27th annual INCOSE international symposium
Adelaide, Australia
July 15 - 20, 2017

Using an Agent-Based Simulation to Evaluate the Performance of Control Algorithms for an Intelligent Traffic Light System

John Panek
Northrop Grumman Corporation

Agenda

Define the Problem

- Objective of Investigation
- Define Measures of Effectiveness (MOEs)

Define the Model

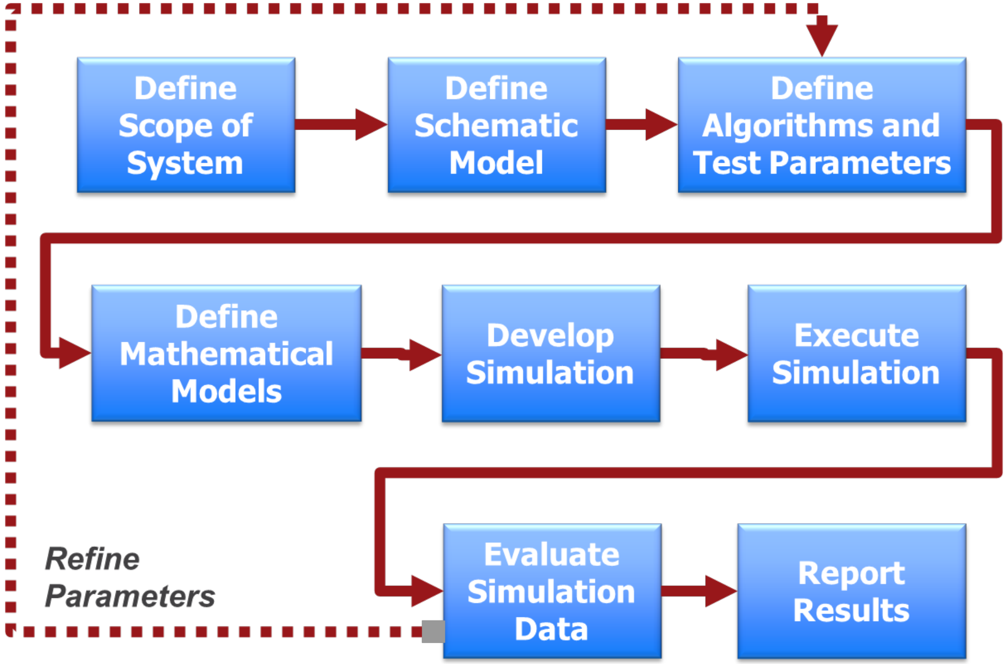
- Define Traffic Control Algorithms
- Evaluate / Select Modeling Tool
- Model Functionality / Architecture
- Identify Simulation Parameters
- Map NetLogo Components

Develop / Execute the Model

- Validate System Model
- Run Algorithm Simulations

Evaluate Data / Report Results

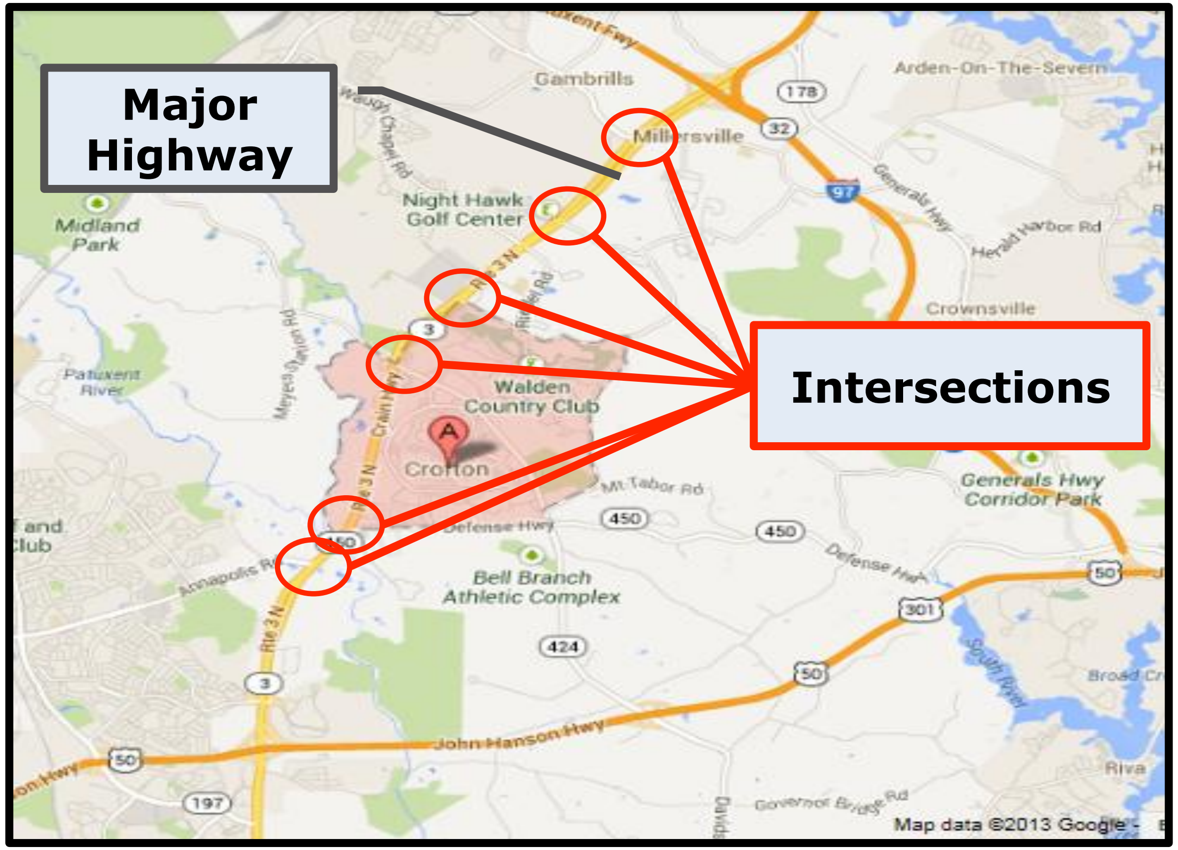
- Algorithm Performance
- Lessons Learned
- Summary of Findings
- Future Application of Results



