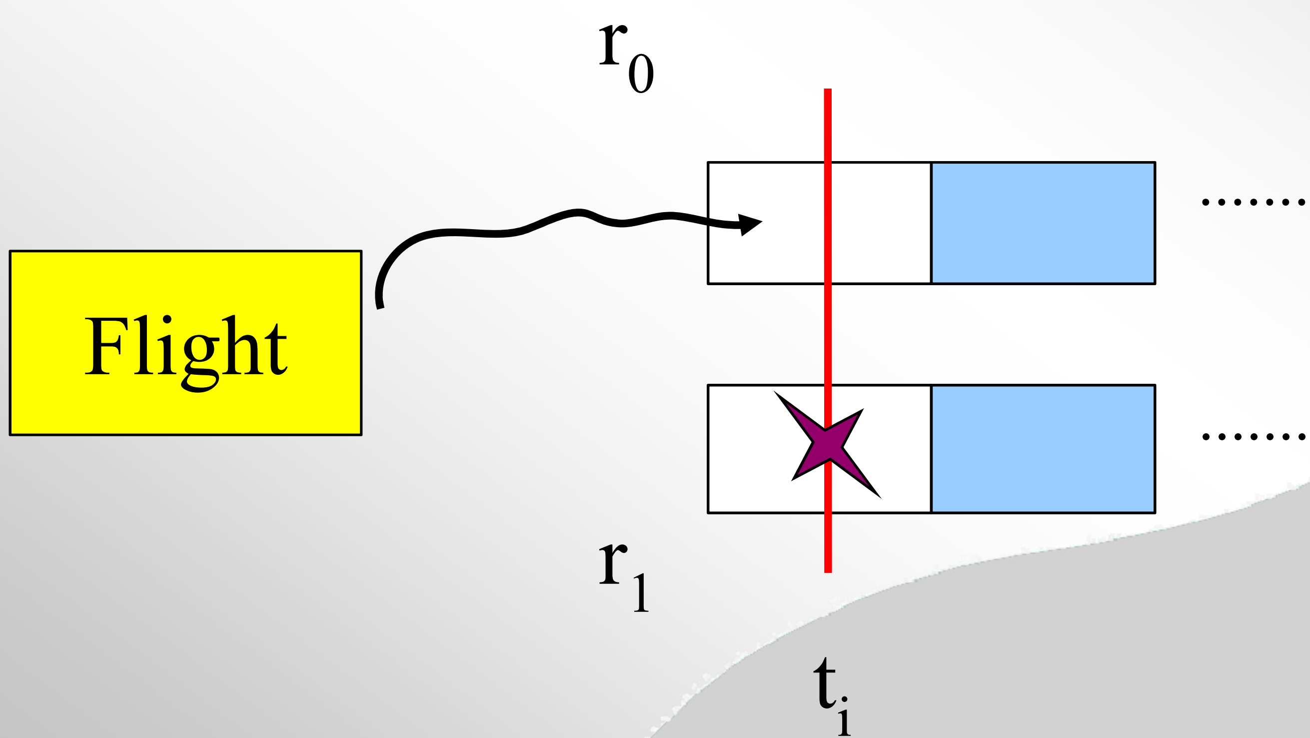
CATSR

- *Airborne cost (flying cost)*
  - Flying 25 nm @ constant speed, same altitude
  - Particular type of aircraft
- *Ground cost (waiting / delay cost)*
  - Waiting (being delayed) 5 min on ground
- *Airline cost* (all flights)
  - Airborne cost
  - Ground cost
- *Aggregated airline cost*
  - Summation across airlines (last step)

GEORGE MASON UNIVERSITY

Definitions

- *Route under-utilization*
  - # of unassigned route slots
  - Cancellations, delays, or choice



