Sample Decision Support ATM Pr ojects

Integration of National Airspace System Models

Modeling NAS Infrastructure Investments

J. Kobza, A.A. Trani, H.D. Sherali, H. Baik and C. Quan

Sponsor

FAA Office of Program Analysis and Investment

(Dr. Randy Stevens)

Integration of National Airspace System Models

Project Objectives

- To investigate alternatives to integrate existing National Airspace System models as a suite of decision making tools
- To connect new algorithms with existing NAS airspace and airport simulation models (e.g., SIMMOD, RAMS, etc.)

Status of the Project:

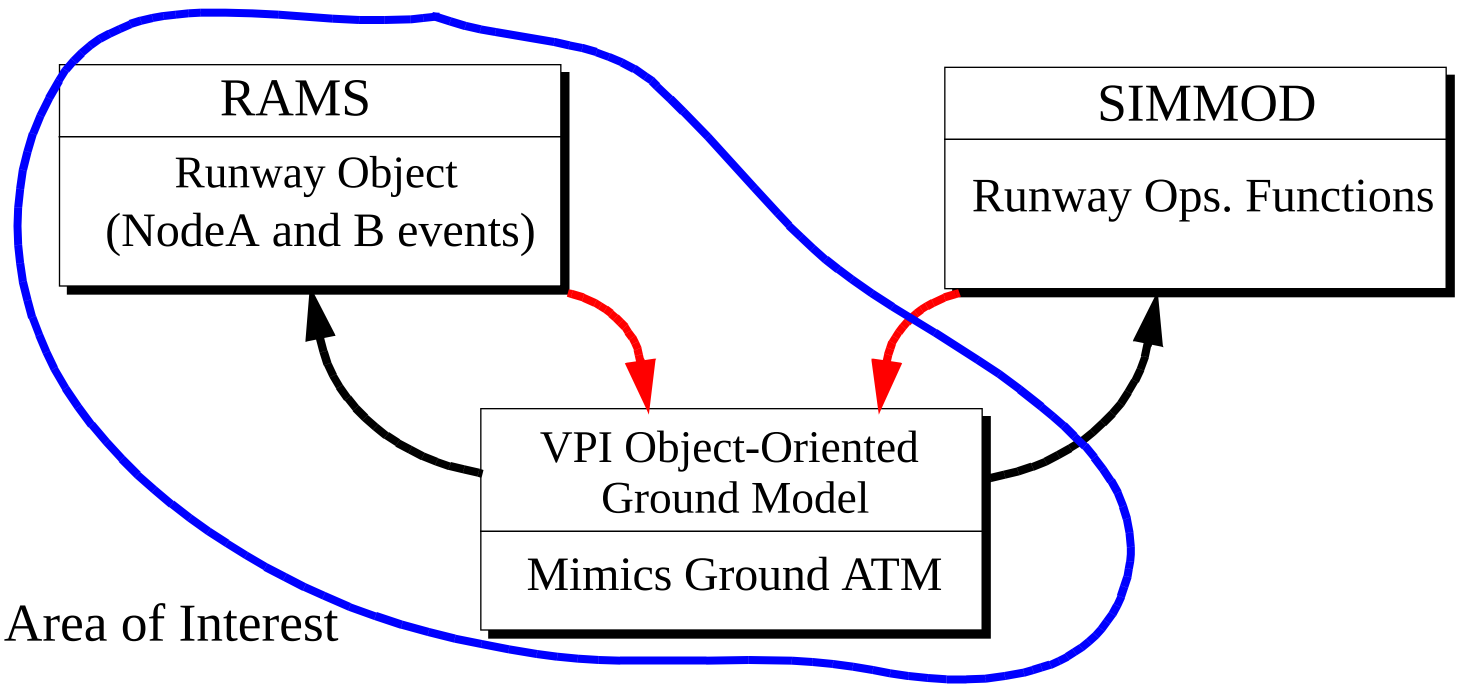
- An object-oriented programming mechanism to connect to the architecture of both models with external processes is under development
- The approach will be demonstrated next using a generic ground network simulation capability to extend RAMS

Integration of Airspace/Airfield Models to External Processes

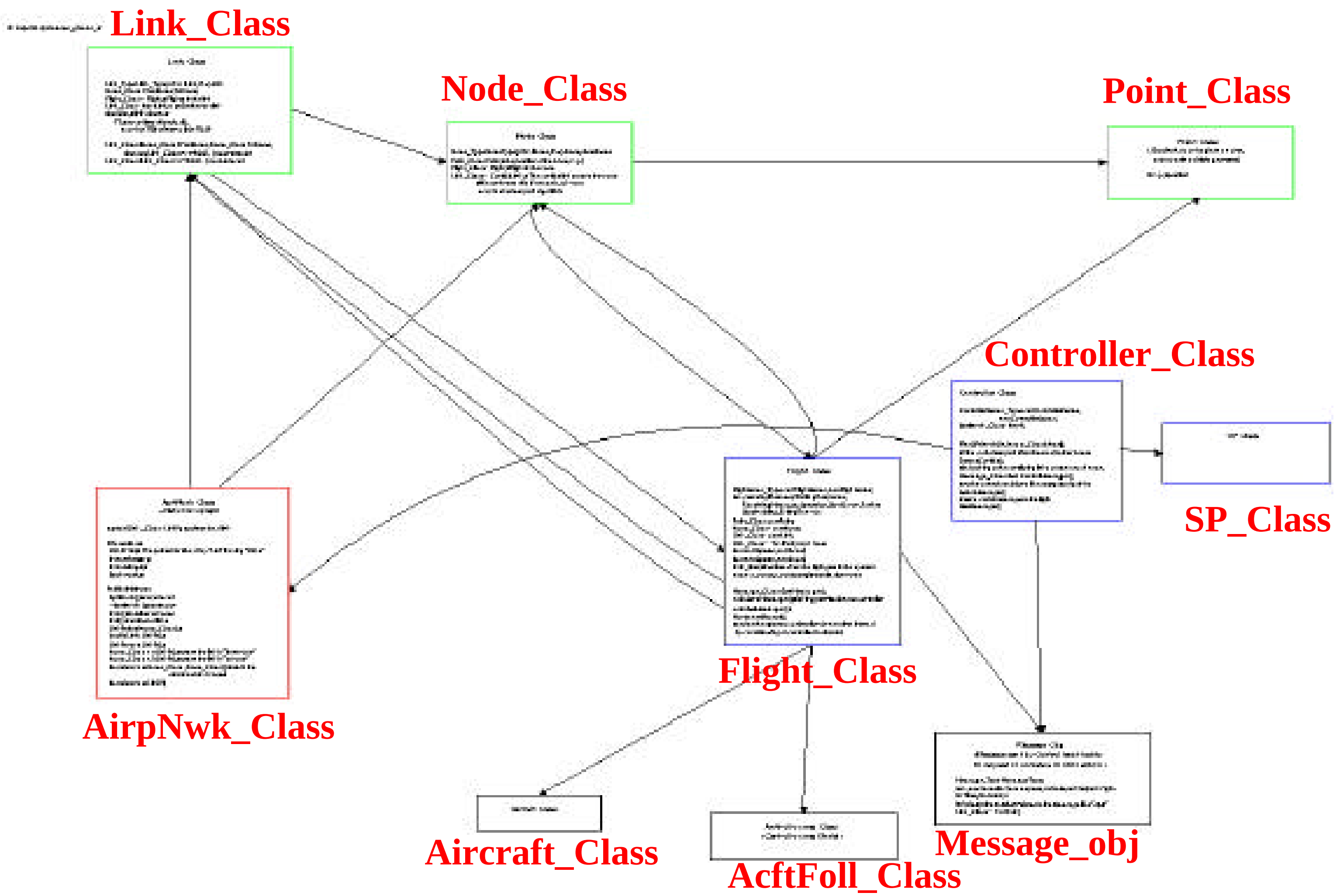
- To demonstrate the integration process RAMS and SIMMOD are being used as testcase
  + RAMS - The Reorganized Airspace Mathematical Simulator
  + Airspace operational model developed by Eurocontrol to simulate advanced airspace concepts
  + SIMMOD - the FAA airfield and airspace model
- Curiously, none of these models was designed with a plug-in architecture in mind (SIMMOD designed in the 1970s and RAMS in the 1980s)
- Both are NARIM tools
- RAMS lacks detailed ground simulation capabilities (perceived as weakness by many)

