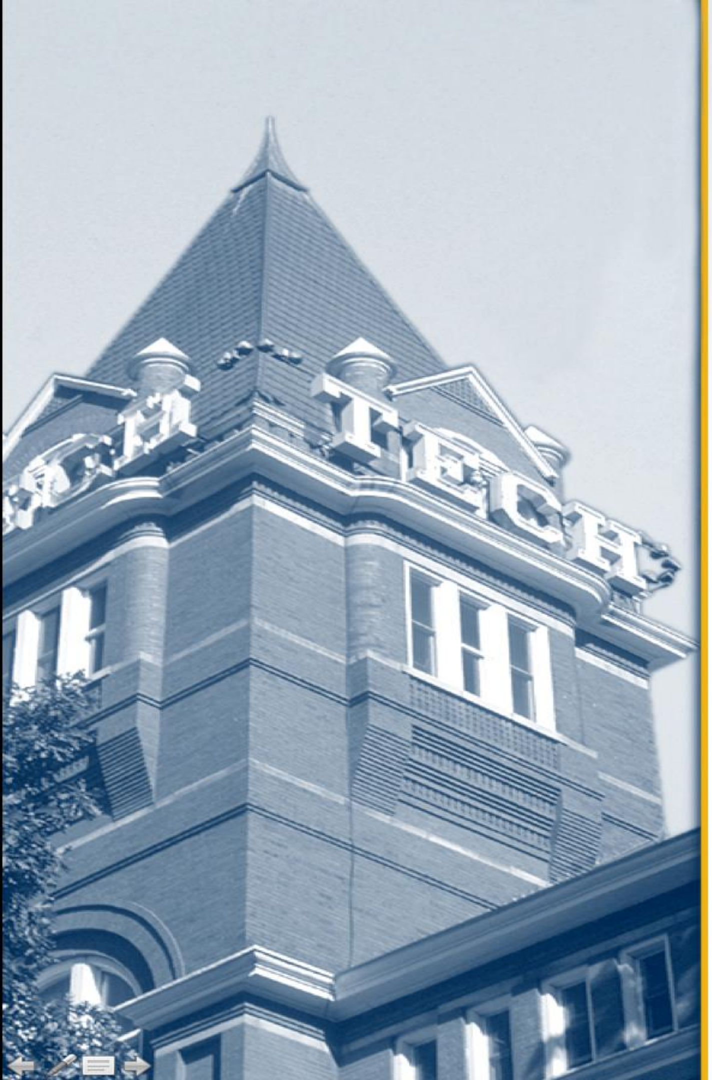

Simulation of Cooperative Vehicle-Highway Automation (CVHA) Behavior on Freeways

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March 2015

Research Objectives

- To investigate the benefits and operational issues of CVHA/Autonomous technology using microscopic simulation (VISSIM); specifically modeling:
  - Technology under different traffic conditions and operational parameters (i.e. gap time and headway), and
  - **The interactions between equipped and non-equipped vehicles**.
- The findings of this research are intended to provide guidance and recommendations to State DOTs and other agencies regarding:
  - The expected impacts of Technology on traffic flow and operations,
  - Regulations on the use of the technology, and
  - Further research needs on autonomous and semi-autonomous technology.