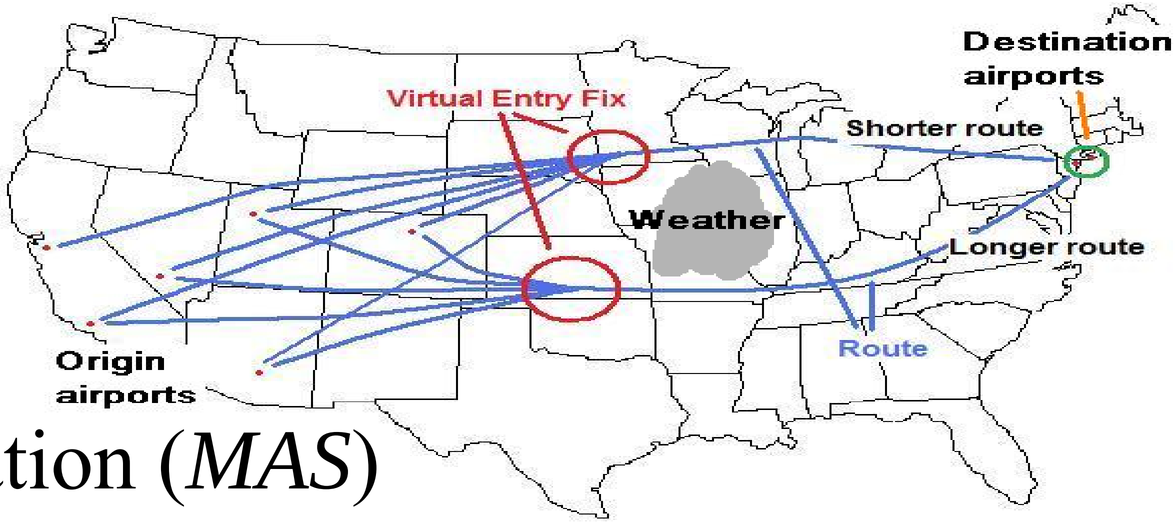
Previous work

CATSR

- Gaming in airlines decisions
  - Tomlin, Waslander (CDC 2006)
  - Wojcik (ATIO 2004)
  - Greenbaum, Wojcik, Campbell, Cooper (ATM 2001)
- Evolving agent behaviors
  - De Jong (Evolutionary Computation. A Unified Approach, MIT Press, 2006)

GEORGE MASON UNIVERSITY

Method

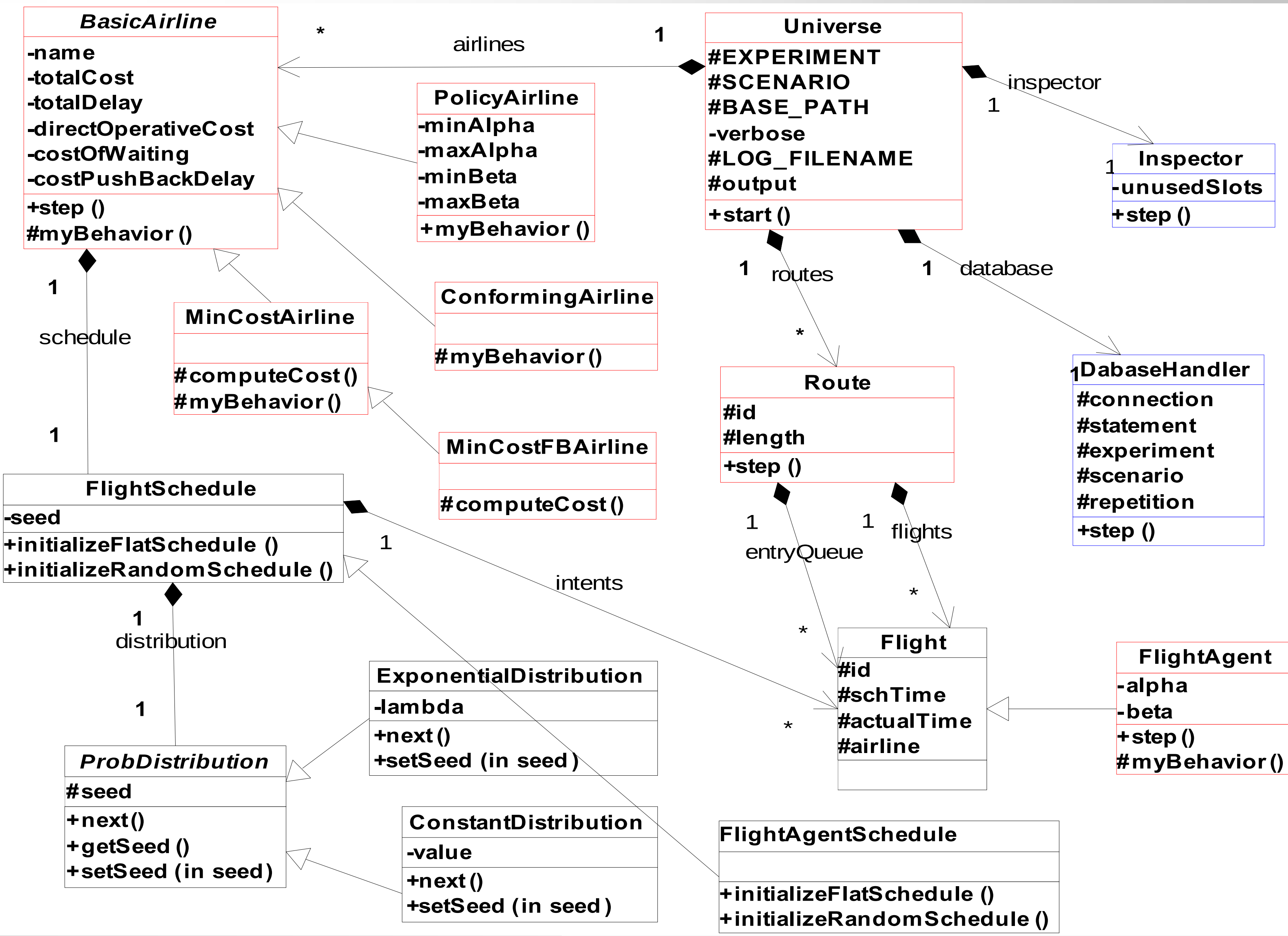


- Multi-agent simulation (*MAS*)
  - 95 agents: 3 airlines, 90 flights, 2 routes
- *Evolutionary computation* (*EC*) platform
- Stochastic behavior
  - *Ties* resolution, *push-back delays*, and *order of agent processing* are random
- *Monte Carlo* simulation
  - Scenarios repeated 30 times
  - Computing *averages* & *variances*