Integration Appr oach

- Develop an integration procedure to link dynamic events into RAMS and SIMMOD
- Ground simulation component is the common element for the integration procedure (RAMS has little ground logic)



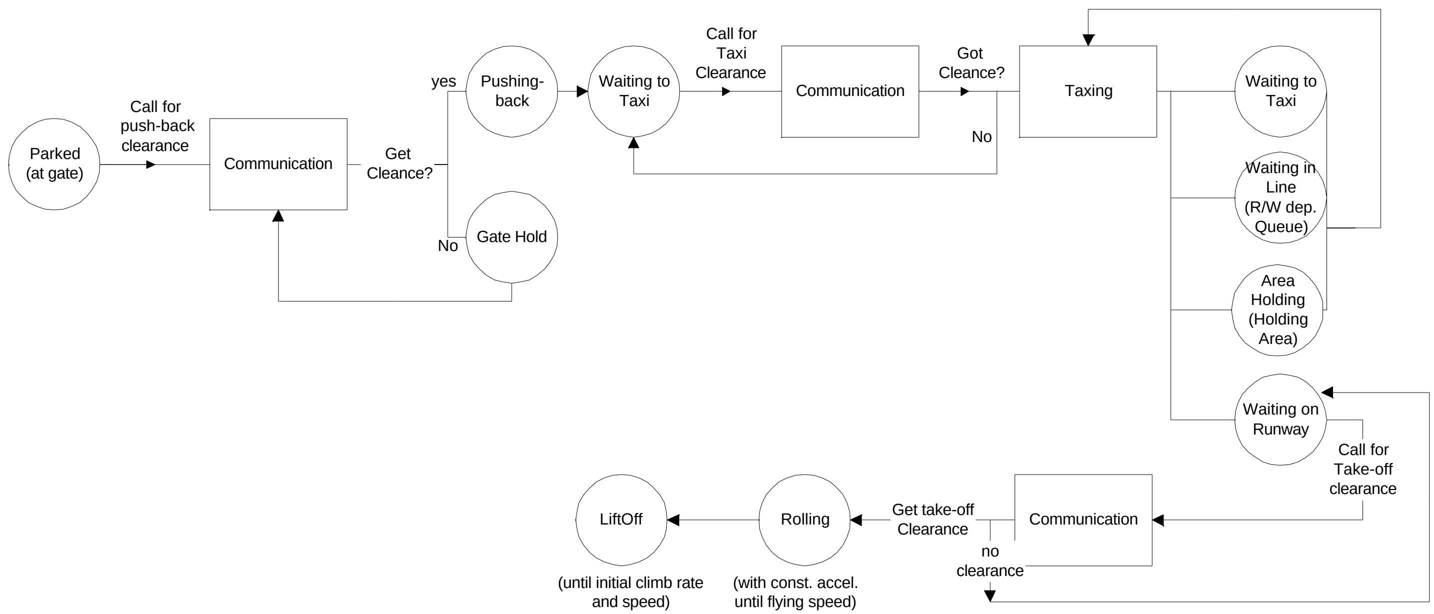
Object-Oriented Ground ATM Model

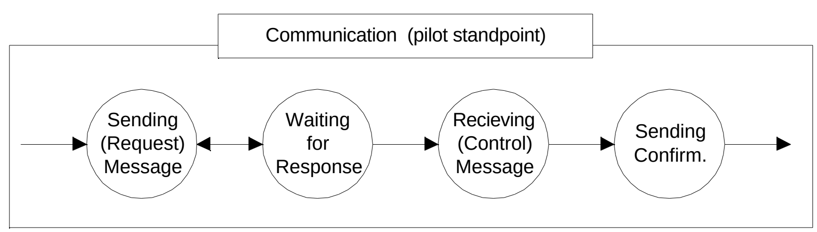


Model Features

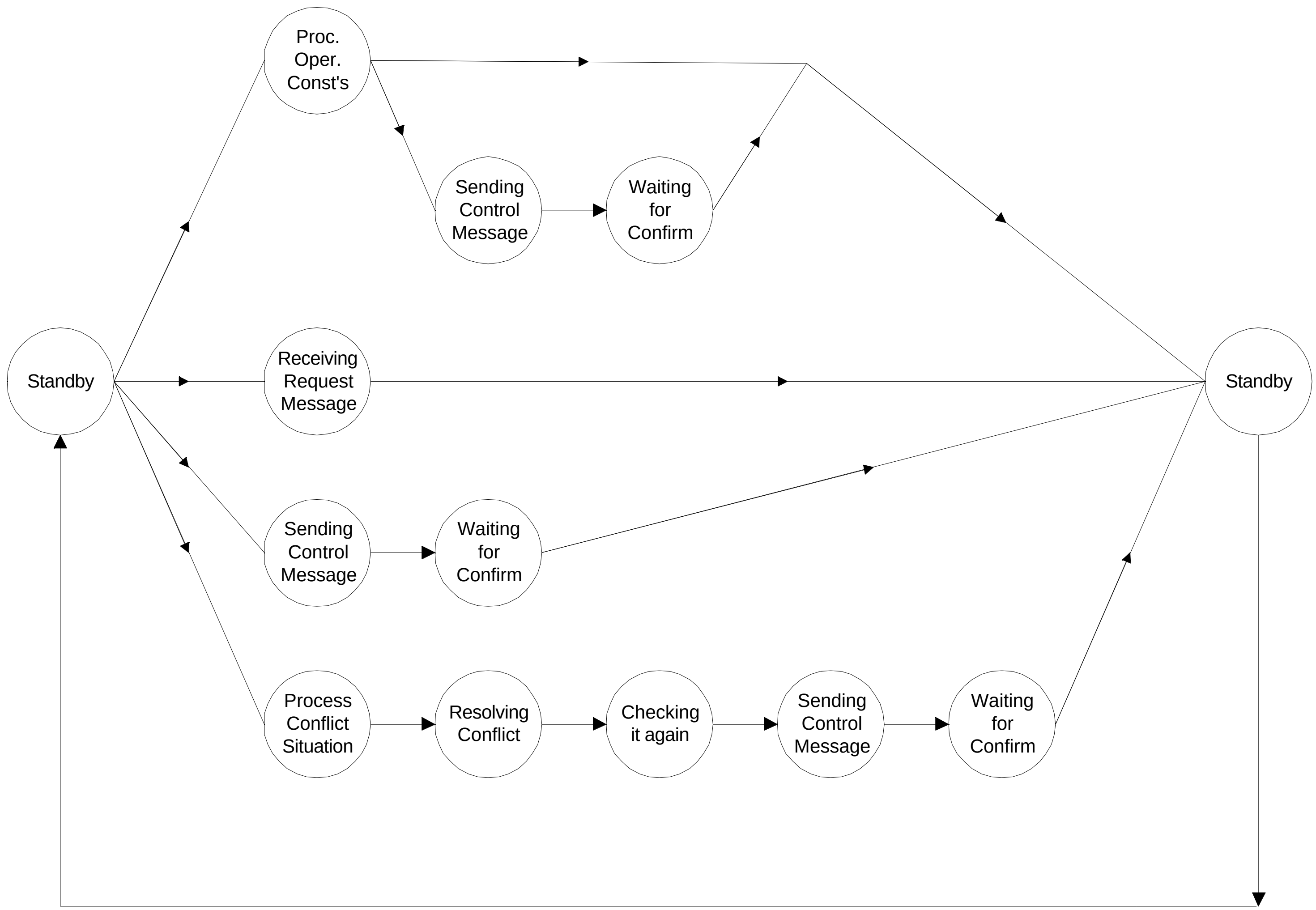
- Continuous (or discrete-event) micro-simulation model
- The total delay due to network congestion can be analyzed
- Implements an “aircraft-following” model
  + The dynamic behavior of moving aircraft can be captured
- Communication delays and frequency congestion is incorporated
- Continuous updating the shortest path (Quasi-Dynamic)
  + More realistic results in reasonable computation time.
- Ground control model attempts to produce a continuous dynamic equilibrium
- Three types of data structures (Array, Linked-list, Mixed) depending on the data type

