Air Traffic

By Chris Van Horn

Basics

- Airways
- Airspace
- Air Traffic Control

Airways

- Referred to as “highways in the sky” because very much like the national highway system
- Like streets most airways bidirectional, but some are one way
- Most pilots flying without visual reference to the ground use them
- Low(1,200-18,000)/High(18,000-45,000) Altitude
  - Prop Planes – “Victor” airways
  - Jets - Jetways

Airspace

- Airspace – All open sky covering the United States from less than one inch to outer space
- Restrictions from A-G – A being most restrictive
  - A (18,000-60,000 feet) - populated mostly jets traveling long distances
  - B to D surround airports with control towers and are shaped like funnels
  - E is around small airports with no control tower
  - G is everything else
  - SUA – special use airspace

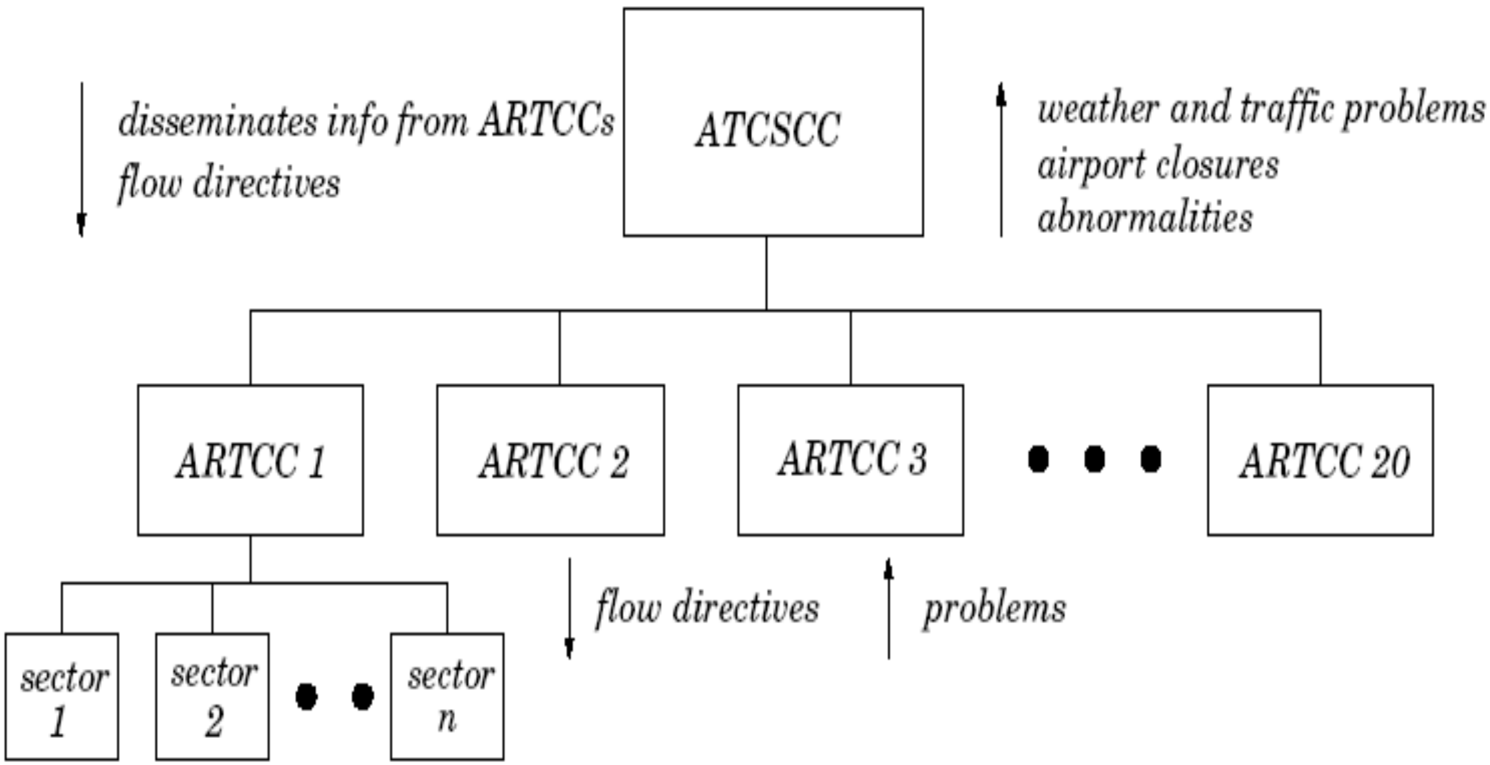
Air Traffic Control

- Vast majority of flights not handled by ATC
- Handled by
  - Control Towers (ATCTs)
  - Air Route Traffic Control Centers (ARTCCs) 21 in US
- Flight Plans
  - Not necessary for VFR flights – Just have to let them know basics in case of disappearance
  - IFR flight rules get allocated airspace that it has exclusive access to for the length of the flight

Air Traffic Controllers

- Each ATCSCC split up into about 20 sectors with one controller per sector
- Each controller can talk to 25-30 aircraft depending on the sector
- Controllers main job is to keep planes separated
  - 5 nm horizontally, 2000 feet vertically