GEORGE MASON UNIVERSITY

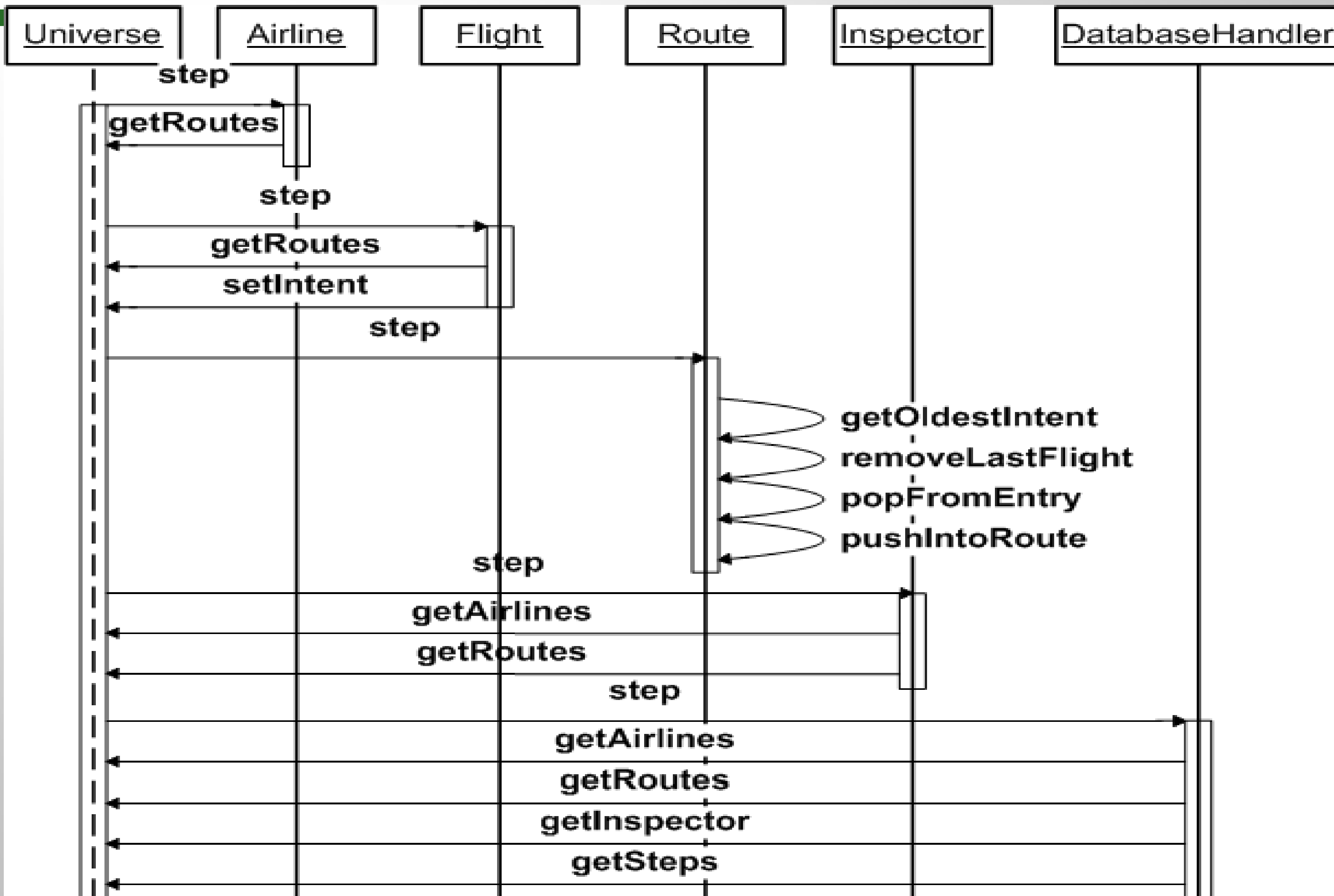
Class diagram

CATSR



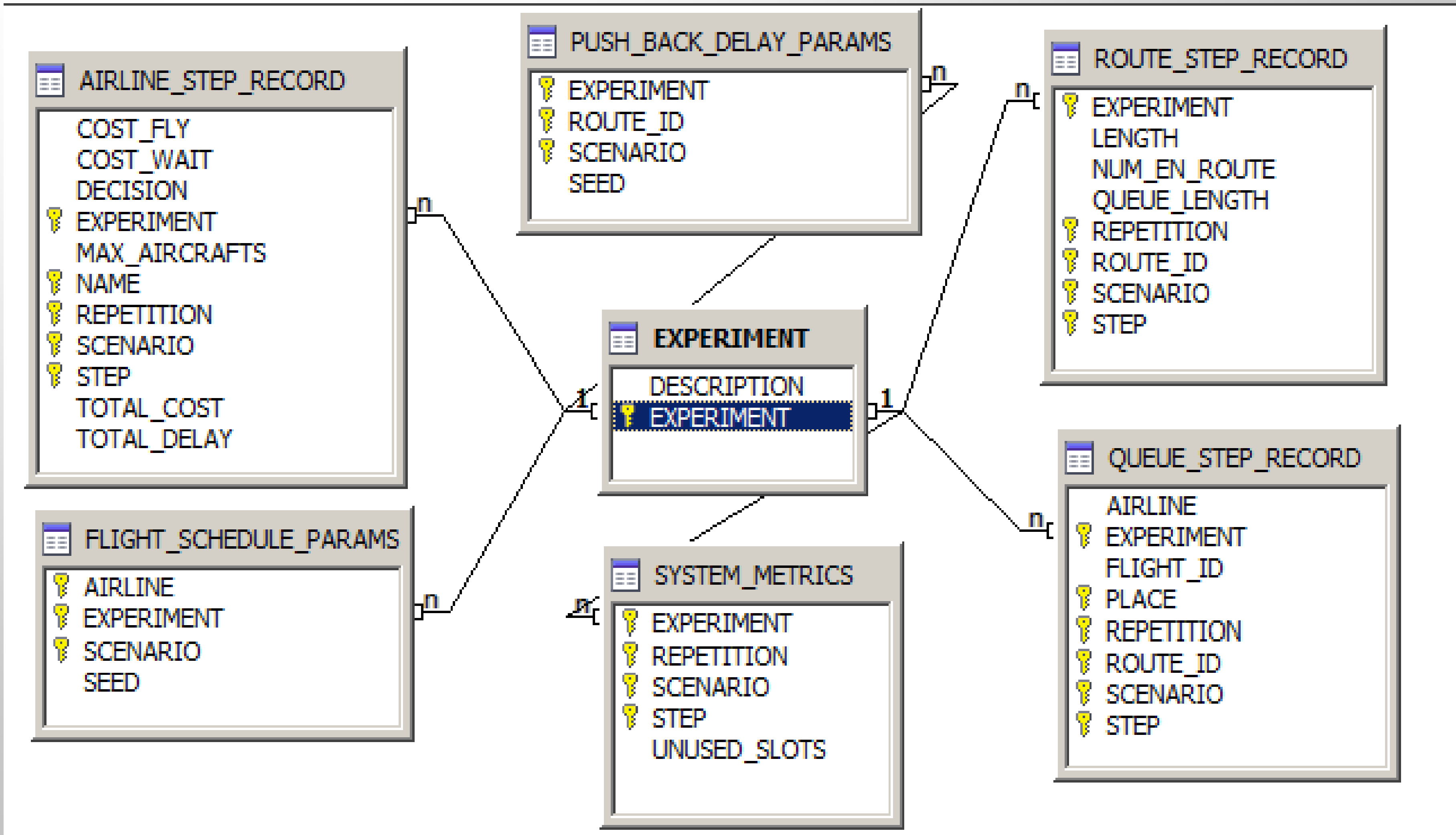
Collaboration diagram

CATSR



The database structure

CATSR



GEORGE MASON UNIVERSITY

Flight agent behavior

CATSR

- Parametric behavior decide on *cost*
  - Weight of *airborne cost* → φ ϵ [0,1]
- Aircraft chooses route according to:

$$r = \text{argmin}\left[(\varphi * f_f * d_r) + ((1-\varphi) * w_f * t_r) \right]$$

  - Conversion factors f_f & w_f in $/slot
  - "*d*" in distance slots & "*t*" in time slots
- In case of ties → ***choose route randomly***.

GEORGE MASON UNIVERSITY

Airline policy ($\approx$ behavior)