Departure State Transition Diagram

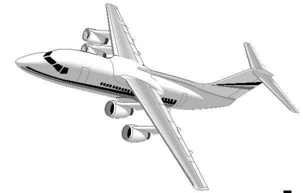




Contr oller State Transition Diagram



Air craft-F ollo wing Logic (second-order model)



Distance control logic

$$\ddot{x}_{n+1}^{t+\Delta t} = k[(x_n^t - x_{n+1}^t) - D], \text{ where } k = \text{design parameter}, D = \text{safety distance}$$

If $\ddot{x}_{n+1}^{t+\Delta t} > \ddot{x}_{\max}$, then $\ddot{x}_{n+1}^{t+\Delta t} = \ddot{x}_{\max}$

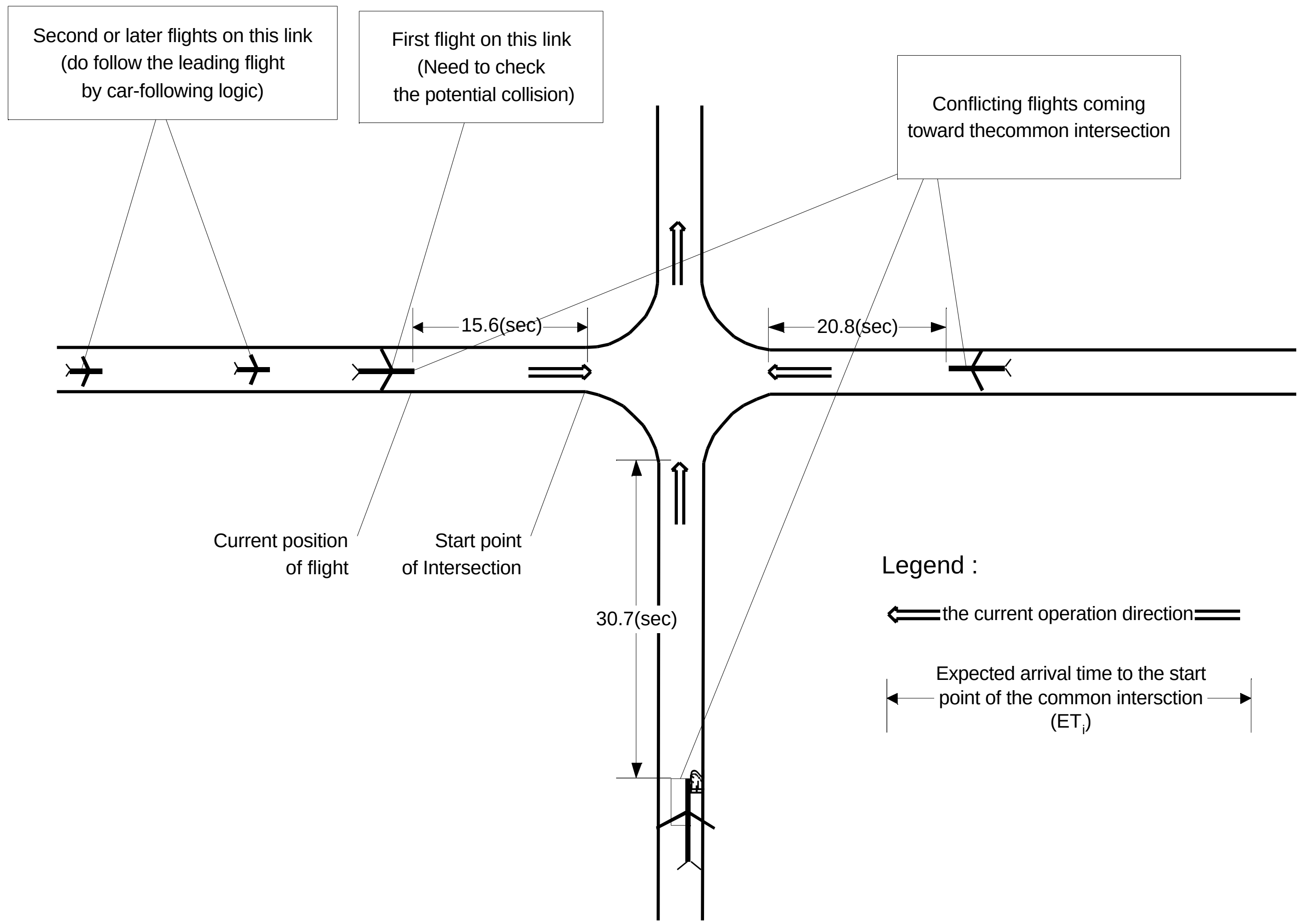
Speed control logic

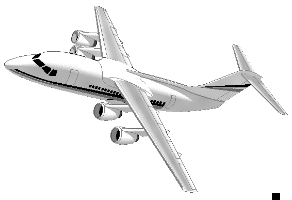
$$\ddot{x}_{n+1}^{t+\Delta t} = k(\dot{x}_n^t - \dot{x}_{n+1}^t) \quad \text{if } \ddot{x}_{n+1}^{t+\Delta t} > \ddot{x}_{\max}, \text{ then } \ddot{x}_{n+1}^{t+\Delta t} = \ddot{x}_{\max}$$