- Can make any changes to plane's flight plan to maintain separation

Control Hierarchy



Lagrangian Air Traffic Flow Model

- Lagrangian – accounts for the trajectories of the aircraft and the parameters transported along them (momentum, average speed)
- Model used to study the effects of aircraft flow density requirements at sector boundaries
- Can be used to
  - How current system may react to imposed flow conditions
  - Test new controller policies in minimizing delays

Air Traffic Flow Modeling

- This model is only concerned with predicting delays so not everything is taken into account (Altitude Changes)
- Motion of aircraft i defined by:

$$\dot{\vec{x}}_i = \frac{d\vec{x}_i}{dt} = \vec{v}_{\text{current heading}}$$

ATC Required Aircraft Maneuvers

- Overflow prevention maneuvers required by ATC
- ATC can modify the velocity of the aircraft
- Aircraft may be required to leave course and then return immediately back to the original course
- Shortcut/Detour sometimes aircraft required to cut between jetways, can increase or decrease total flight time
- Holding pattern a plane is forced to stay in one section before letting it return to its original flight plan

Air Traffic Flow Modeling Continued

$$\vec{v}_{\text{modified speed}} := \lambda \cdot \vec{v}_{\text{current heading}}$$

$$\vec{v}_{\text{part 1}} := R_{\psi} \cdot \vec{v}_{\text{current heading}} \quad \text{(First half of the maneuver)}$$
$$\vec{v}_{\text{part 2}} := R_{-2\psi} \cdot \vec{v}_{\text{part 1}} \quad \text{(Second half of the maneuver)}$$