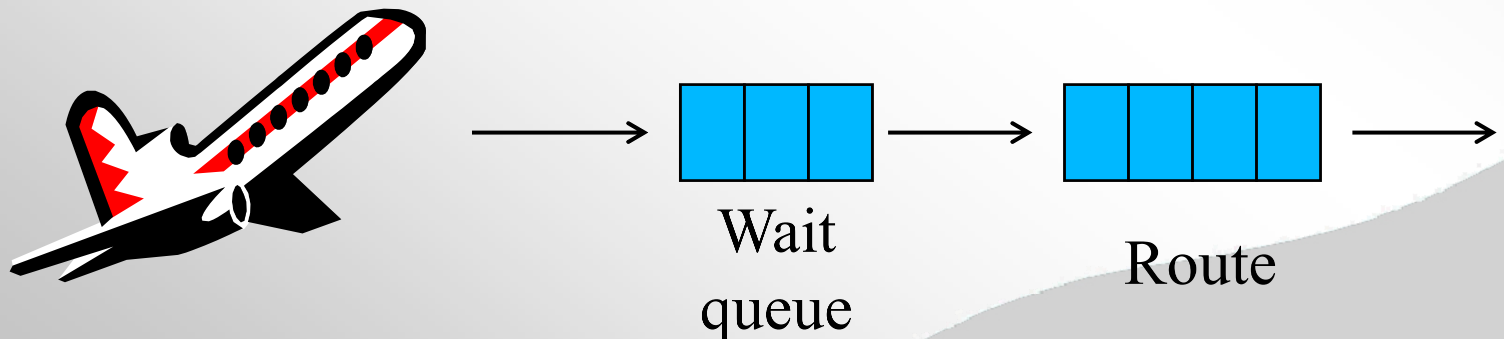
CATSR

- Determines *acceptable range* of φ for the flights
- Described by $<\beta, \alpha>$ pair
  - Condition: $0 \leq \beta \leq \alpha \leq 1$
  - β lowest acceptable value for φ
  - α highest acceptable value for φ
- Could change in time $\rightarrow$ *adaptation*
- Flight's φ *randomly chosen* before push back occurs

GEORGE MASON UNIVERSITY

Route agent behavior

- Pushes airline route *selection* into entry queue
- Removes last flight from route (if it reached end of route)
- Takes oldest flight from entry queue and pushes it into route