Distance-speed control logic

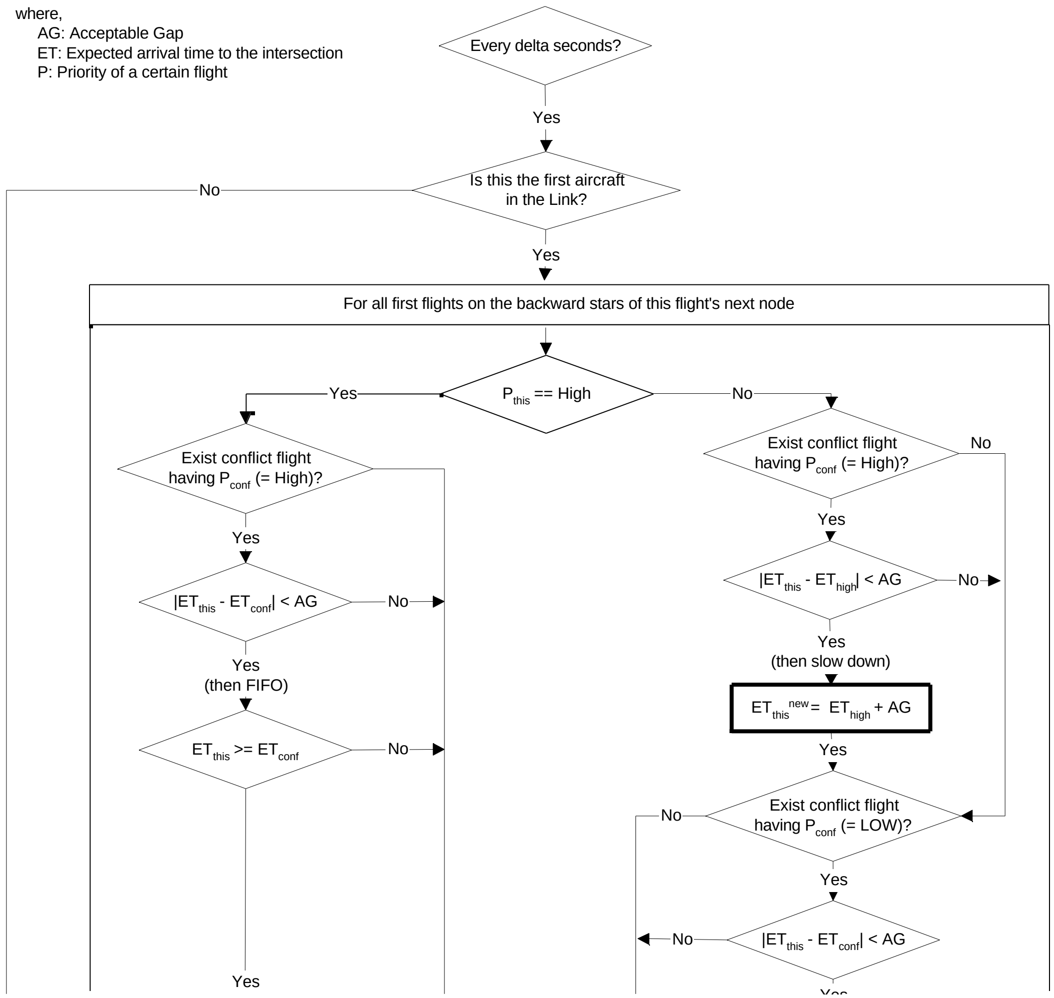
$$\ddot{x}_{n+1}^{t+\Delta t} = \alpha[\dot{x}_n^t - \dot{x}_{n+1}^t] \quad where, \alpha = C\frac{(\dot{x}_{n+1}^{t+\Delta t})^m}{[x_n^t - x_{n+1}^t]^l}$$