The Problem

Case Study: Evaluate Traffic Light Control Algorithms in a Real-World Environment

- **Objective**: Develop and evaluate the performance of control algorithms for an intelligent traffic light system
- **Scope**: Simulate a real highway, in Maryland (US), with multiple intersections
- **Methodology**: Use an agent-based modeling tool



Measures of Effectiveness (MOEs) are Used to Evaluate Traffic Control Algorithm Performance

- Critical MOEs determine a successful implementation

Measure of Effectiveness	Critical or Desirable	Source / Justification
Vehicle Throughput (vehicles / hour)	Critical	• Government study, derived • Top priority to reduce gridlock
Vehicle Wait Time on Main Route	Critical	• Feedback from local residents • Source of driver frustration
Vehicle Wait Time On Cross Roads	Desirable	• Derived • Not as urgent as on main route
Fuel Consumption	Desirable	• Derived • Supports environmental causes

Quantitative Vehicle Throughput MOE was Obtained by Sub-Allocating Traffic Estimates into Rush Hours

- Assumption for partitioning daily vehicle traffic loads
  - Sub-allocated traffic into morning / evening rush hour periods
  - 2.5 hour time segments
- Vehicle throughput MOE:
  - 8,167 vehicles / hour

Vehicle Traffic Loads 2000→ 2025

(Maryland SHA, 2004)

Intersection with MD 3	Year 2000 Existing Conditions ADT	Year 2025 No-Build Conditions ADT
MD 450 West (Annapolis Road)	67,125	105,375
MD 450 East (Defense Highway)	67,125	105,375
Cronson Boulevard	57,925	93,025
MD 424 (Davidsonville Road)/Conway Road	56,475	90,275
Waugh Chapel Shopping Center	54,200	86,100
Waugh Chapel Road/Reidel Road	56,325	90,575
St. Stephen's Church Road	57,400	91,675
MD 175/Millersville Road	57,400	91,675

Cars / hour (average over 1 day)

Allocation of 24 hrs to each traffic level

$$\text{Traffic Level (Cars/Hr)} = \frac{\text{(Total Daily Cars)/(24 hrs)} * \text{(Alloc. Factor)}}{\text{(Duration of traffic level in hrs)}}$$

# of hours that the traffic level lasts

Four Traffic Control Algorithms Define Unique Techniques for Traffic Light Control

Random
- Fixed red light time intervals with random light initialization

Fixed
- Intelligent fixed intervals, calibrated based on anticipated traffic load

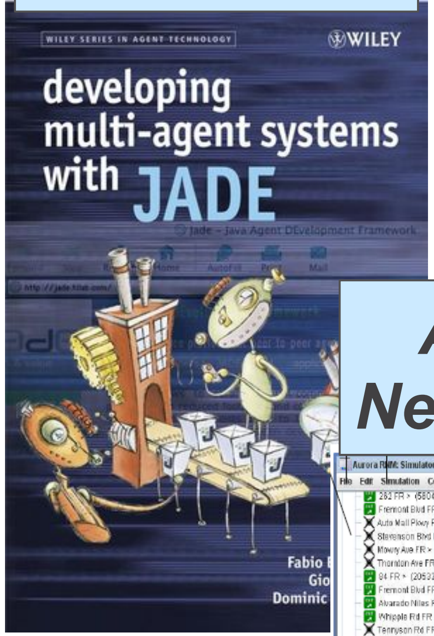
Adaptive Density
- Calculates density and distance of incident traffic flow at each intersection to set light changes

Adaptive Train
- Identifies a “train” of vehicles, sequences all light durations based on train length and distance from intersections