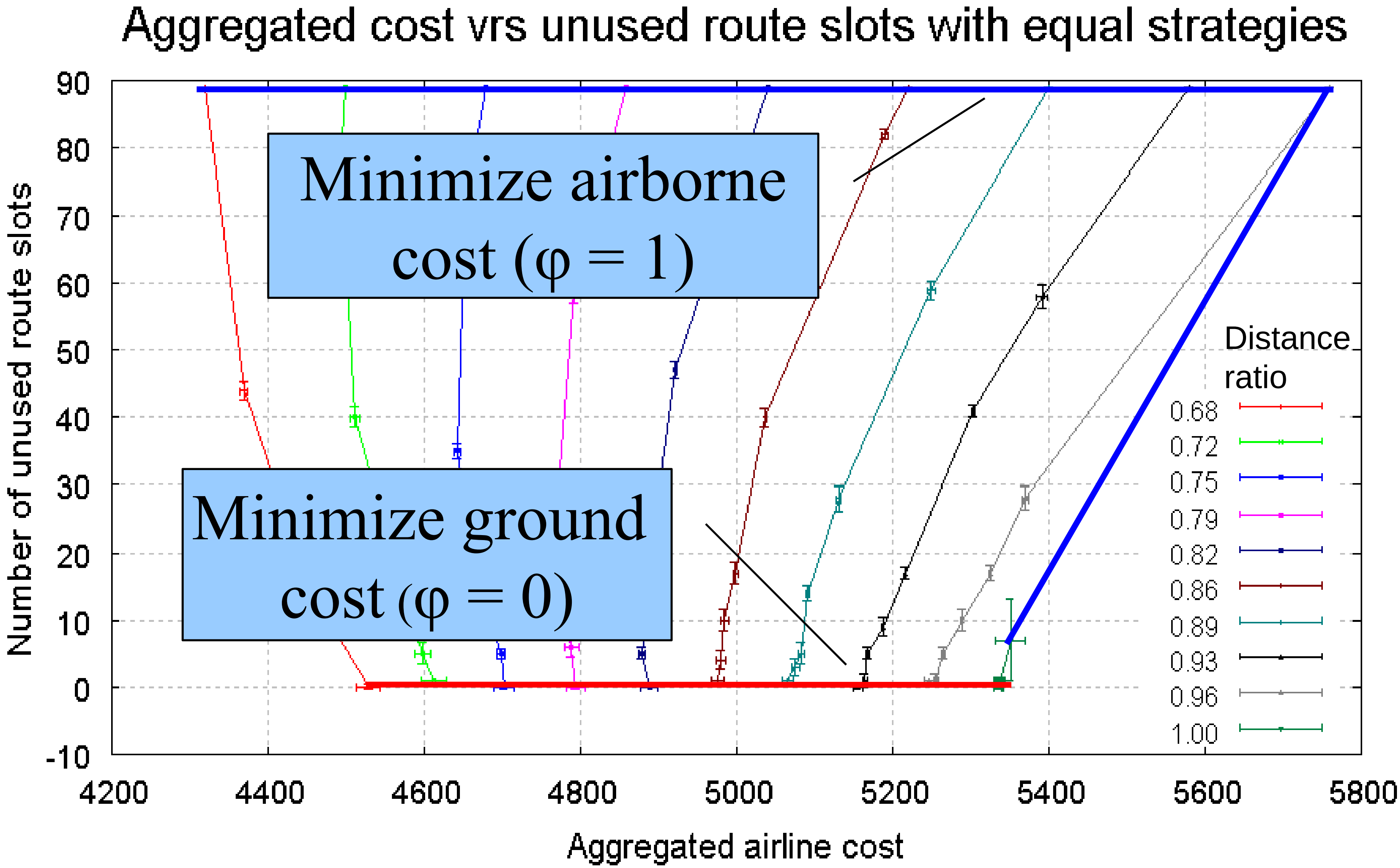
Assumptions for simulation

CATSR

- All flights with same (normalized) $\mathbf{f_f}$ = 1.0
- All flights @ *constant speed* → 300 ks
- *Time slot* = 5 min, *distance slot* = 25 nm
- All airlines with 30 scheduled flights
  - 1 flight per time slot (before push back delay)
  - No gaps between flights
- Flights & airlines are *partially informed*
  - "d" and "t" are known to flights
  - Do not know other's decisions (until next tick)
  - No *learning* or *prediction*

GEORGE MASON UNIVERSITY

Detailed results (Experiment #0)



NOTE: Valid for wait/fly ratio of 0.3

CATSR

MASON UNIVERSITY

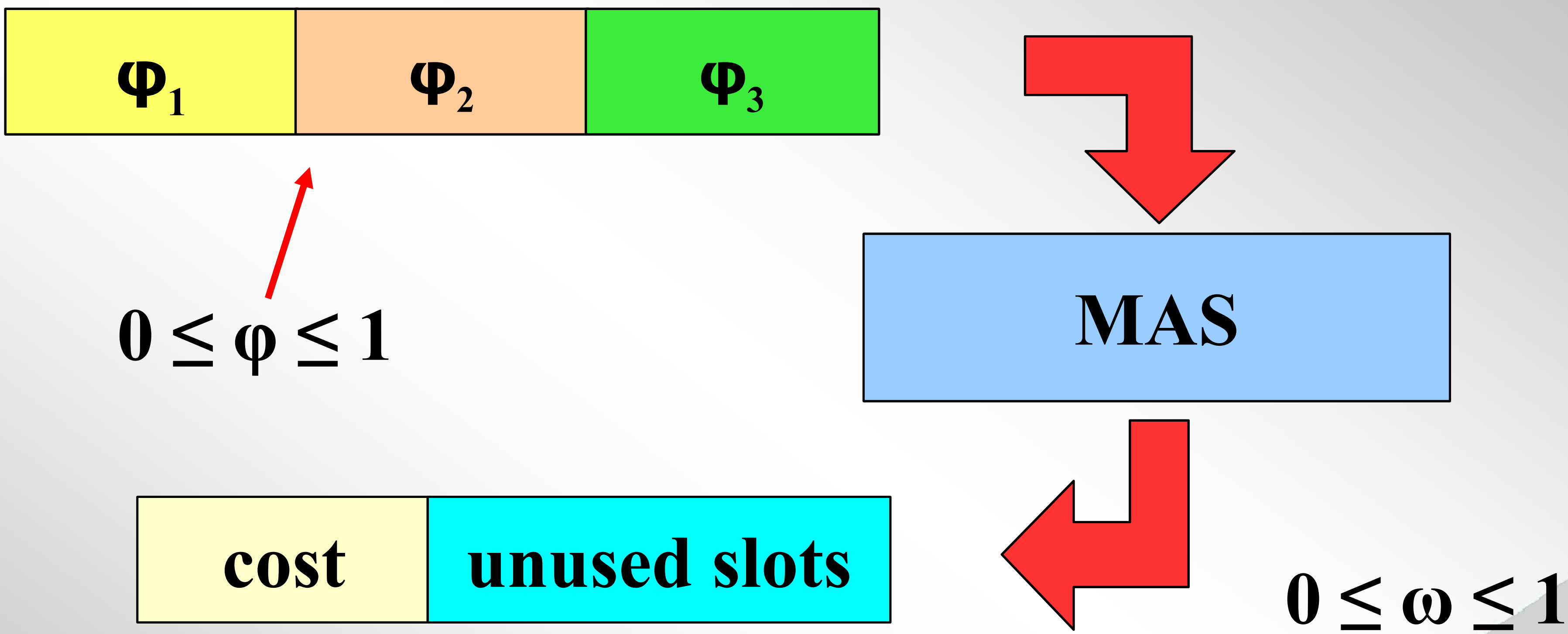
What if policies are not equal?