Assistive/Autonomous Driving Technologies

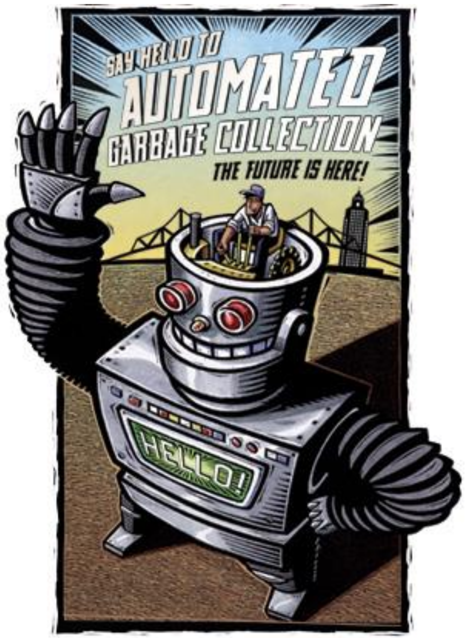
Level	Type	Definition
Level 0	No-Automation	driver is in complete and sole control
Level 1	Function-specific Automation	driver has overall control, but can choose to cede limited authority; automation function works independently from one another
Level 2	Combined Function Automation	automation of at least two primary control functions designed to work in unison
Level 3	Limited Self-Driving Automation	driver can cede full control of all safety-critical functions under certain conditions; but driver expected to be available for occasional control
Level 4	Full Self-Driving Automation	vehicle performs all safety-critical driving functions and monitor roadway conditions for an entire trip

Word Choice

***Autonomous* – acting independently**

***Automated* – predetermined series of operations**

***Driverless* – vehicle takes on all driving tasks**



http://brgov.com/dept/dpw/solidwaste/images/06automated.jpg

Assumptions

"Nice, but as long as there are readers there will be scrolls."

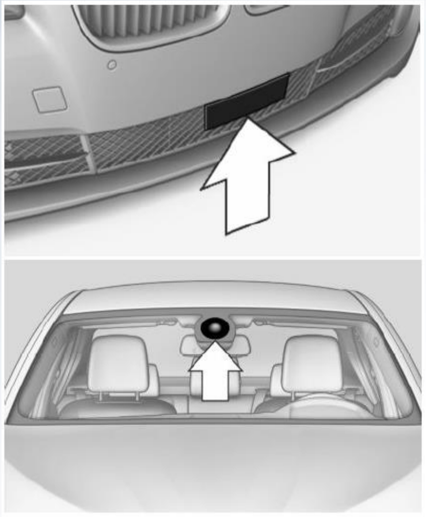
http://37.media.tumblr.com/tumblr_m3gsrzgDiG1qav5oho1_1280.png

Mixed Fleet

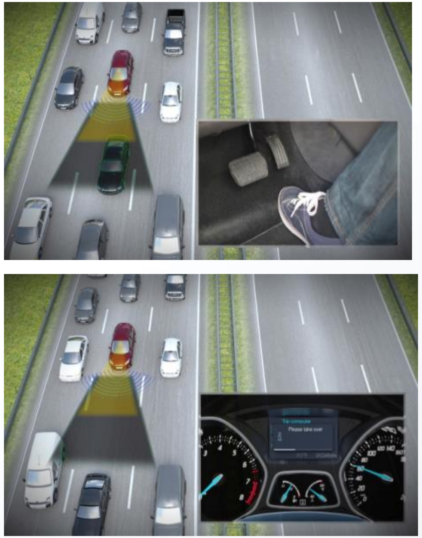
I believe that for (at least) decades after the introduction of the of commercially available driverless vehicle that both human driven and driverless vehicles will be allowed on most facilities and have significant interaction.

http://www.collectivedata.com/images/fleetOfCars.jpg

Existing Systems



BMW Radar Sensors (Top) & Rearview Mirror Mounted Camera (Bottom) [5]



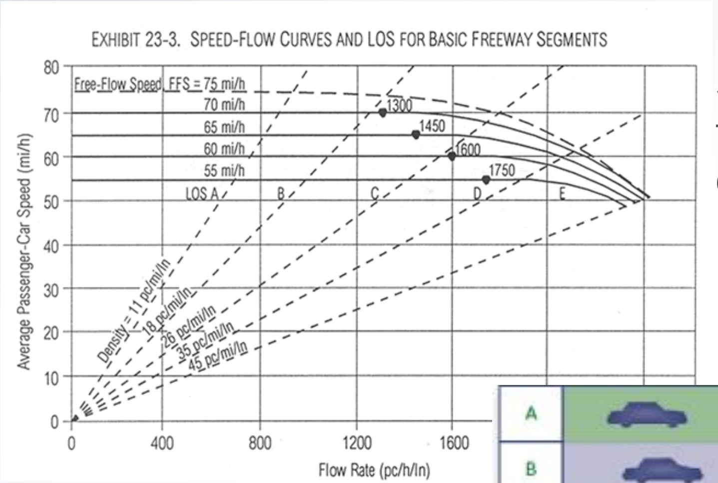
Autonomous Driving (Top), CVHA System Prompts Driver to Take Control (Right) [7]