Extreme Adaptive Train Intersection

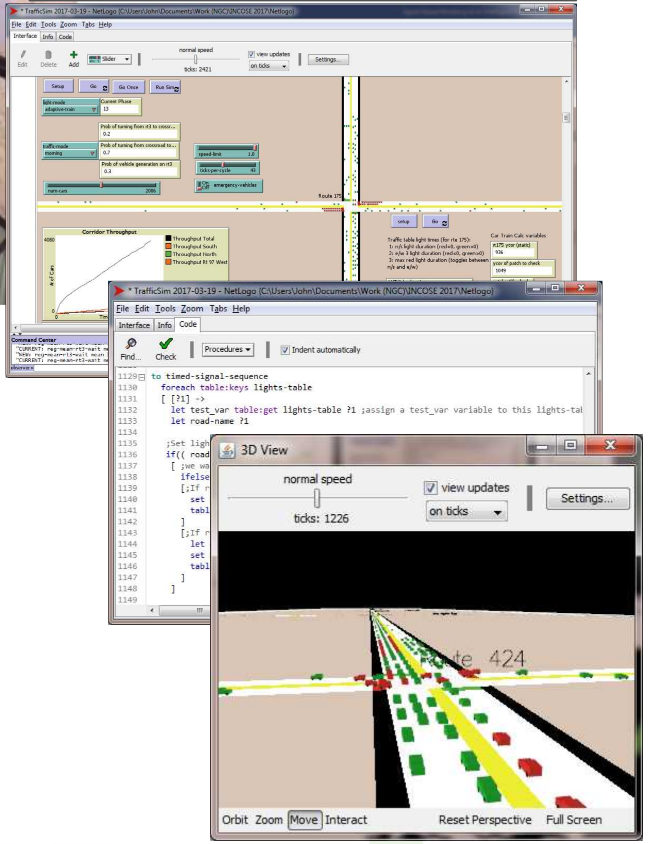
Identify Available Modeling Tools

JADE

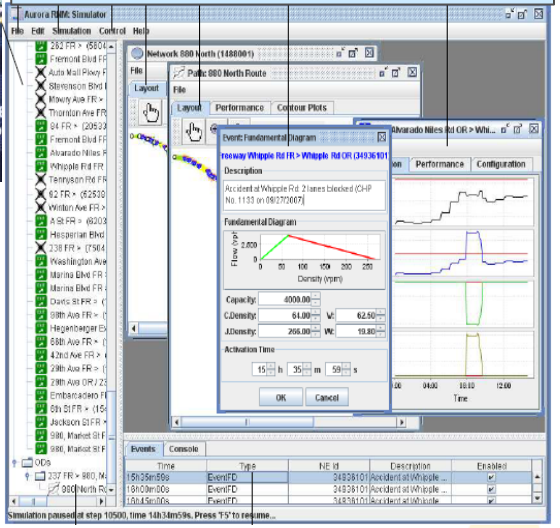


TOPL

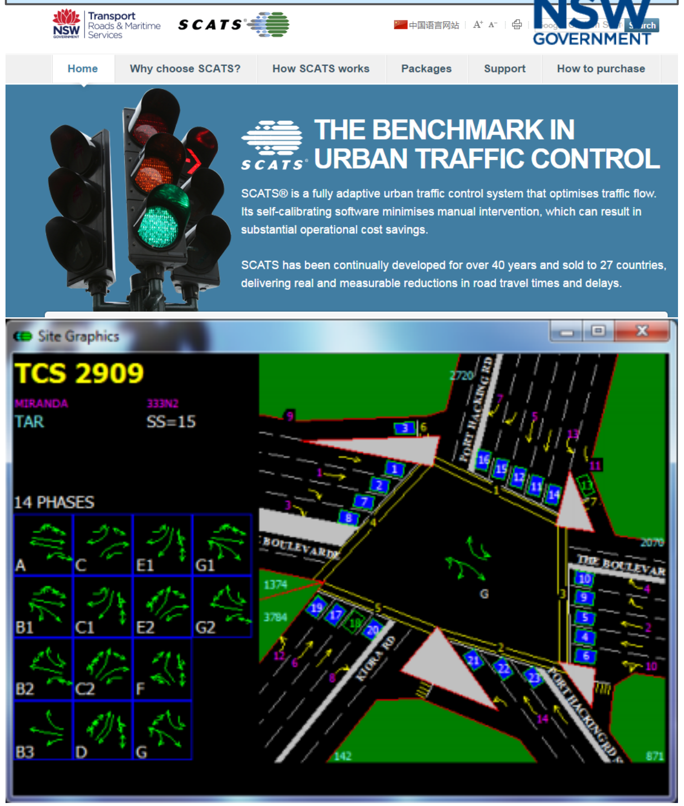
NetLogo



Aurora Road Network Modeler



SCATS

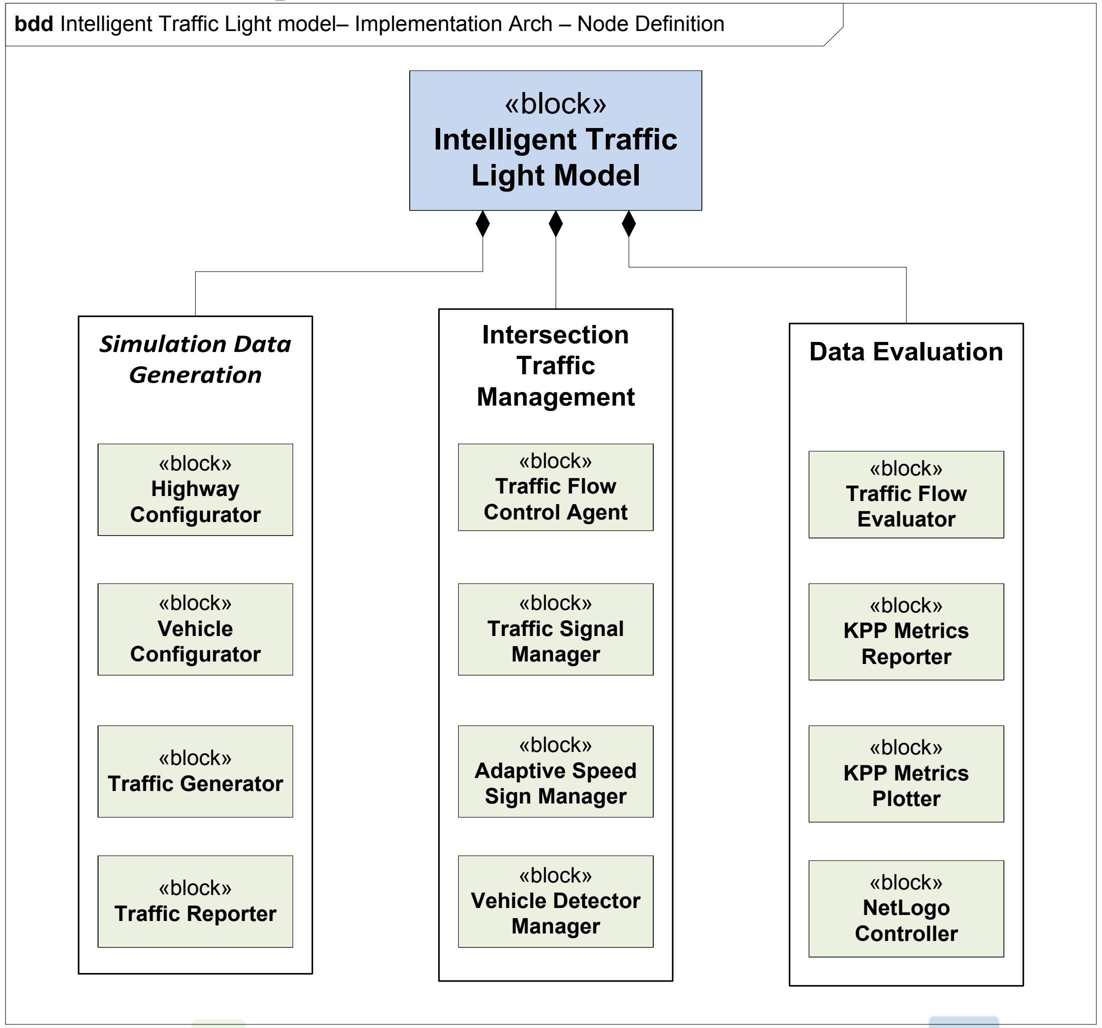


Evaluate / Select Modeling Tool

Modeling Tool	Type of Modeling Tool	Evaluation vs. Selection Criteria
MATLAB	General scientific programming language	Requires development of vehicle interaction dynamics, road structures
Discrete Agent Framework (**DAF**)	Agent-based, developed in object oriented MATLAB	Limited documentation and code for re-use. Use for Perdue University.
Aurora Road Network Modeler	Object-oriented framework with base objects for to model flow networks	Tool not supported since ~2009. No on-line community and little re-use code available.
Tools for Operational Planning (**TOPL**): CTMSim, FwyModel, etc.	Dynamic macroscopic cell transmission model (CTM)	Limited documentation and code for re-use. Use for Univ. of CA, Berkley
NetLogo	Agent-based programming language and integrated modeling environment	Large online community with readily available models for traffic grids, intersections. Vehicle interaction dynamics and on-screen simulation built into tool. **Cost = $0.**