CATSR

- Use *evolutionary computation* to explore the space
- *Parameter* optimization (Experiment #1)
  - Requires new parameter
- *Multi-objective* optimization (Experiment #2)
  - Approximate Pareto surface

GEORGE MASON UNIVERSITY

Description (Experiment #1)



$$f = -(\omega * \text{cost} + (1-\omega) * \text{unused\_slots})$$

ω is *social value* $\rightarrow$ importance of cost

Conditions (Experiment #1)

CATSR

- Evolutionary Algorithm
  - *Evolutionary Strategy*
  - Population size: 15 (offspring 15)
  - Overlapping populations
  - Parent selection: fitness proportional
  - Survival selection: fitness proportional
  - Mutation & recombination
  - 300 iterations (birth counts)

GEORGE MASON UNIVERSITY

Conditions (Experiment #1)

CATSR

- MASON simulation
  - 3 "*Policy Airline*" agents
  - 30 scheduled *"Flight Agents"* per airline
  - Push back delays random (exponential), $\lambda = 5$
  - 2 "*Route*" agents. One 57 slots, another 39 slots
  - Each scenario repeated 30 times

GEORGE MASON UNIVERSITY

Detailed results (Experiment #1)

CATSR

Importance of cost (ω)	φ_1	φ_2	φ_3	Aggregated cost	Unused slots
0.0	0.756	0.009	0.025	4518.0	1
0.1	0.756	0.009	0.025	4518.0	1
0.2	0.888	0.010	0.027	4517.4	1
0.3	0.565	0.020	0.031	4516.0	1
0.4	0.565	0.020	0.031	4516.8	1
0.5	0.010	0.115	0.011	4516.3	1
0.6	0.002	0.016	0.436	4515.7	1
0.7	0.014	0.884	0.010	4516.8	1
0.8	0.508	0.028	0.031	4512.9	1
0.9	0.244	0.520	0.021	4383.1	19
1.0	0.716	0.651	0.034	4320.4	33

NOTE: distance ratio 0.68 and wait/fly cost 0.3

GEORGE MASON UNIVERSITY

Detailed results (Experiment #1)

CATSR

Importance of cost (ω)	φ_1	φ_2	φ_3	$Airline_1$ cost	$Airline_2$ cost	$Airline_3$ cost
0.0	0.756	0.009	0.025	1248.6	1757.7	1511.7
0.1	0.756	0.009	0.025	1249.5	1757.7	1510.8
0.2	0.888	0.010	0.027	1248.9	1758.3	1510.8
0.3	0.565	0.020	0.031	1252.8	1632.3	1632.9
0.4	0.565	0.020	0.031	1254.0	1632.0	1632.0
0.5	0.010	0.115	0.011	1632.6	1249.2	1636.2
0.6	0.002	0.016	0.436	1634.1	1634.1	1249.8
0.7	0.014	0.884	0.010	1636.5	1248.0	1633.5
0.8	0.508	0.028	0.031	1252.2	1630.2	1635.6
0.9	0.244	0.520	0.021	1378.2	1303.5	1701.3
1.0	0.716	0.651	0.034	1322.7	1322.1	1675.2

NOTE: distance ratio 0.68 and wait/fly cost 0.3

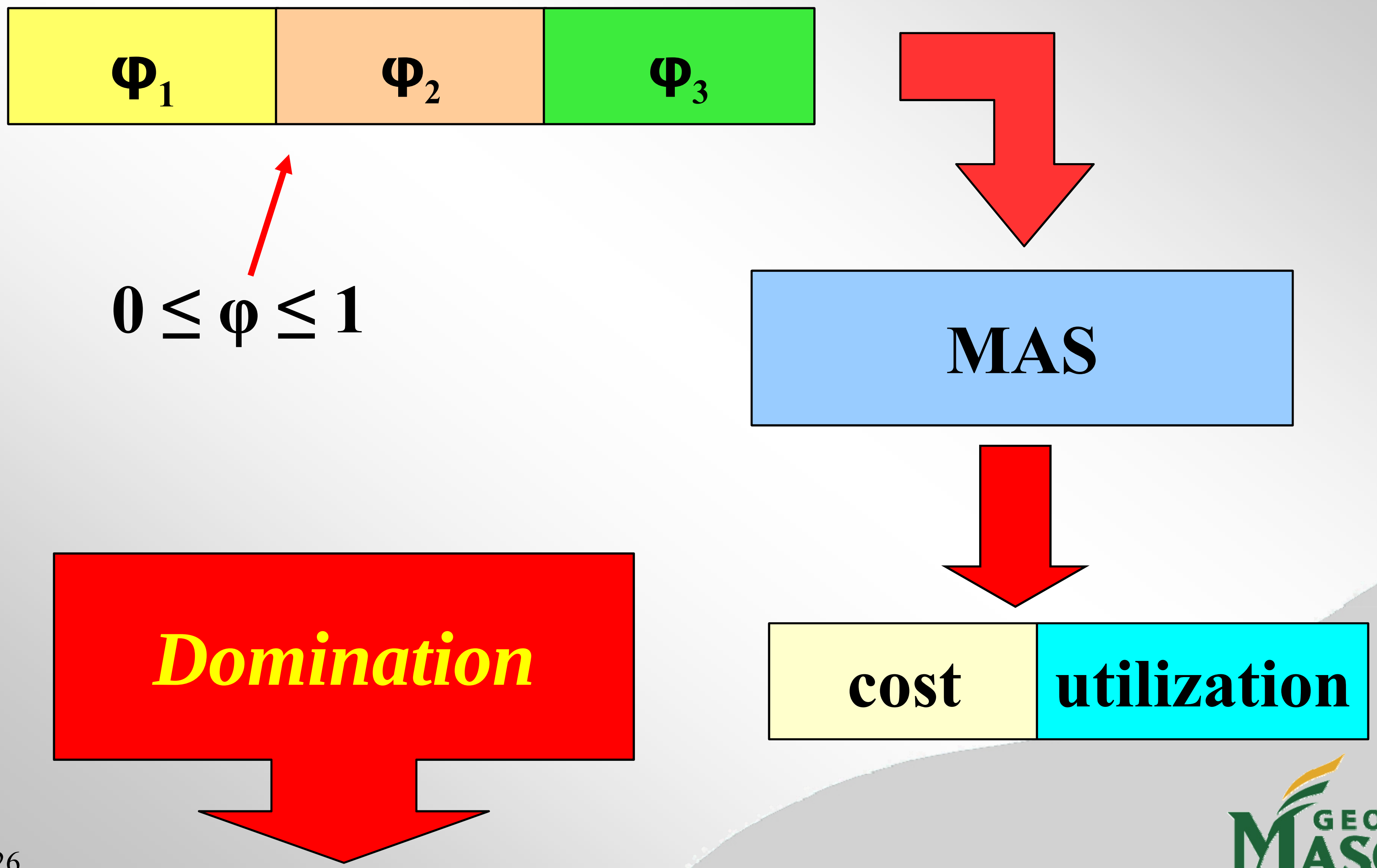
Detailed results (Experiment #1)