Previous Research

- Adaptive cruise control (ACC) has been found to increase speeds and eliminate congestion even for a 20% penetration rate [2].
- V2V hazard alert systems have the potential to mitigate traffic congestion with higher penetration rates, particularly if it can provide lane-specific information about incidents [3].
- Cooperative ACC is able to increase capacity at moderate to high market penetration rates [4].
- A research study on a congestion assistant prototype has concluded that [6]:
  - Participants generally did not appreciate automatic actions from vehicle, except during congested conditions.
  - All variants of the system resulted in less congestion and higher congestion outflows compared to reference situation.
  - Average delay time is decreased by 30% with a penetration rate of 10% and up to 60% with a penetration rate of 50%.
  - Some variants of the system led to higher percentages of hard-braking due to a smaller minimum headway.

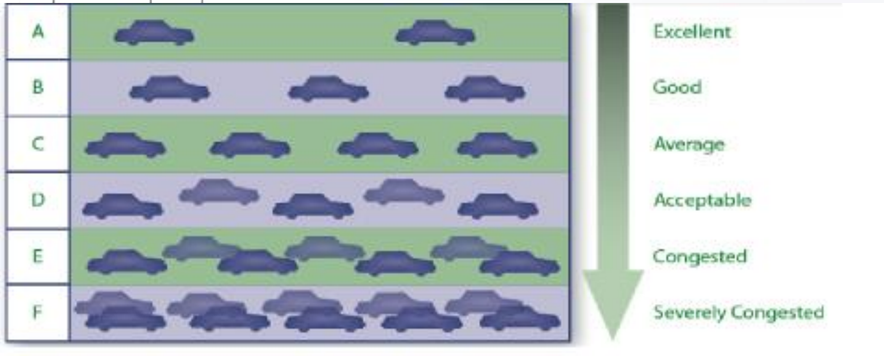
- CVHA has also been claimed by manufacturers to provide congestion benefits. For example, Ford Motor Company claims that "individual simulation studies have found that where 25% of vehicles on a stretch of road are equipped to automatically follow traffic ahead, journey times can be reduced by 37.5% and delays by 20%."

Capacity: Maximum Sustainable Flow



Speed Flow Density Curve from the Highway Capacity and Quality of Service Manual

http://www.ops.fhwa.dot.gov/publications/fhwahop09017/008_section_2.htm



http://www.clarksvillesmartgrowth.com/Sec3-TransportationAnalysis.htm

A few capacity factors:

http://www.motorward.com/wp-content/images/2012/01/highway-traffic.jpg

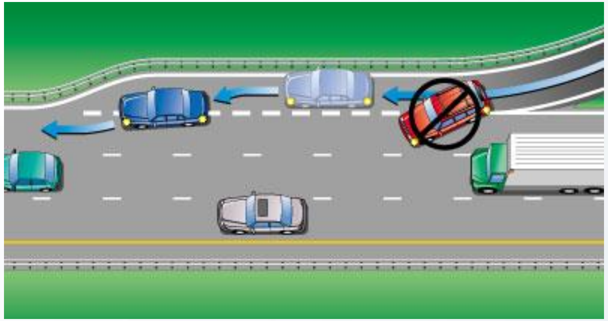
Is there dedicated infrastructure?

What following distance is allowed?

Willingness of drivers in traditional manned vehicles to interact driverless vehicles?

Are traffic laws strictly enforced?