SCATS in microscopic **sim**ulation (**SCATSIM**): Aimsun,PTV,VISSIM, Quadstone Paramics, Commuter	Microscopic modelling package	Suite of complex traffic operations simulation tools from **S**ydney **C**oordinated **A**daptive **T**raffic **S**ystem. Very complex, expensive.

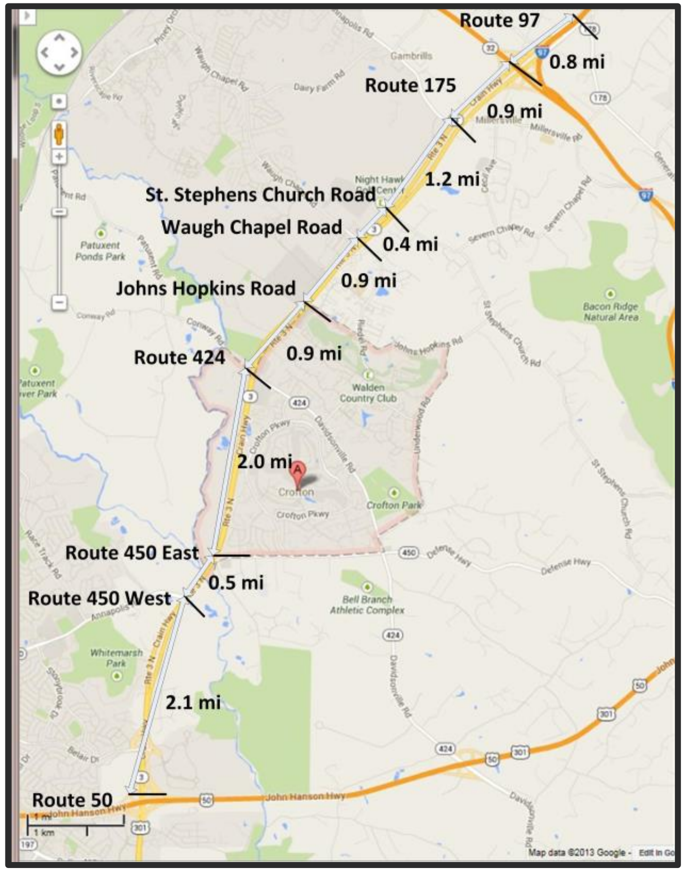
Defining the Model Functionality / Architecture Provides Insight into the Development Effort

- Major Model Functions
  - Simulation Data Generation
  - Intersection Traffic Management
  - Data Evaluation
- Additional architectural nodes defined for each function



Model Development Using Agent-Based Modeling and Simulation (ABMS)

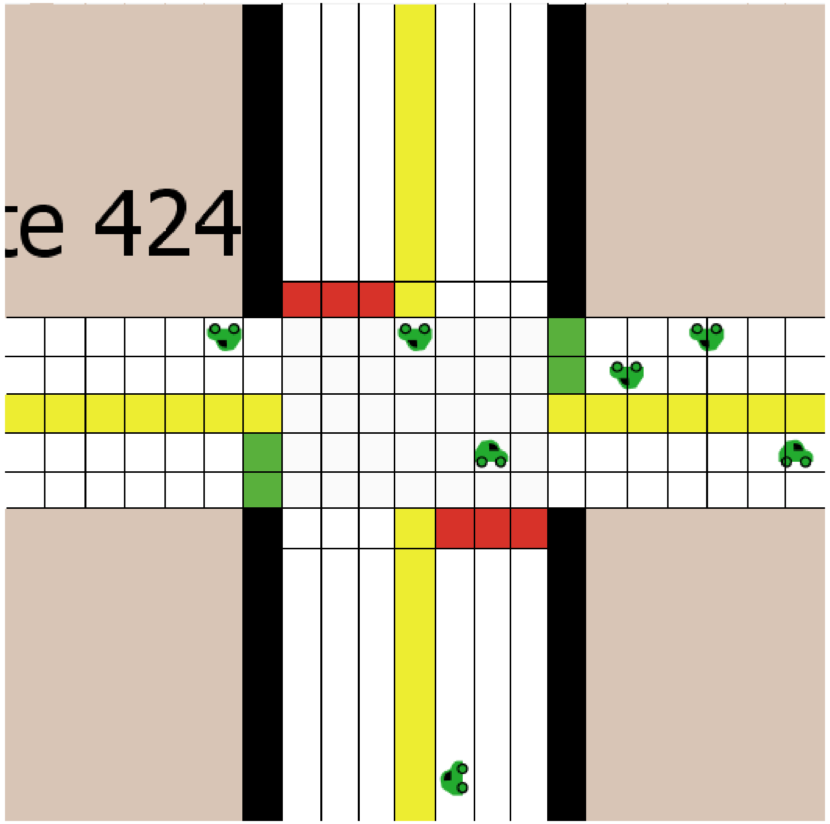
- Environment
  - Define the environment in which the agents will exist
- Agent Definition
  - Agent types and associated attributes
  - Methods by which agents respond to the environment or other agents
- Implementation
  - Develop / run the agent-based model in software tool
- Unique benefit of an ABMS
  - Enables exploration of emergent phenomena due to the complex interactions of agents