Collision Detection at Intersections

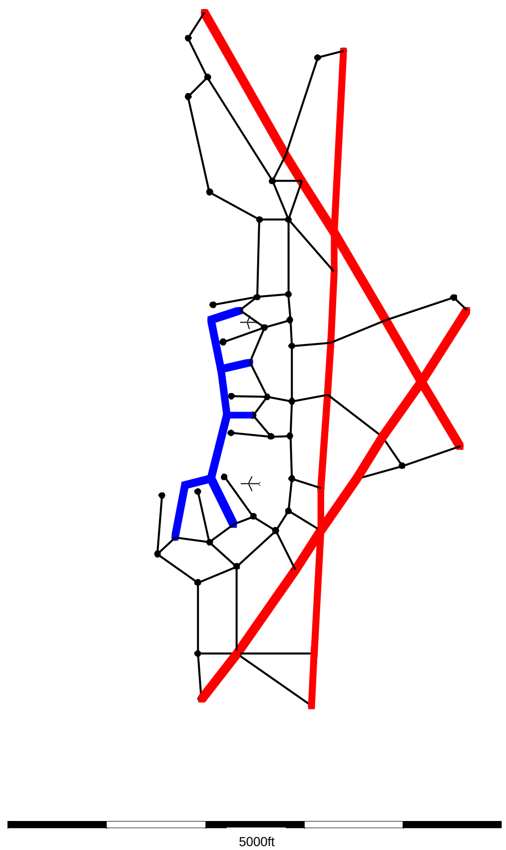




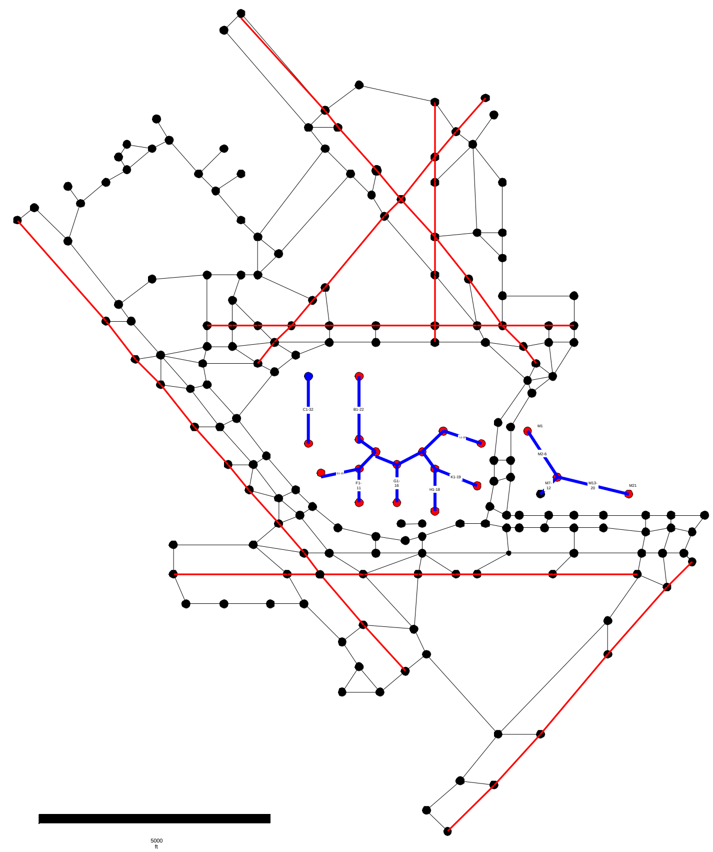
Intersection Resolution Algorithms



Sample Airport Networks



DCA



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Sample Data Files

File 1: Node Data

1. NodeId
2. NodeType (Gate/Taxiway/Runway)
3. TT
4. Restriction

File 2: Link Data

1. FromNode
2. ToNode
3. LinkType
4. LinkId
5. Restriction
6. Direction

File 3: Aircraft Model

1. Model_Id
2. Wingspan
3. Length_f
4. MaxAccel
5. Etc.

File 4: Flight Plan

1. Flt No.
2. Acft_Type
3. Flt_Type
4. S_Time: Start time
5. O_Node: Origin Node
6. D_Node: Destination node
7. etc

File 5: MinPath Matrix

from\to	0	1	2	3	4	5
0	0	1	1	3	3	3
1	-9999	0	2	-9999	4	4
2	-9999	-9999	0	-9999	-9999	5
3	-9999	-9999	-9999	0	4	4
4	-9999	-9999	-9999	-9999	0	5
5	-9999	-9999	-9999	-9999	-9999	0

Rele vance of the Integration

- RAMS is the subject of three integration processes to enhance its capabilities as a decision support tool (our viewpoint)

    + RAMS-OPGEN

    + RAMS-Weather

    + RAMS-Ground_Sim

- While moderate gains in airspace capacity might be possible in NAS under various future Concept of Operations the airport capacity limits of the system remain a critical ATM issue

Modeling NAS Infrastructure Investments

Research Objectives:

- Develop a modeling framework to estimate NAS investments, their effects in NAS operational metrics (delay, capacity, etc.) and macroeconomic impacts

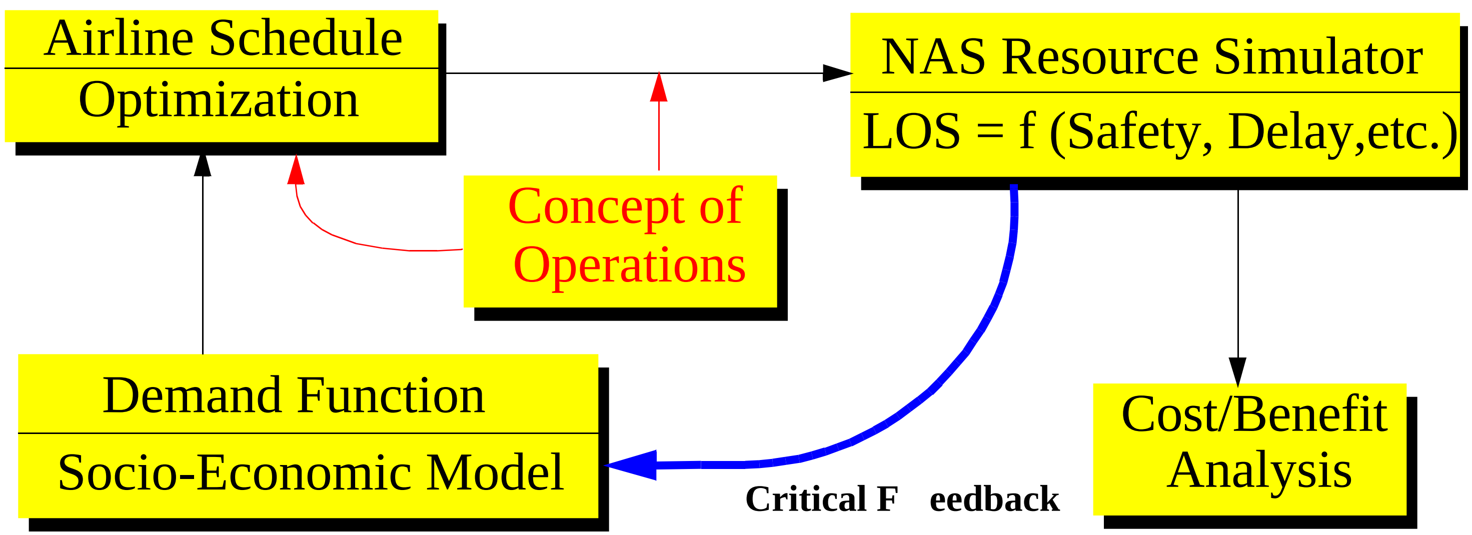
Approach:

- A macroscopic modeling framework to assess the development of NAS has been postulated using Systems Dynamics
- Backbone of the modeling framework has been developed
- Implementation of the framework using State-Flow[1] is in progress (proof-of-concept)

1.State-Flow is a simulation environment developed by the Mathworks in Natick, MA.

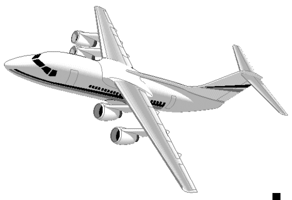
Investment Models Cycle (NARIM)

- A conglomerate of models (belonging to three specific domains - per Odoni et al., 1996):
  - + Operational models (RAMS, SIMMOD, ACM, etc.)
  - + Architectural models (NASSIM - National Airspace Systems Simulation)
  - + Investment analysis modeling



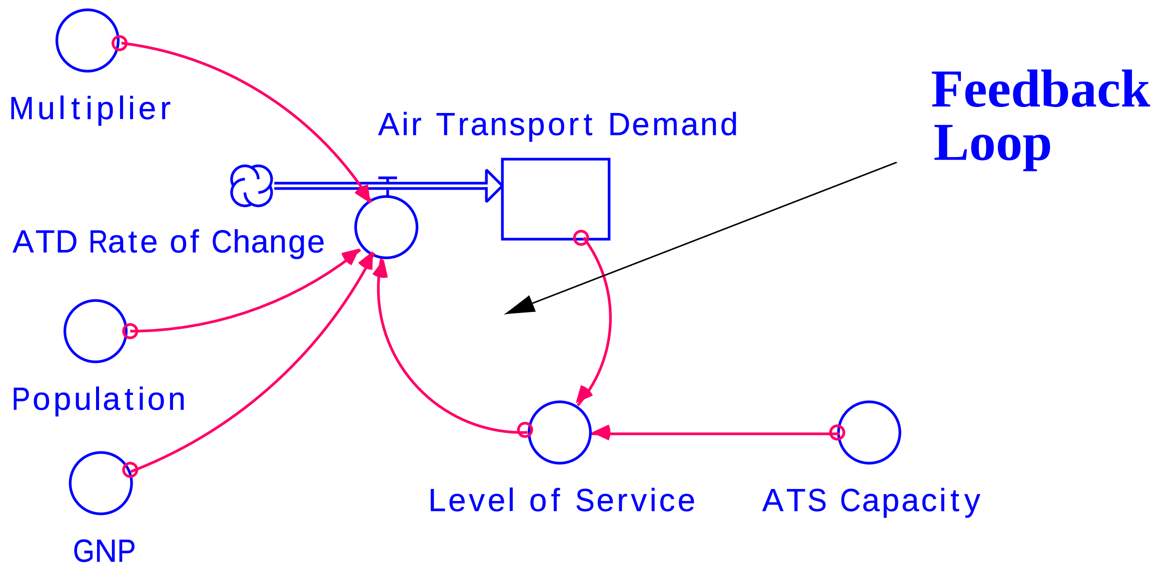
Complementary Approach to NARIM

- We are not trying to create a new NARIM
- The framework being investigated could be used (if successful) as an integration approach that binds NARIM models together
- The difficulty with the current approach in NARIM is that each case scenario needs to be studied independently and models run individually
- The Systems Dynamics approach proposed uses a response curve approach coupled with a dynamic model to ‘encapsulate’ agent behavior researched elsewhere (i.e., ATM Group # 1)
- The approach tries to answer questions without running each model every time