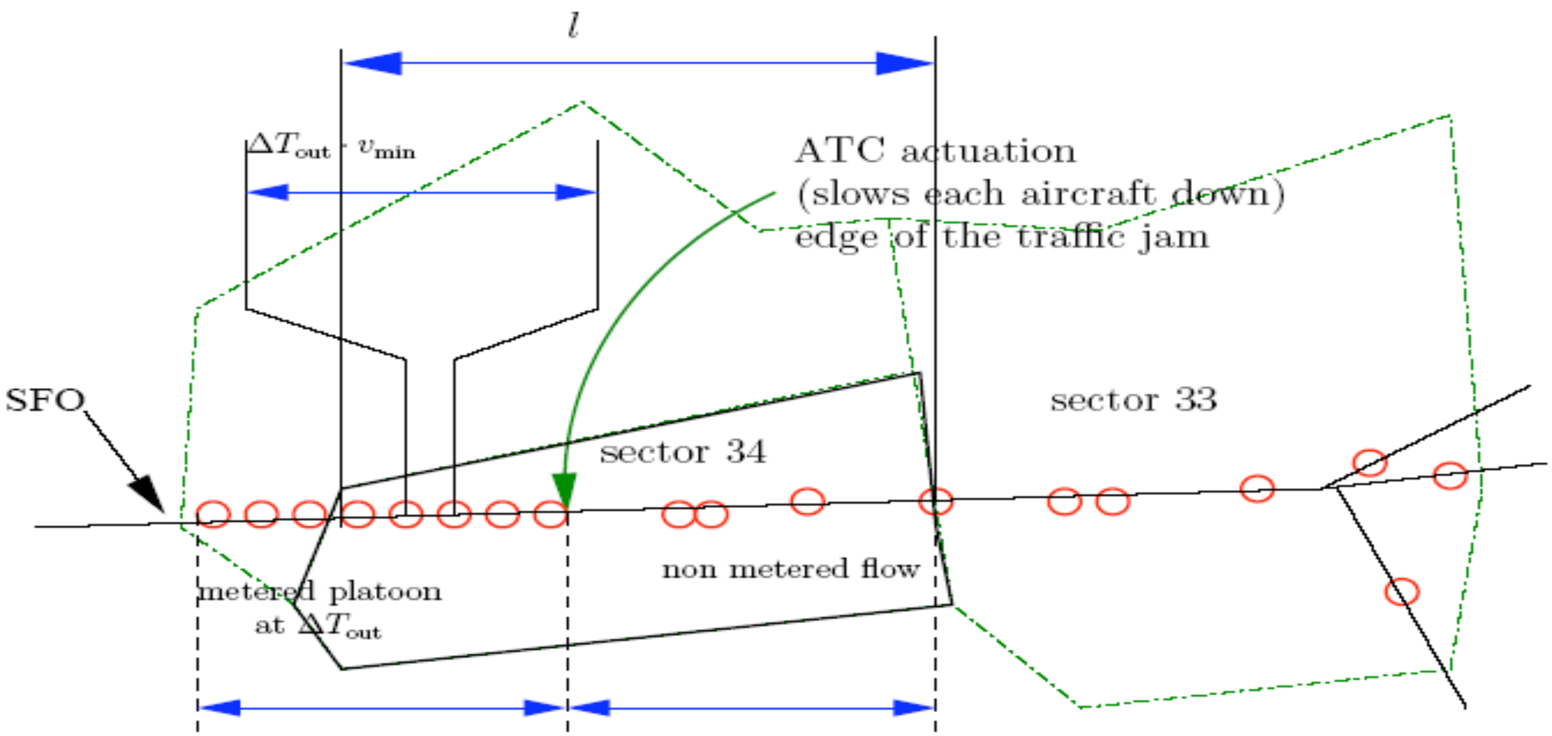
$$\vec{v}_{\text{shortcut}} := R_{\psi} \cdot \vec{v}_{\text{current heading}} \quad \text{for the duration of the maneuver}$$

Air Traffic Jams

- Most air traffic jams caused by restrictions imposed at destination airports
- Usually driven by weather or airport congestion
- This congestion can cause backups throughout the entire network – like a domino effect

Traffic Jam Propagation

- Merging flow of airplanes
- Assume all airplanes are initially traveling at their maximum velocity



Determining Edge of Traffic Jam

ΔT_{out} *metering constraint*

$x_{\text{ex}} \in \mathbf{R}$ the location at which the metering condition is imposed.