Environment replicated highway intersections

NetLogo Provides an Environment to Create the Agent Based Model and Demonstrate Algorithms

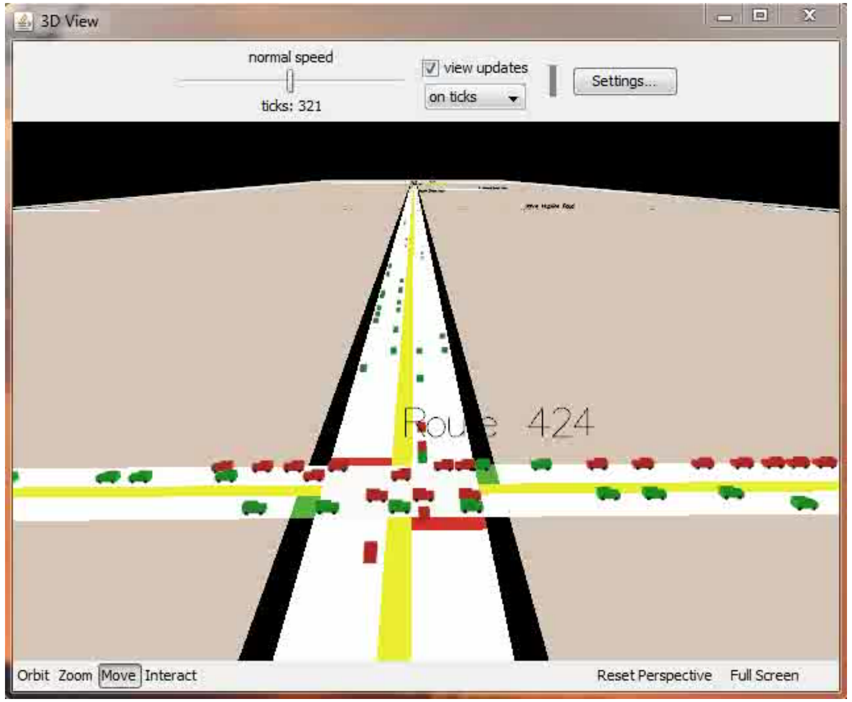
- An Agent-Based Language and Integrated Modeling Environment
- Provides behavioral simulation of actions and interactions of autonomous agents
- World = square “patch” agents
  - Roads
  - Intersections with traffic lights
- Vehicles = Turtle agents in NetLogo
  - Assigned to coordinates
  - Heading or direction of travel
  - Integrated counters
    - Age, Distance traveled, Wait times



NetLogo Model GUI for Intersection

Model Parameters Define the Operating Environment and Agent Behavior

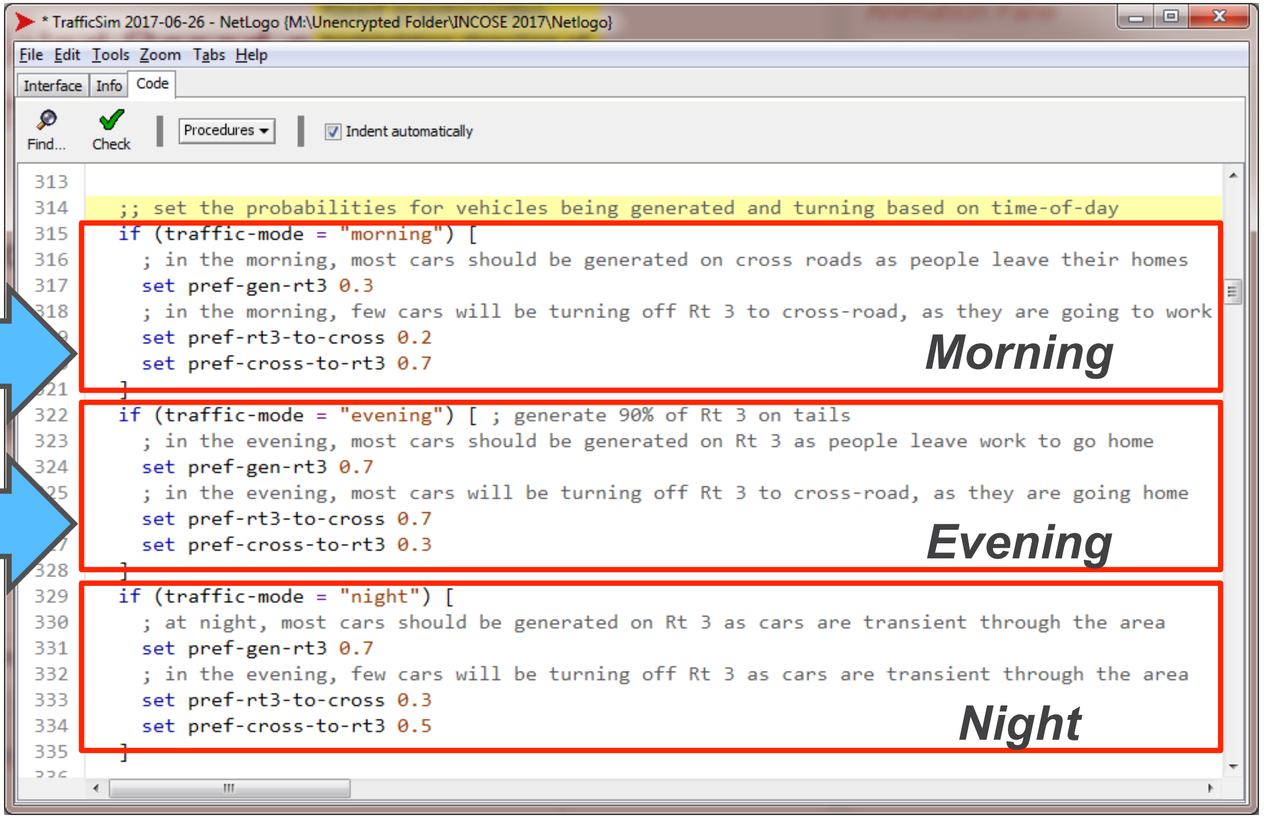
- Highway definition
  - Road lengths, traffic light locations
- Vehicle behavior
  - Speed, braking, acceleration, spacing, reaction to traffic lights
- Traffic light control
  - Defined by four control algorithms
  - Includes intelligent light sequencing