Systems Dynamics Variables (STELLA II TM Representation)

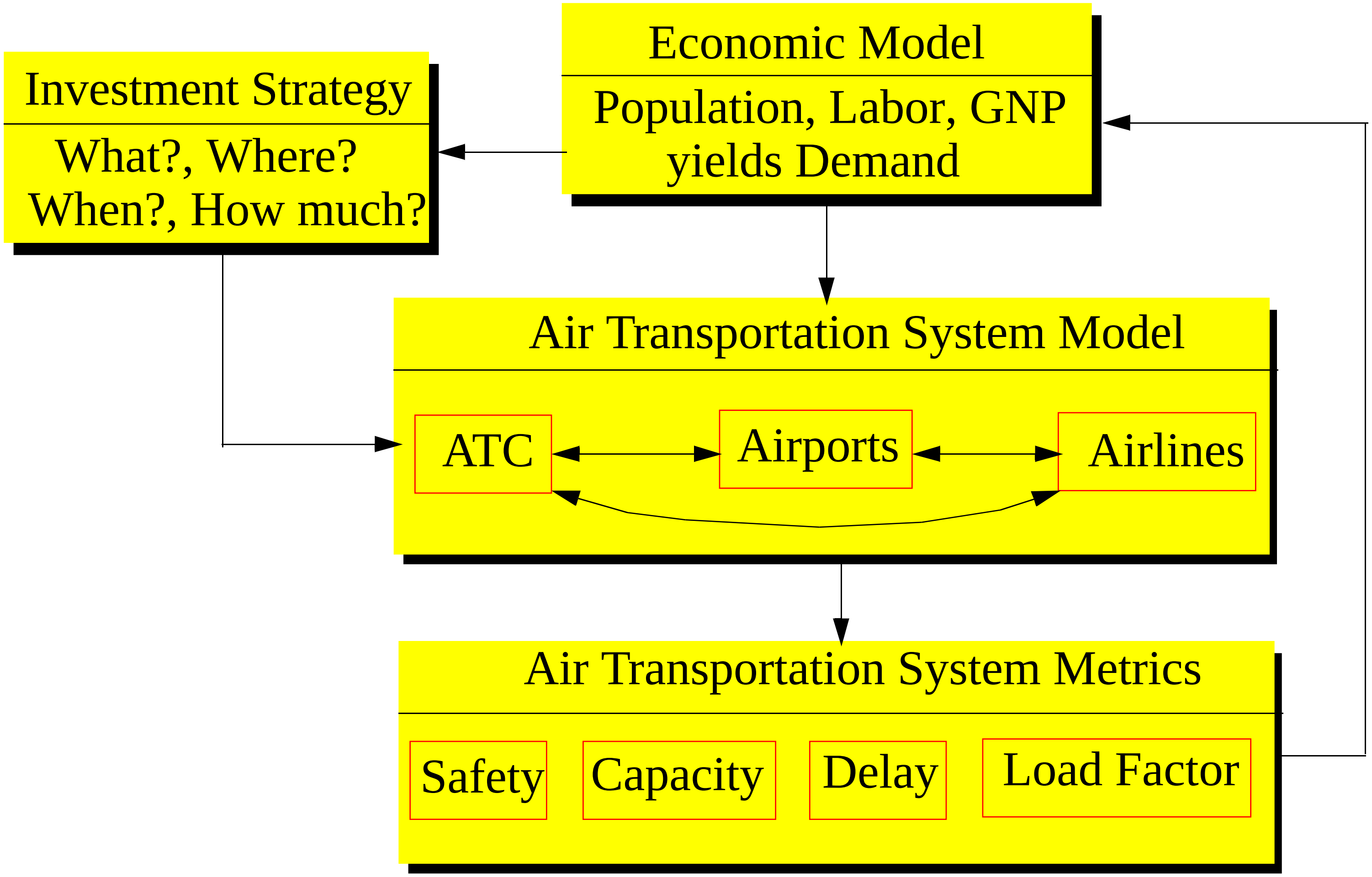
- Level variables - represent accumulation of resources (also called state variables of the system)
- Rate variables - represent the rates of change of level variables
- Auxiliary variables - other variables used to estimate rate variables



Issues in Modeling NAS Agents

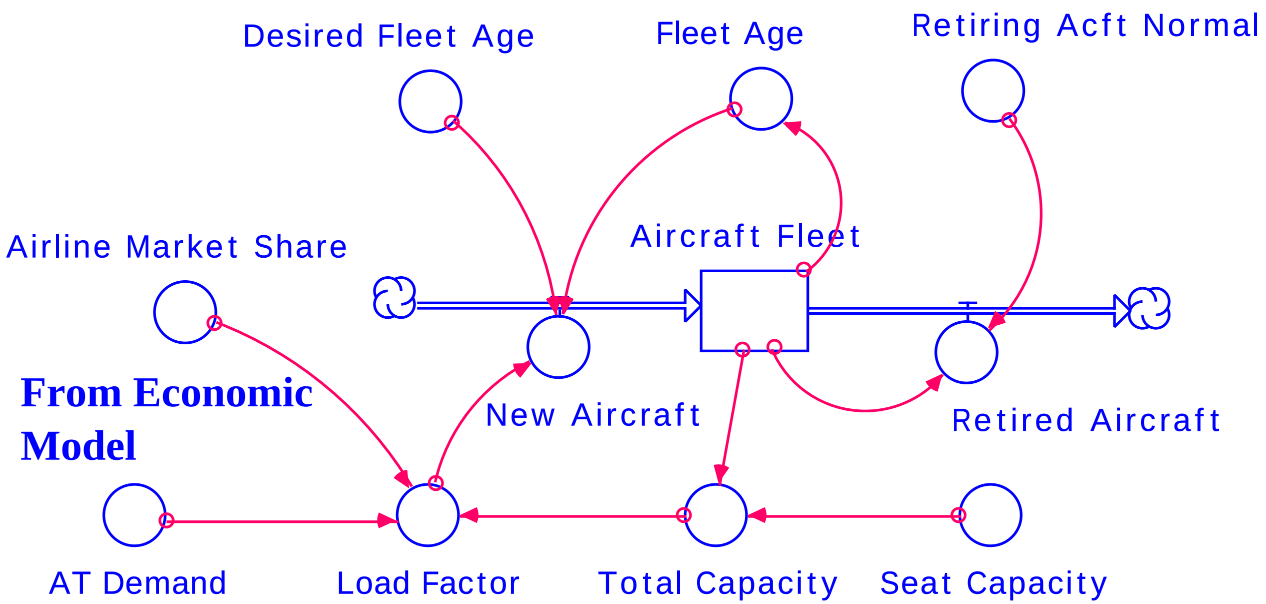
- Level of aggregation
  - + NAS agents can be modeled individually or using some level of aggregation
  - + The level of aggregation in modeling is very critical
- Who should be considered?
  - + FAA (infrastructure facilities such as centers, sectors, CNS assets; staff,etc.)
  - + Airlines (fleet assets, gaming strategy)
  - + Users (the basis for air transport demand)
- Modeling agent dynamics
  - + Part of NEXTOR's challenge is to research how agents respond to short and long term system changes
  - + Agent dynamics are being studied concurrently