$x_{\text{ex}} = -50$ means that the metering is applied 50 nm from the airport

aircraft cross the metering point x_{ex} at exactly $t_{\text{block}} + (i-1)\Delta T_{\text{out}}$

t_{block} is the time at which the metering condition is initiated

$$x_i(t) = a_i^0 + v_{\max} t \quad t \in [0, t_i^{\text{switch}}]$$
$$x_i(t) = b_i + v_{\min} t \quad t \in [t_i^{\text{switch}}, t_{\text{block}} + (i-1)\Delta T_{\text{out}}]$$

$$t_i^{\text{switch}} = \frac{x_{\text{ex}} - v_{\min} t_{\text{block}} - (i-1)\Delta L - a_i^0}{v_{\max} - v_{\min}}$$
$$x_i^{\text{switch}} = a_i^0 + \frac{v_{\max}[x_{\text{ex}} - v_{\min} t_{\text{block}} - (i-1)\Delta L - a_i^0]}{v_{\max} - v_{\min}}$$
$$\Delta L := v_{\min} \Delta T_{\text{out}}$$

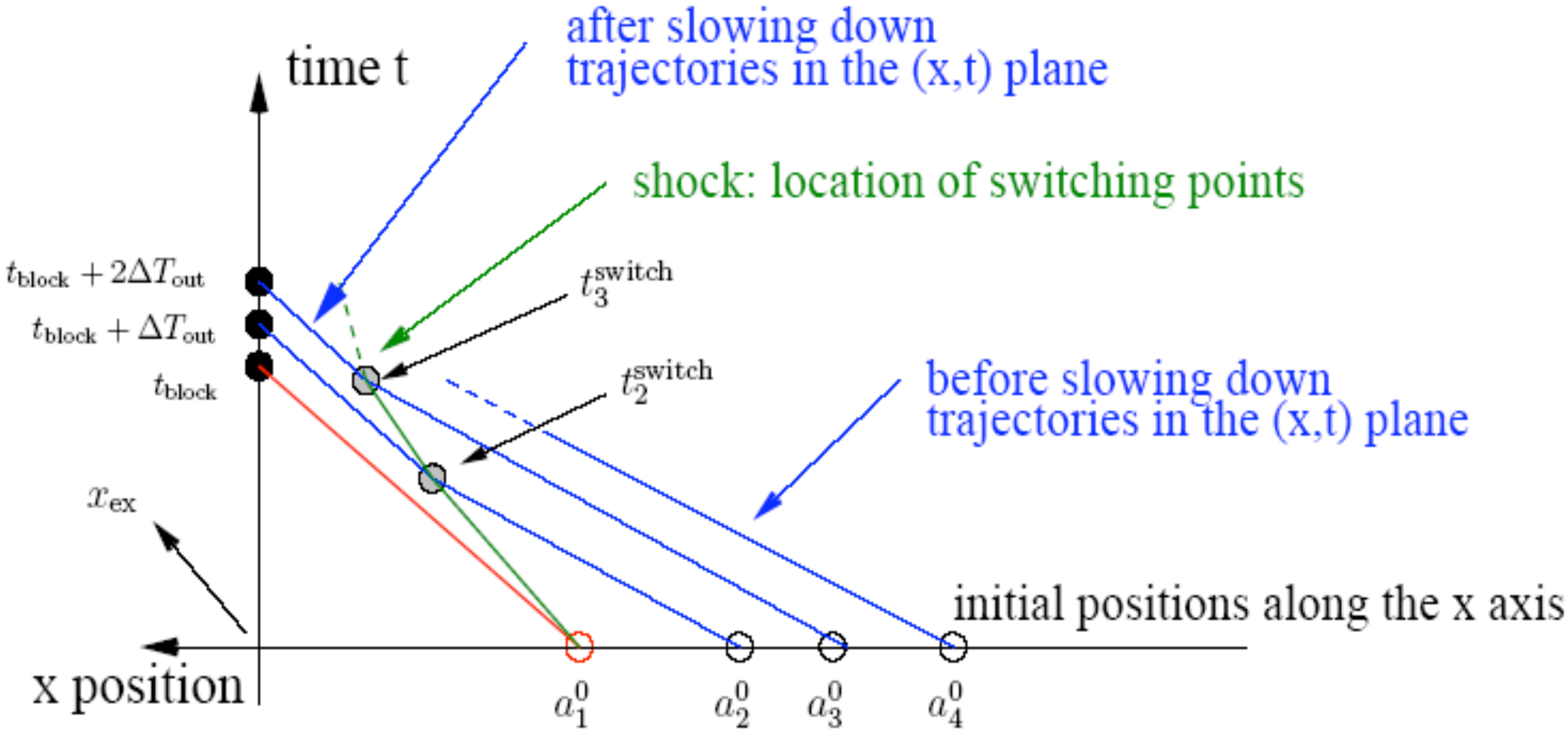


Figure 7: Shock construction. The aircraft trajectories are represented in the (x, t) plane. They originate at $t = 0$ from the horizontal axis (white circle on each trajectory). After some amount of time, the aircraft may be switched to speed $v_{\min}$ at location $(x_i^{switch}, t_i^{switch})$ (shaded circle on each trajectory). Ultimately they reach x_{ex}, the entrance of TRACON (black circle).

$$t_i^{switch} < t_{i+1}^{switch} \quad \Leftrightarrow \quad \Delta L < a_i^0 - a_{i+1}^0$$

$$x_{i+1}^{switch} < x_i^{switch} \quad \Leftrightarrow \quad \left(\frac{v_{\min}}{\Delta L}\right) < \left(\frac{v_{\max}}{a_i^0 - a_{i+1}^0}\right)$$