NetLogo Model 3D GUI of Intersection

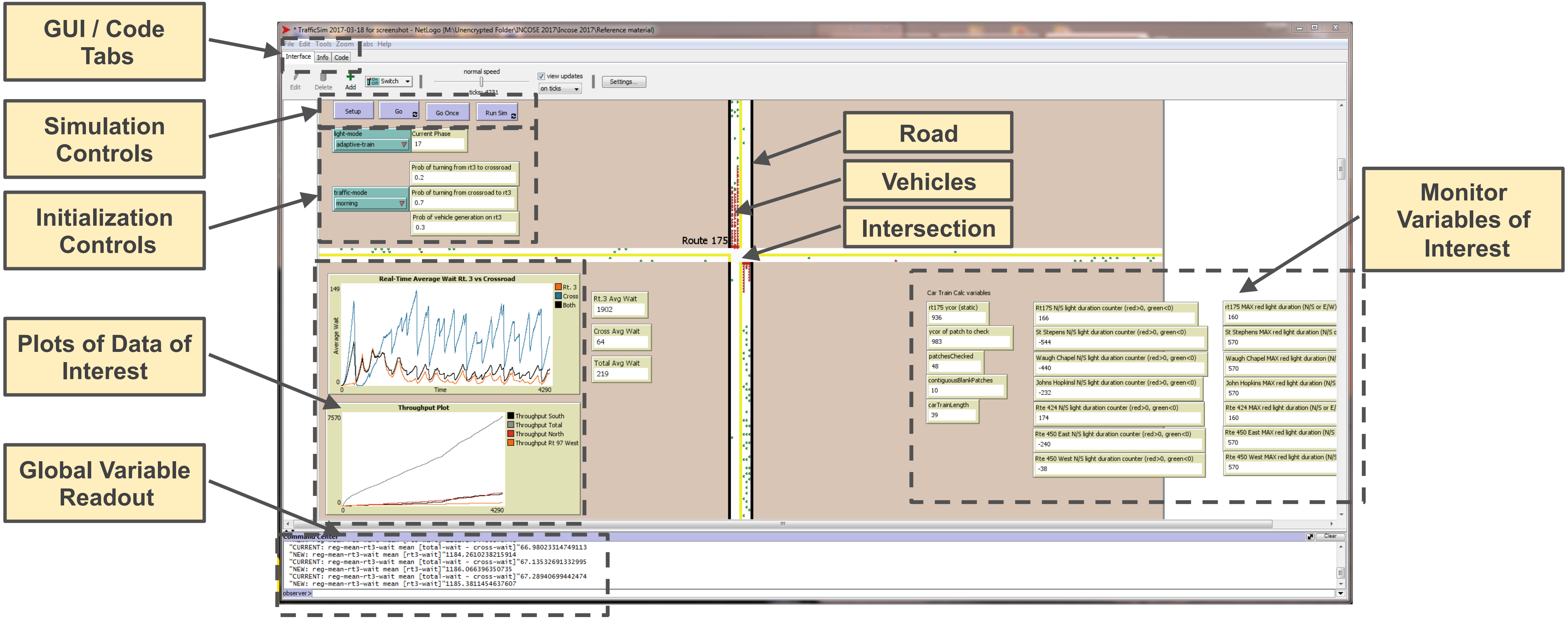
Vehicle Behavior was Modeled Based on Driver's Goals During Each Time Period

	Probability that a vehicle turns: - <u>Off a *cross-road* to get</u> onto the main route	Probability that a vehicle turns: - <u>Off of the *main route* to</u> get onto a cross-road
Morning Rush Hour	70% (most vehicles going to work)	20%
Evening Rush Hour	30%	70% (most vehicles going home)



NetLogo Code Window

NetLogo Model Execution Provides Real-Time Data Plots and Variable Monitoring



Validation of the Simulation Baseline was Based on Published Traffic Estimates

- Static and dynamic tests verify the simulator performs as expected
  - Road configuration
  - Vehicles characteristics
  - Traffic level
  - Traffic light time intervals (planned and changes)
  - Red light count

Intersection with MD 3	Year 2000 Existing Conditions				Year 2025 No-Build Conditions			
	AM Peak Hour LOS	V/C	PM Peak Hour LOS	V/C	AM Peak Hour LOS	V/C	PM Peak Hour LOS	V/C
MD 450 West (Annapolis Road)	E	0.91	F	1.06	F	1.46	F	1.58
MD 450 East (Defense Highway)	E	0.96	F	1.11	F	1.40	F	1.68
Cronson Boulevard	E	0.94	E	1.00	F	1.34	F	1.46
MD 424 (Davidsonville Road)/Conway Road	E	0.96	E	0.98	F	1.42	F	1.51
Waugh Chapel Shopping Center	B	0.64	B	0.70	F	1.06	F	1.00
Waugh Chapel Road/Reidel Road	D	0.88	D	0.88	F	1.44	F	1.39
St. Stephen's Church Road – West*	D	0.84	D	0.84	F	1.11	F	1.35
St. Stephen's Church Road – East	C	0.76	B	0.71	F	1.31	E	0.98
MD 175 (Annapolis Road) – West	E	0.95	F	1.00	F	1.27	F	1.59
MD 175/Millersville Road – East	F	1.07	E	0.95	F	1.80	F	1.30