Modeling Framework Structure



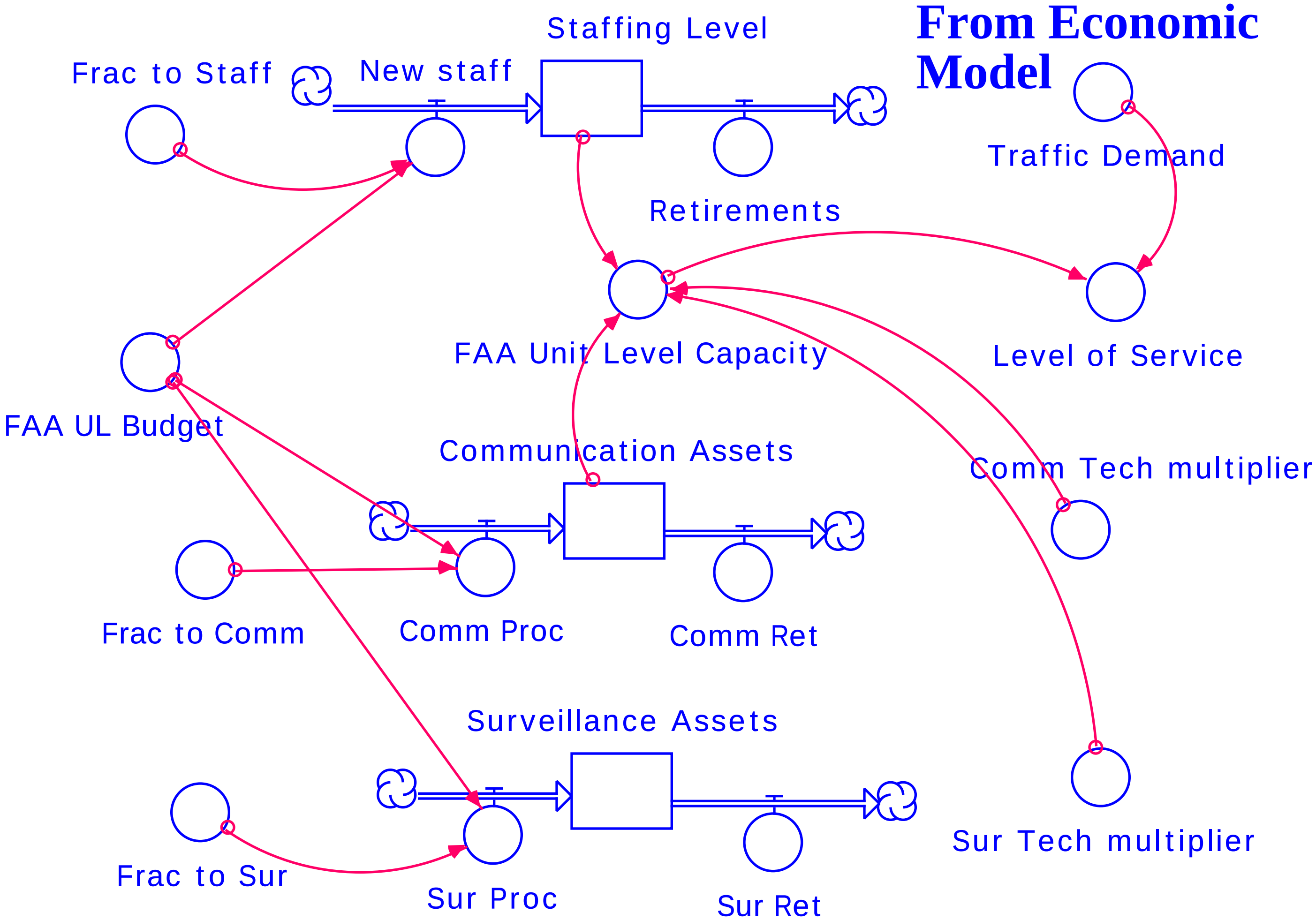
Example of Airline Asset Modeling

- The following example illustrates in a very simplified way how an airline might add or retire fleet assets



In practice the aircraft fleet level variable could be replaced by *n* levels representing various aircraft age groups

Example of FAA Resources Modeling



US Socio-Economic Development Model (SEM)

- The model includes the following relevant variables from the following sectors:
  - + Industrial
  - + Infrastructure (includes transportation)
  - + Social
  - + Population
- Predicts socio-economic activity over time
- Predicts demand functions (regional, city pair, national, etc.)
- Ties in with air transport model (described in the following pages)
- An adaptation of ACIM can be made to link traditional economic parameters (GNP) and the technical model

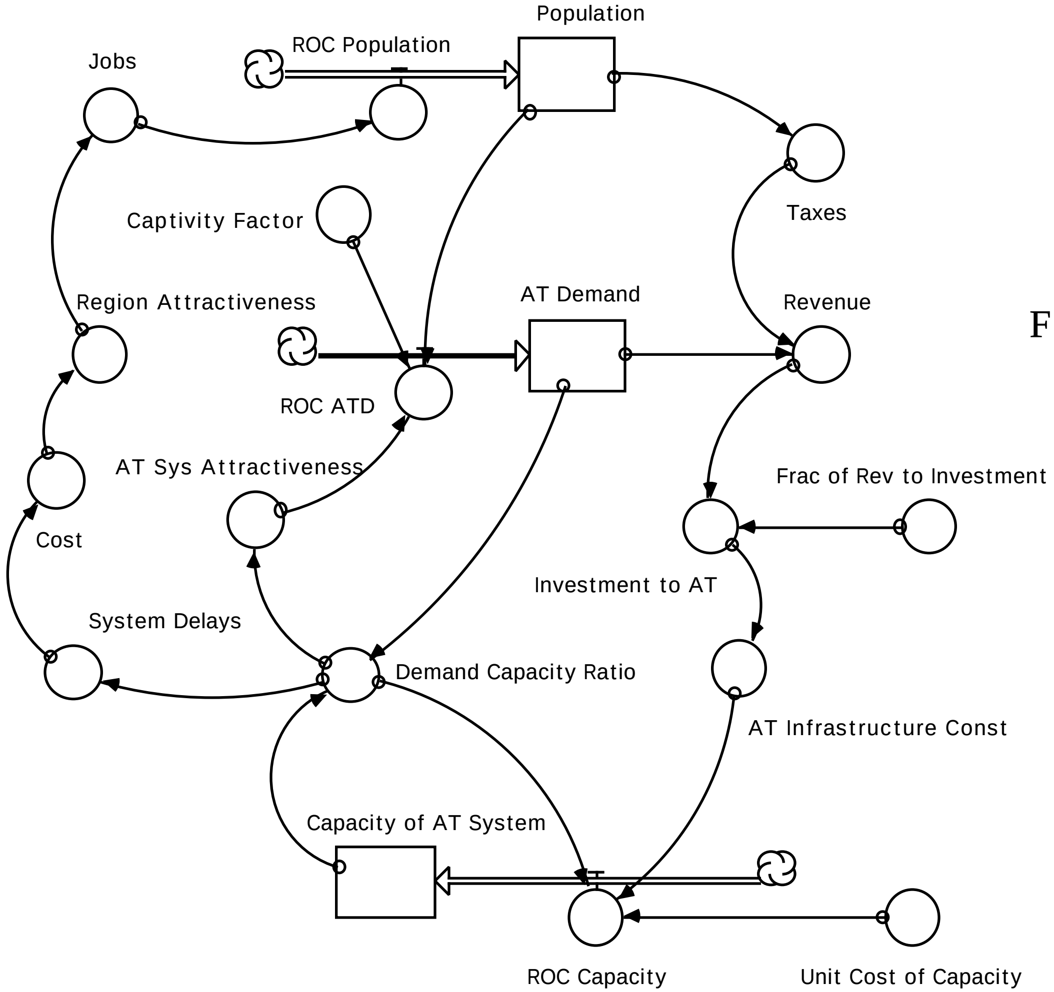
US Air Transportation System Development Model (ATSDM)