How aggressive are drivers in the non-driverless vehicles?



http://drivingschool.ca/drivereducation/images/2b8_1.jpg

Aggressiveness

Photo credit: Chris Toth

Simulation

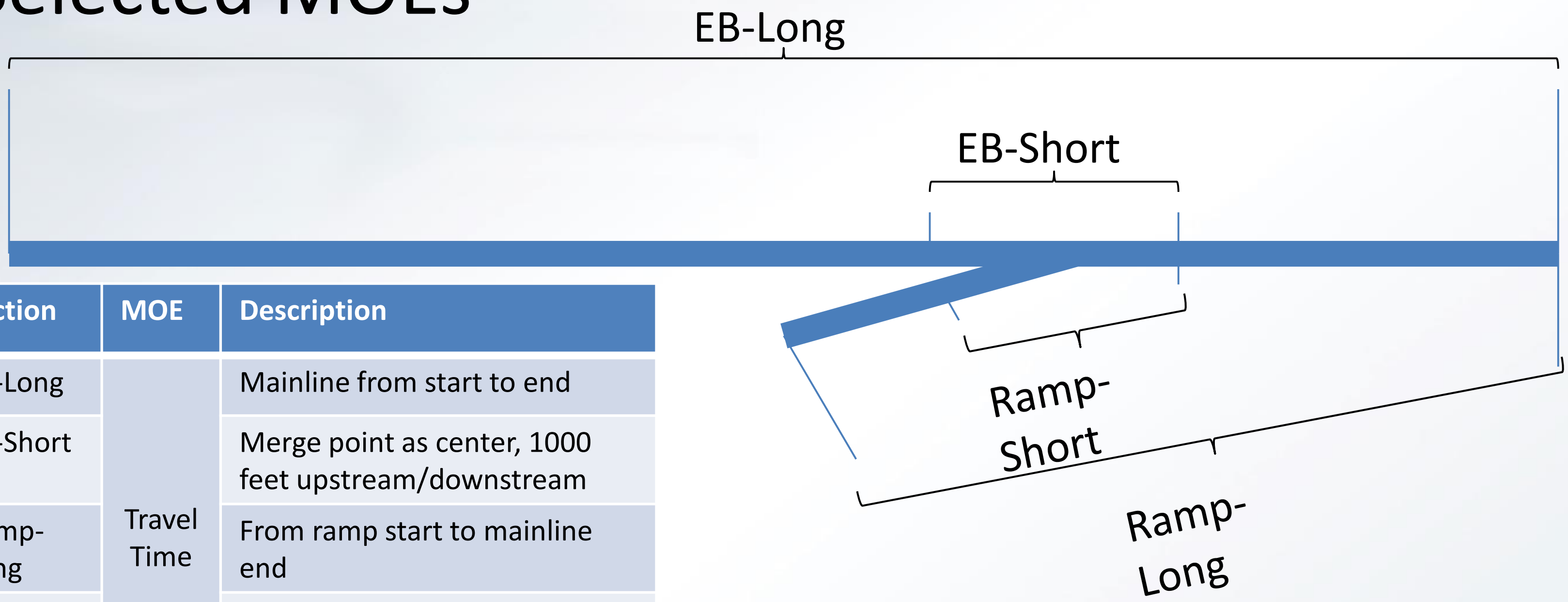
- Off-The Shelf (VISSIM) vs Custom
- VISSIM
  - Parameter sensitivity
  - COM
  - EDM

Simulation – What Parameters Matter

- VISSIM Parameter sensitivity
  - A Monte Carlo experiment
  - Influence on travel time and capacity
  - 29 driving parameters
  - Randomly generated1000 parameter sets simulated in VISSIM.
  - 12.5-mile, three-lane freeway segment with an on-ramp merging at approximately mile 9.5. Each simulation runs for a total of 8 simulated hours.