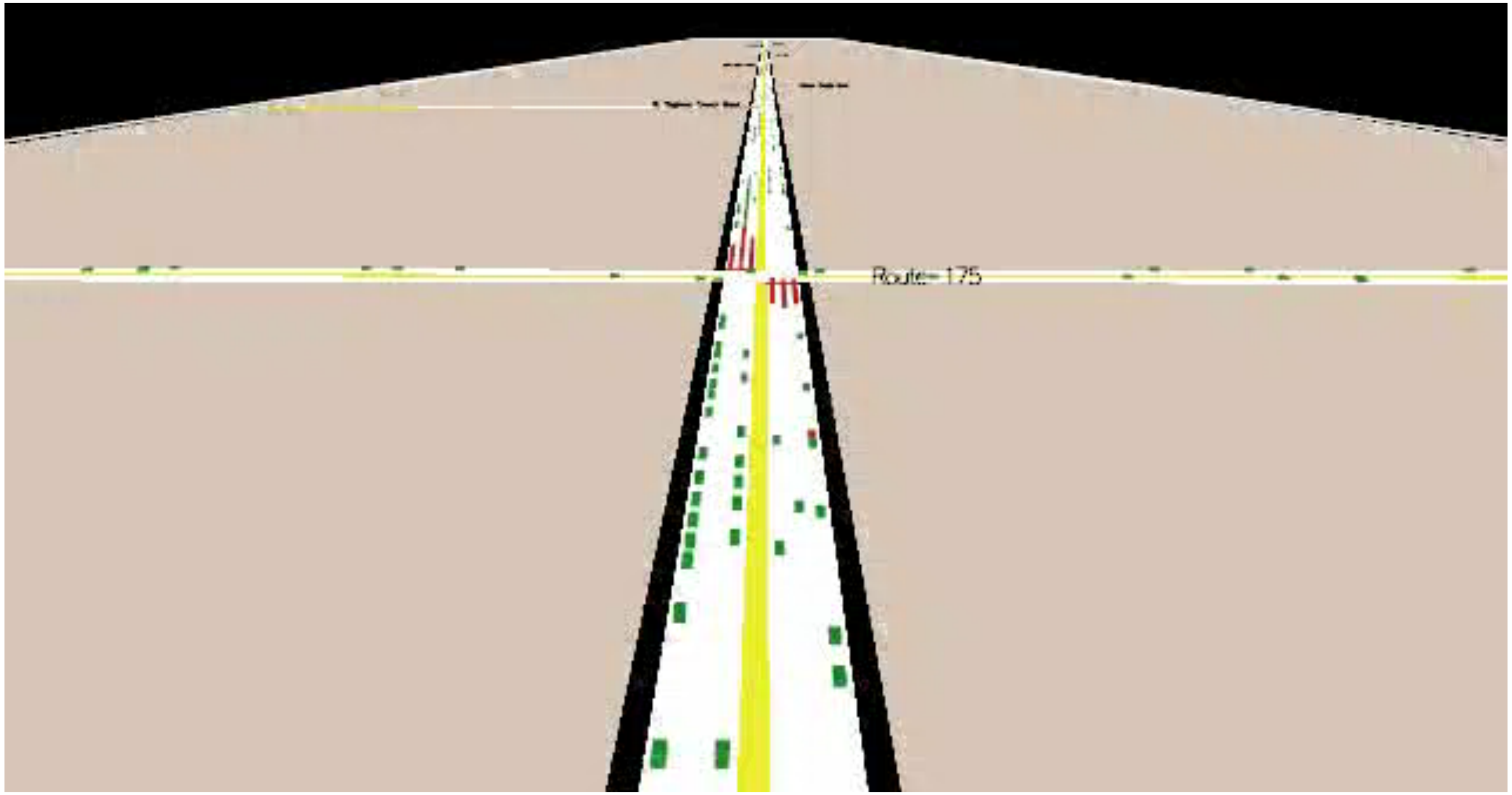
**Unsignalized Intersections*

Volume-to-Capacity Ratio

(Maryland SHA, 2004)

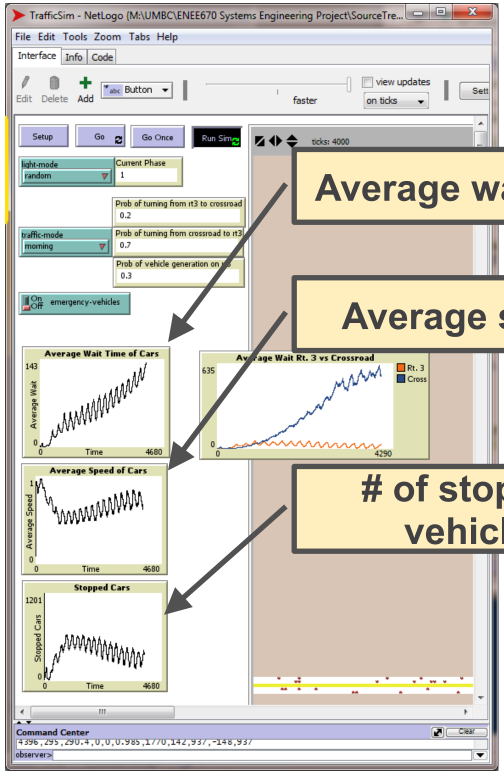
Simulation Evaluates the Effectiveness of Traffic Light Control Algorithms to Move Traffic Through Corridor

- NetLogo demo of adaptive train algorithm moving group of vehicles by sequencing series of lights
- Simulation set to run with 2,000 vehicle agents



Multiple Simulation Runs Provided Visual and Exported Data for Traffic Algorithms Evaluation