- A technology model to predict air transport specific variables consists of the following sectors:
  - + Air Traffic Control
  - + Airlines
  - + Airport
- Tracks airport infrastructure, air fleet, and ATC assets over time
- Contains the dynamics of agents evolve as system state variables change
- Uses the results of SEM (economic model)

Why is Feedback Modeling Important?

- Traditional NAS metric predictions are based on a point performance model (base and horizon years)
- Agents (FAA, airlines, users, and the economy itself) exhibit various degrees of adaptive behavior that are impossible to capture with such a model
- Feedback occurs naturally as these agents adapt over time and thus a dynamic model offers an interesting alternative (as long as we know how this adaptation behavior occurs)
- A dynamic model is capable of responding to external inputs as the model evolves (gaming is possible with such a model)
- Life cycle analysis is a secondary benefit of a dynamic model without gross assumptions in evolution

Model with Explicit Capacity Formulation



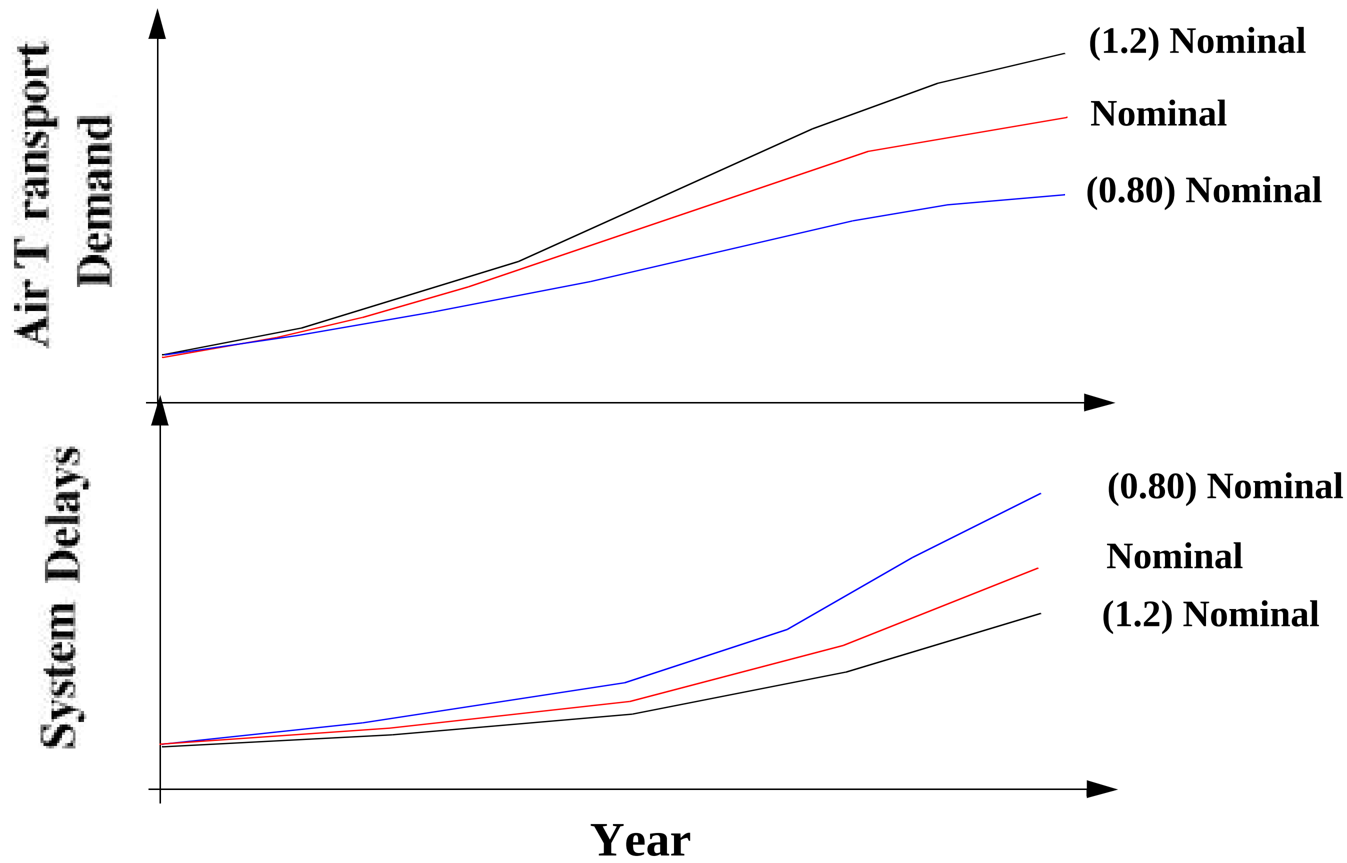
Third Order
Feedback System

Scenario Analysis

- Scenarios of interest to air transportation service providers, users and FAA can be constructed and analyzed
- The proposed modeling framework can be used to understand important investment strategies for NAS and how these affect NAS metrics
  - + Level of ATC automation
  - + Level of airline investments and return
  - + Free flight impacts on NAS metrics
  - + Levels of investment needed
- Perhaps most important is the question when to invest to achieve any benefit on investment (the classical ROI airline and FAA question)

Expected Results of the Model

- Notional patterns for various NAS capital investment policies



Closing Remarks

- Systems Dynamics is just one method to understand ties between variables of social, economic and technological order in complex dynamic systems like NAS
- A properly developed and calibrated model of NAS behavior could serve as a living laboratory where FAA can examine investment policies before implementation
- The approach presented here is a first order modeling effort that complements the our understanding of the NARIM umbrella of models
- While it can be argued that establishing causality between technology and economic variables is difficult it is important to realize that many concurrent (or previous studies and models) can be useful to sort out these details