VISSIM Parameter Studies

- Selected MOEs



Section	MOE	Description
EB-Long	Travel Time	Mainline from start to end
EB-Short		Merge point as center, 1000 feet upstream/downstream
Ramp-Long		From ramp start to mainline end
Ramp-short		Merge point as center, 1000 feet upstream/downstream

VISSIM Parameter Studies

- Parameter Elimination Procedure
  - Generate 1,000 sets of random parameters as input;
  - Run simulation for 1000 runs and record travel time, delay and speed-flow as selected;
  - For each MOE, draw the scatter plot with respect to all parameters and perform linear regression on mean, 5% percentile and 95% percentile;
  - Compute Effect on the Mean (EOM) = Slope of linear regression*parameter range;
  - Eliminate those parameters with three or more EOMs less than 5%, while examine their variability's change manually;
  - Eliminate no more the 25% of parameters, iterate process.

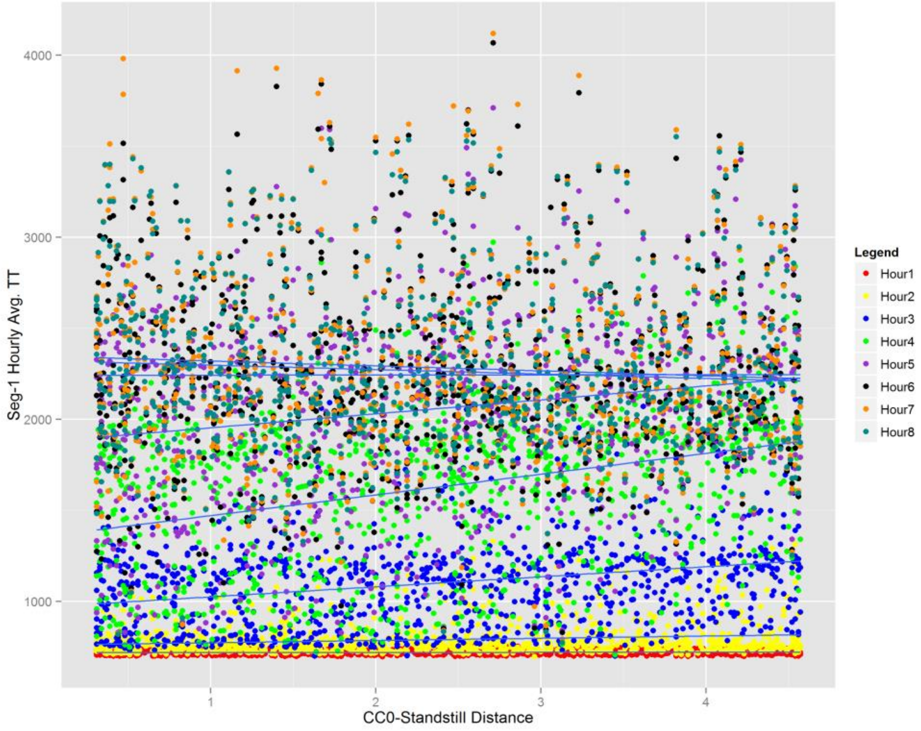
Full parameter list

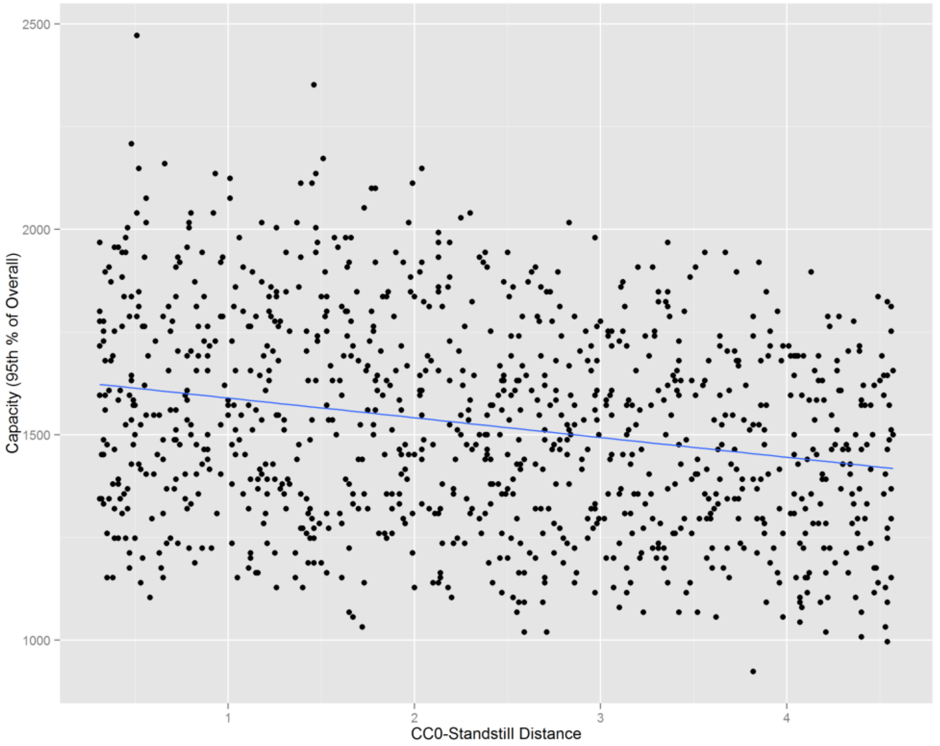
1	Desired speed distribution
2	Look Ahead Distance Min. (ft)
3	Look Ahead Distance Max. (ft)
4	Number of Observed Vehicles
5	Look Back Distance Min. (ft)
6	Look Back Distance Max. (ft)
7	CC0 standstill distance (ft)
8	CC1 headway time (s)