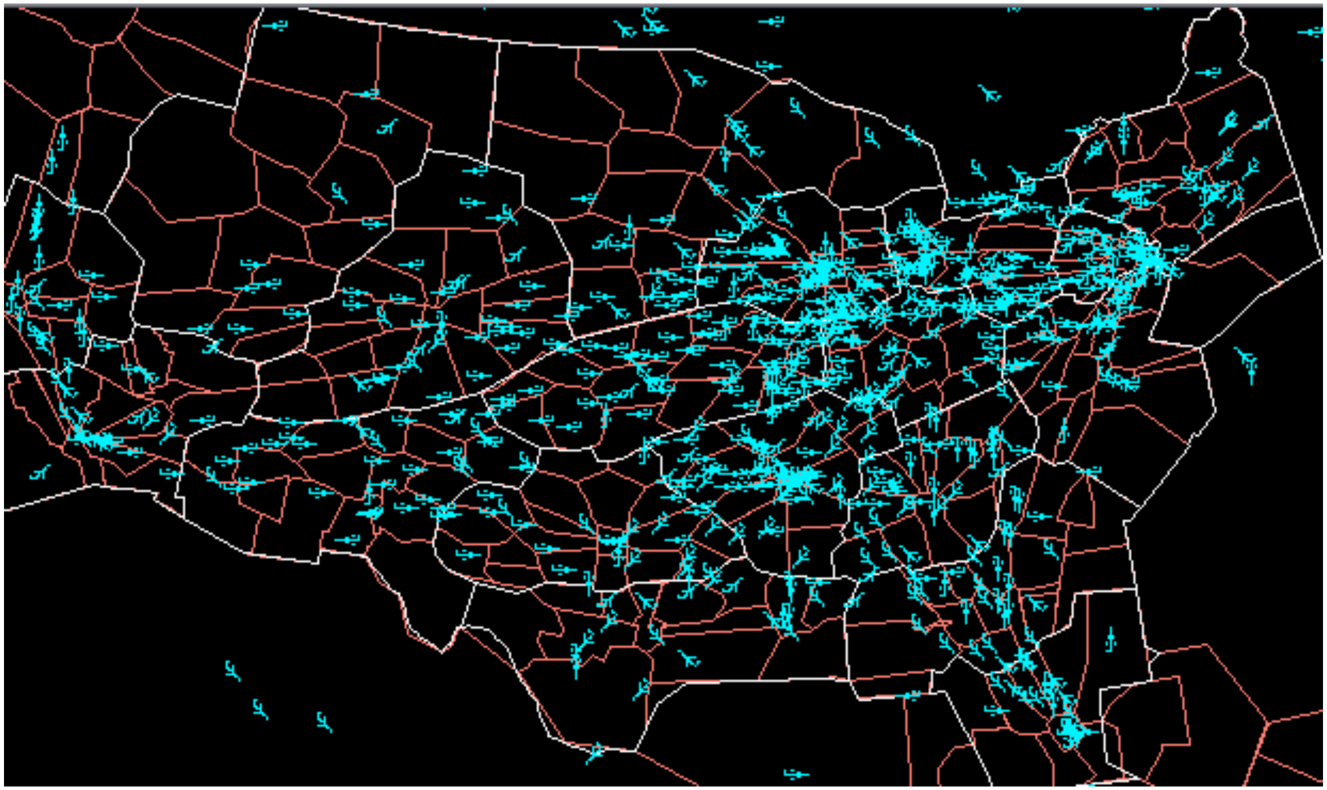
Traffic Jam Predictions

- Using the previous equations we can compute when a sector will become backed up based on how airplanes are flowing in to the sector and how fast they are leaving the sector
- Also able to predict conditions when air space congestion can not be treated by a single sector

FACET

- Future ATM Concepts Evaluation Tool
- Simulation analysis tool developed by NASA
- Flexible simulation environment