CATSR

- Need to normalize values outputs
  - No upper limit for aggregated cost (using 5000)
  - Lower limit hard to compute (using 3510)
- If cost is less important → 1 greedy, 2 polite
- If cost is most important → 2 greedy, 1 polite
- *Several individuals* with same best fitness
- Highest φ results in lowest airline cost
  - Differences are statistically significant

GEORGE MASON UNIVERSITY

Experimental design (Experiment #2)



Experimental design (Experiment #2)

- Evolutionary Algorithm
  - Type: Pareto
  - Population size: 50+ (offspring 50+)
  - Birth count: 500+

- MAS remains the same

Detailed results (Experiment #2)

CATSR

Fitness	φ_1	φ_2	φ_3	Aggregated cost	Unused slots
39.0	0.031	0.943	0.403	4320.0	31
39.0	0.031	0.943	0.403	4320.0	31
39.0	0.031	0.446	0.878	4320.0	31
39.0	0.861	0.811	0.008	4320.0	31
40.0	0.031	0.943	0.403	4320.0	31

NOTE: distance ratio 0.68 and wait/fly cost 0.3

GEORGE MASON UNIVERSITY

Detailed results (Experiment #2)

CATSR

Fitness	φ_1	φ_2	φ_3	$Airline_1$ cost	$Airline_2$ cost	$Airline_3$ cost
39.0	0.031	0.943	0.403	1692.3	1314.9	1312.8
39.0	0.031	0.943	0.403	1692.0	1313.1	1314.9
39.0	0.031	0.446	0.878	1692.6	1313.1	1314.3
39.0	0.861	0.811	0.008	1315.5	1312.5	1692.0
40.0	0.031	0.943	0.403	1692.6	1313.1	1314.3

NOTE: distance ratio 0.68 and wait/fly cost 0.3

GEORGE MASON UNIVERSITY

Detailed results (Experiment #2)

CATSR

- Fitness is relative to population
  - Need to implement *Hall of fame*

- Two minimize airborne cost & minimize ground cost

- Lowest policy value gets the highest costs

- Fitness has not reached the highest value

GEORGE MASON UNIVERSITY

Conclusions

CATSR

- Experiment #0 (equal strategies)
  - Trade-off controlled by policy
- Experiment #1 (single objective)
  - Procedure favors utilization…
- Experiment #2 (multi objective)
  - Finds a balance between objectives…

GEORGE MASON UNIVERSITY

Future work

CATSR

- *Evolve* behaviors
  - Different MAS implementation required
- Set airlines to *compete* or *cooperate*
  - Observe individual & global results
- *Learn* from past results
  - Can be combined with behavior evolution
- Effects of *imperfect information*
  - Delayed
  - Uncertain

GEORGE MASON UNIVERSITY

Future work

CATSR

- Alternate airline / flight behaviors
  - *Minimize delay*
  - *React* to other agents actions
  - *Predict* and adjust accordingly
- Relax assumptions
  - Aircraft speed
  - Different costs
  - Different schedules

GEORGE MASON UNIVERSITY

Questions?

CATSR

More info?

Visit the Center for Air Transportation Systems and Research (CATSR) website

http://catsr.ite.gmu.edu/

GEORGE MASON UNIVERSITY