9	CC2 following variation (ft)
10	CC3 threshold for entering 'following'
11	CC4 negative following threshold
12	CC5 positive following threshold
13	CC6 speed dependency of oscillation
14	CC7 oscillation acceleration (ft/s^2)
15	CC8 standstill acceleration (ft/s^2)
16	CC9 acceleration at 80 km/hr (ft/s^2)
17	Maximum deceleration (own)
18	Maximum deceleration (trailing)
19	Accepted deceleration (own)
20	Accepted deceleration (trailing)
21	Reduction rate (as ft per 1 ft/s2) (own)
22	Reduction rate (as ft per 1 ft/s2) (trailing)
23	Waiting time before diffusion
24	Minimum headway (front/rear)
25	Safety distance reduction factor
26	Maximum deceleration for cooperative braking
27	Emergency stop distance
28	Lane change distance
29	Random seed number

Current List

- Currently, the following variables show some effect on mainline travel time and capacity (pending final results of experiment):
  - CC0 - Standstill Distance
  - CC1 - Headway Time
  - CC2 - Following Variation
  - CC4/CC5 - Negative/Positive ‘Following’ Threshold
  - Safety Distance Reduction Factor
  - Max. Deceleration for Cooperative Braking
  - Lane Change Distance

Influence of Standstill Distance on Mainline Travel Times (Left) and 95th Percentile Capacities (Right)