- Allows NASA to quickly simulate the effects of new air traffic management algorithms

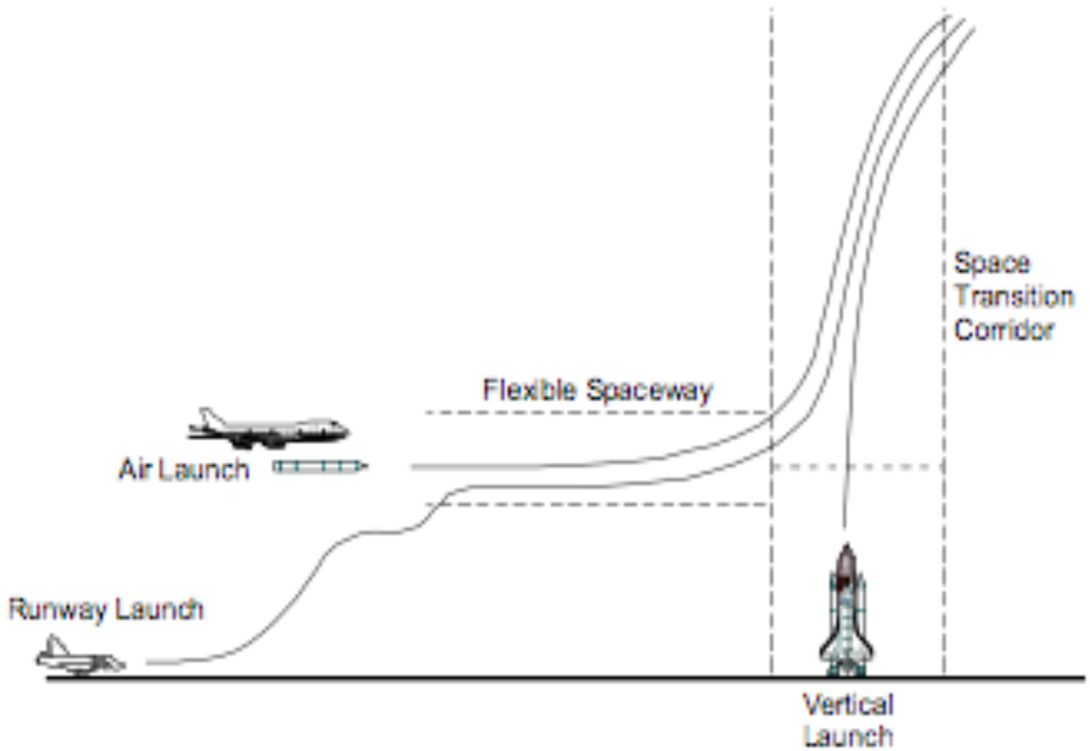
FACET continued



CARAT

- Built on top of FACET to analyze the affect of space launch and return vehicles on the NAS
- Currently have SUA designation which is used to reserve air space for space craft
- Inefficient to completely remove these areas from the NAS
- Dynamic allocation of Airspace
  - Space Transition Corridors - vertical corridors
  - Flexible Spaceways (like jetways)