Random

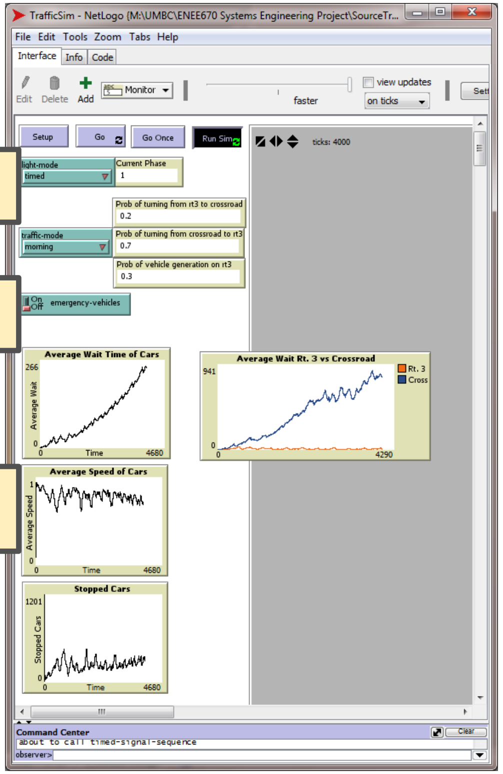


Average wait time

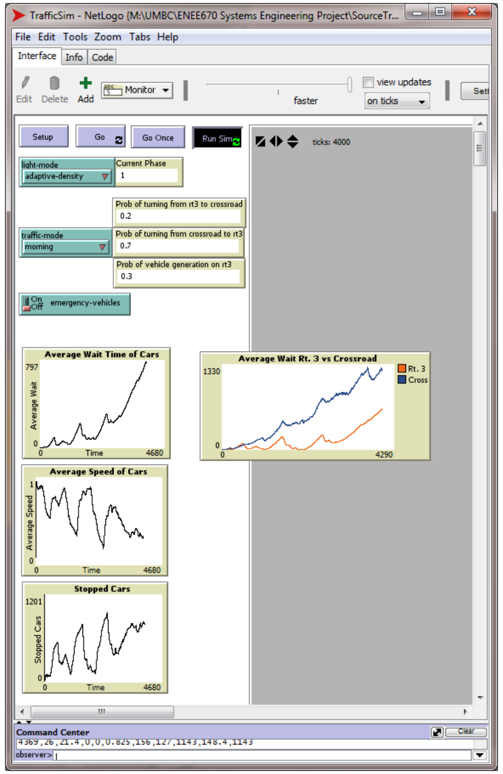
Average speed

# of stopped vehicles

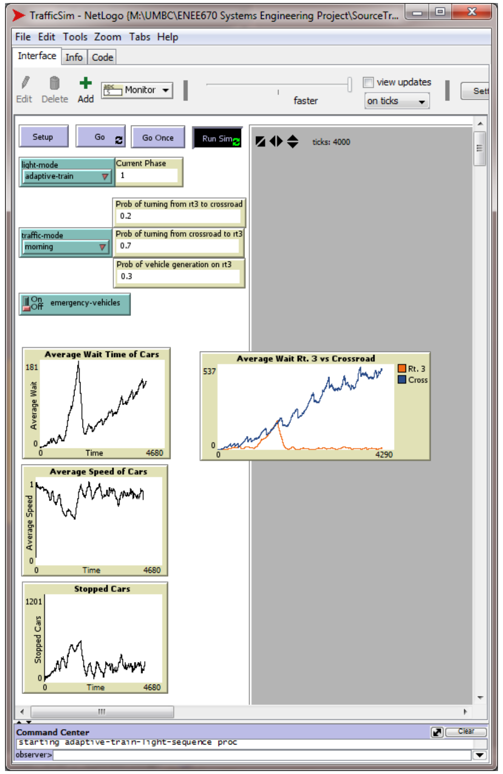
Timed



Adaptive Density



Adaptive Train



Algorithm Performance vs. MOEs Shows the Relative Performance of Each Algorithm

Measure of Effectiveness	Random	Timed	Adaptive Density	Adaptive Train
MOE1: Vehicle Throughput (Ave. of Morning & Evening) (vehicles / hour)	8,670	9,216	***9,263***	8,667
MOE2: Vehicle Wait Time on Main Route (sec.)	42	54	***18***	60
MOE3: Vehicle Wait Time On Cross Roads (sec.)	***7***	8	17	10
MOE4: Fuel Consumption (gallons of gas)	5,095	4,950	***4,536***	4,579

Lessons Learned

- **Modeling Baseline Conditions**
  - Accurately replicate and validate the real-world traffic environment to provide credibility for algorithm evaluations
- **Resolving Non-Intuitive Behavioral Interactions**
  - Random “gridlock” situation at an intersection required “clearing” code
- **Evaluation of MOEs**
  - Difficulty reaching a steady state traffic flow to evaluate MOEs
- **Use of NetLogo**
  - Integrated development environment but limited debugging capabilities

Summary of Findings

- Validating optimized system performance is difficult due to challenges in validating the underlying baseline model
- Intelligent traffic control algorithms can provide effective improvements over baseline implementations
- Additional model refinements and experimentation is required to provide comprehensive algorithm optimization/evaluation:
  - Adaptive speed controls
  - Adaptive vehicle acceleration
  - Main/cross road density comparisons
  - Red light time durations vs. vehicle densities
- NetLogo is an effective agent-based simulation tool for behavioral modeling and performance evaluations

Future Application of Results Could Provide the Implementation of an Intelligent Solution

- Project was featured in local newspaper as a cost-effective Solution to a Major Traffic Problem

Crofton-West County Gazette

A12

Opinion

A CAPITAL-GAZETTE NEWSPAPER
AMERICA'S OLDEST NEWSPAPER PUBLISHERS
FOUNDED 1727

Route 3

As a Crofton resident since 1994, I have been following the Route 3 traffic problem since the State Highway Administration published their 2002 study with an estimated $500 million of construction costs to change Route 3 into a throughway.

I am a systems engineer with 30 years' experience developing "systems" and Route 3 is a big system with serious problems. However, I am working on a cost-effective solution. I am a graduate student at UMBC where I am leading a team that is developing a simulation for an Intelligent Traffic System to more efficiently, and safely, control the traffic flow through the Route 3 corridor. The solution involves gathering vehicle position/speed data from smart phones and traffic sensors and then using this data in an algorithm to determine how to optimize the traffic flow by: posting adaptive (varying) speed limits for each highway segment, and optimally sequencing the traffic lights across all intersections.

The benefits of implementing an Intelligent Traffic System solution are:

1. It will enable cars to traverse through the entire corridor with a minimal amount of stopping.
2. The system will adapt to any level of traffic, now or in the future.
3. The impact to the existing infrastructure is minimal.
4. The implementation cost is a fraction of the cost for re-constructing the corridor roadway.

At the completion of our project, I plan on sharing our proposed solution and analysis with the SHA for their consideration as a viable and affordable option for resolving the traffic problem.

JOHN PANEK
Crofton

27th annual INCOSE international symposium

Adelaide, Australia

July 15 - 20, 2017

ENGINEERS AUSTRALIA

SESA

www.incose.org/symp2017