STCs and Flexible Spaceways



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- Cheng, V., B. Sridhar, and C. Draper, “Computer Simulation and Analysis Tool for Air and Space Traffic Interaction Research,” 21st IEEE/AIAA Digital Avionics Systems Conference, Irvine, CA, October 29–31, 2002
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Street Traffic Simulation

Charles Erwin

Topics to Cover

- What is involved in Traffic Simulation?
- Value/Usefulness of Traffic Models
- Examples of Current Traffic Models
- References

Traffic Simulation

- Traffic Simulators are a type of Traffic study. There are three types of traffic flow studies, differing in scope:
  - **microscopic scale**: at a first level, every vehicle is considered as an individual, so an equation is written for everyone, usually an ODE.
  - **macroscopic scale**: in analogy with fluid dynamics models, it is something more useful to write a system of (PDE) balance laws for some gross quantities of interest, e.g the density of vehicles or their mean velocity.
  - **mesoscopic (kinetic) scale**: a third, intermediate, possibility, is to define a function f(t,x,V) which expresses the probability of having a vehicle at time t in position x which runs with velocity V. This function, following methods of statistical mechanics, can be computed solving an integro-differential equation, like the Boltzmann Equation.

Traffic Simulation (cont)

- Even though Traffic Flow has been studied as early as the 1950s, there still isn't one general theory applied in real flow conditions.
- Traffic is very difficult to simulate because not only are the elements mechanical, the reactions and behaviours of human drivers must also be accurately predicted.

Usefulness of Traffic Models

- Modeling traffic is useful to engineers and city planners.
- Simulate control measures available:
  - Speed Limits
  - Vehicle specific limitations (trucks)
  - Lane changing restrictions
  - Flow control at ramps
- Simulate Infrastructure before it is bought.
- Introduce new parameters such as cruise control and see the effects.

Specific Example: IDM

- The Intelligent Driver Model (IDM) is a "car-following model", i.e., the traffic state at a given time is characterized by the positions, velocities, and the lane index of all vehicles. The decision of any driver to accelerate or to brake depends only on his own velocity, and on the "front vehicle" immediately ahead of him.

IDM (cont)

- Lane-changing decisions, however, depend on all neighboring vehicles. Specifically, the acceleration dv/dt of a given driver depends on his velocity v, on the distance s to the front vehicle, and on the velocity difference Delta v (positive when approaching).

$$\frac{dv}{dt} = a\left[1 - \left(\frac{v}{v_0}\right)^{\delta} - \left(\frac{s^*}{s}\right)^2\right]$$

where

$$s^* = s_0 + \left(vT + \frac{v\Delta v}{2\sqrt{ab}}\right)$$

v0	Desired velocity on free road.
T	Desired safety headway following other vehicles.
a	Acceleration in every day traffic.
b	Comfortable braking deceleration.
s0	Minimum bumper-to-bumper distance to front of vehicle.
Δ	Acceleration exponent.

IDM (cont)

- In general, every "driver-vehicle unit" can have its individual parameter set.
  - Trucks are characterized by low values of **v0**, **a**, and **b**.
  - Careful drivers drive at a high safety time headway **T**.
  - Aggressive ("pushy") drivers are characterized by a low **T** in connection with high values of **v0**, **a**, and **b**.

  Here are some Values in General:

Parameter	Car	Truck
v0	120 km/H	80 km/H
T	1.5 s	1.7 s
s0	2.0	2.0
a	0.3m/s^2	0.3m/s^2
b	3.0 m/s^2	2.0 m/s^2

IDM (cont)

- IDM is only a "Longitudinal Traffic model", in that it only takes into account traffic in a world where there is only ever one lane. This of course is not very useful by itself.
- To fully utilize IDM, another traffic model is necessary to allow for multiple lanes. The example utilised here used "**MOBIL.**"

MOBIL: Lane Change Model

- **MOBIL** = **M**inimizing **O**verall **B**raking decelerations **I**nduced by **L**ane changes
- Lane changes takes place, if
  - the potential new target lane is more attractive, i.e., the "incentive criterion" is satisfied,
  - and the change can be performed safely, i.e., the "safety criterion" is satisfied.
- Introduce new parameter **p**: Politeness factor.

MOBIL (cont)

- While other lane-change models typically assume purely egoistic behaviour, i.e., ***p***=0, MOBIL can model different behaviours by varying this factor:
  - ***p*** > 1 => a very altruistic behaviour.
  - ***p*** ϵ [0, 0.5] => a realistic behaviour: Advantages of other drivers have a lower priority, but are not neglected: Notice that this feature means that yielding to "pushy" is included into MOBIL.
  - ***p***=0 => a purely selfish behaviour. Notice that also selfish drivers do not ignore the safety criterion!
  - ***p***<0 => a malicious personality who takes pleasure in thwarting other drivers even at the cost of own disadvantages. This may have some interesting game-theoretic consequences. Of course, even those mischief makers do obey the safety criterion.

Microsimulation of Road Traffic

Online Applet

http://vwisb7.vkw.tu-dresden.de/~treiber/MicroApplet/index.html

Traffic Model: Dresden 3d Model

- **Instance:** Driver notices that traffic suddenly stops for no apparent reason.
  - After some time, vehicles begin to move again.
  - Modeled in a traffic microsimulation by Dirk Hellbing of Dresden University of Technology.
  - Presented with the idea of allowing a driver to see what the cause of the traffic jam really is instead of just stopping.

Dresden 3d Model (cont)

- Example of the "Phantom Traffic Jam"

Dresden 3d Model (cont)

- Traffic with Environmental Conditions

A Famous Traffic Model: SimCity

SimCity's Traffic Generation Model

- Traffic has been a major part of SimCity since the very first version of the game.
- Generating reasonable routes for a City's inhabitants is handled via *trip generation*, where a Sim attempts to find a way from one destination to another via the road network.
- The programmers wanted to capture intent in transportation simulation.

SimCity (cont)

- **SimCity's Traffic Generation Model**
  - The solution to how a Sim finds a route between two destinations is solved using **A* search**.
  - Instead of using distance as a heuristic, which would prevent things like mass transit or walking from being likely options, SimCity's search routine uses time as the parameter to minimize.
  - Travel time is calculated by a number of factors. Each form of transportation can move over each different kind of tile at a different speed. Pedestrians can travel over all types of roads at a fixed rate, but cars and busses can go faster on main roads than on residential streets. In addition, they can go really fast on highways, which are forbidden to pedestrians by the laws of the city.

SimCity (cont)

- **SimCity's Traffic Generation Model**
  - Most forms of transportation are affected by how much traffic has previously traveled over a tile. Each type of road has a different capacity for traffic, and once a tile reaches capacity traffic slows down. A very congested tile can be extremely slow, causing Sims to investigate other paths first.
- However, there are major flaws in the SimCity model.
  - The suggested solution to most congestion in SimCity is to add more routes for Sims to choose from. An alternative solution I independently discovered was adding multiple toll booths along congested paths. The engine allows for as many booths as can fit and therefore you can maximize transportation profit as well as minimize congestion along routes, a very unlikely solution in real life.

References

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- "TU Dresden 3d traffic simulator" at www.mtreiber.de
- SimCity 4's Traffic Model
  http://simcity.ea.com/about/inside_scoop/traffic.php