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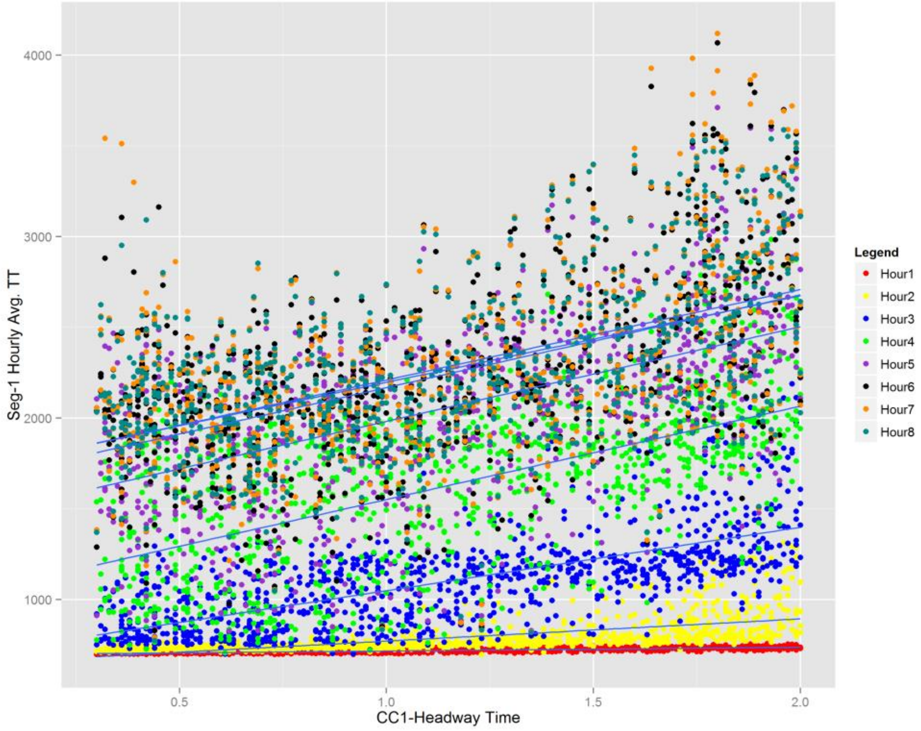
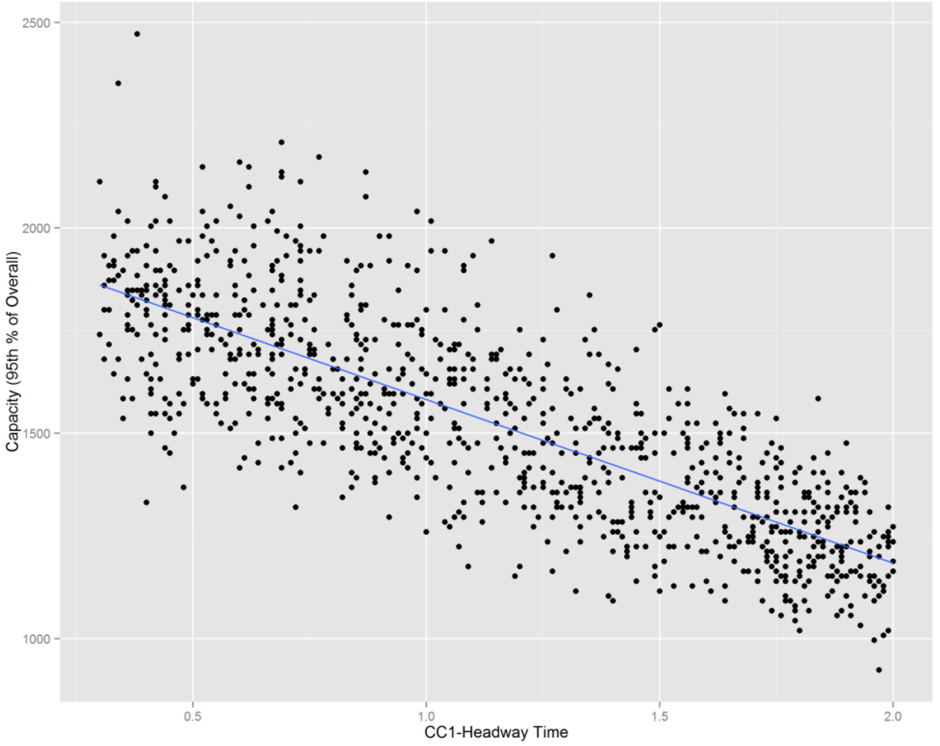
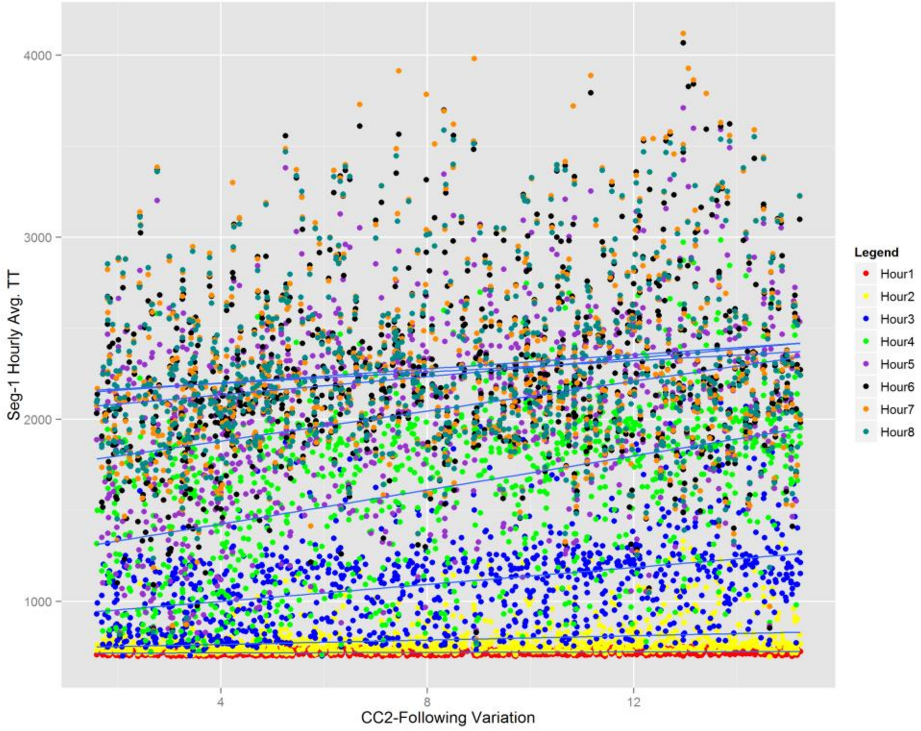
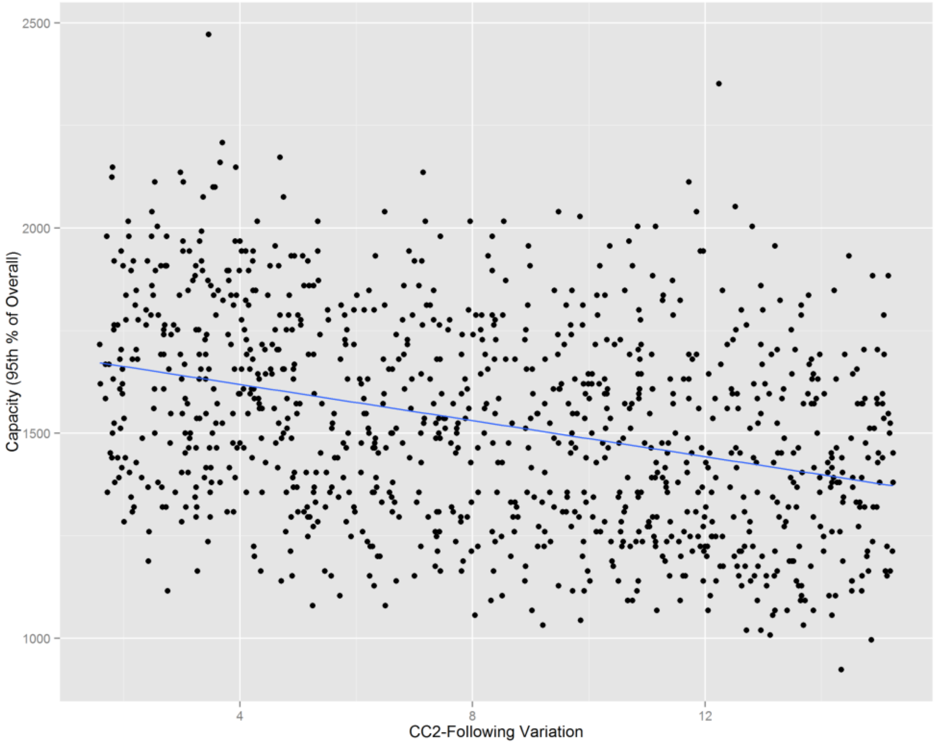
Influence of Headway Time on Mainline Travel Times (Left) and 95th Percentile Capacities (Right)





Influence of Following Variation on Mainline Travel Times (Left) and 95th Percentile Capacities (Right)





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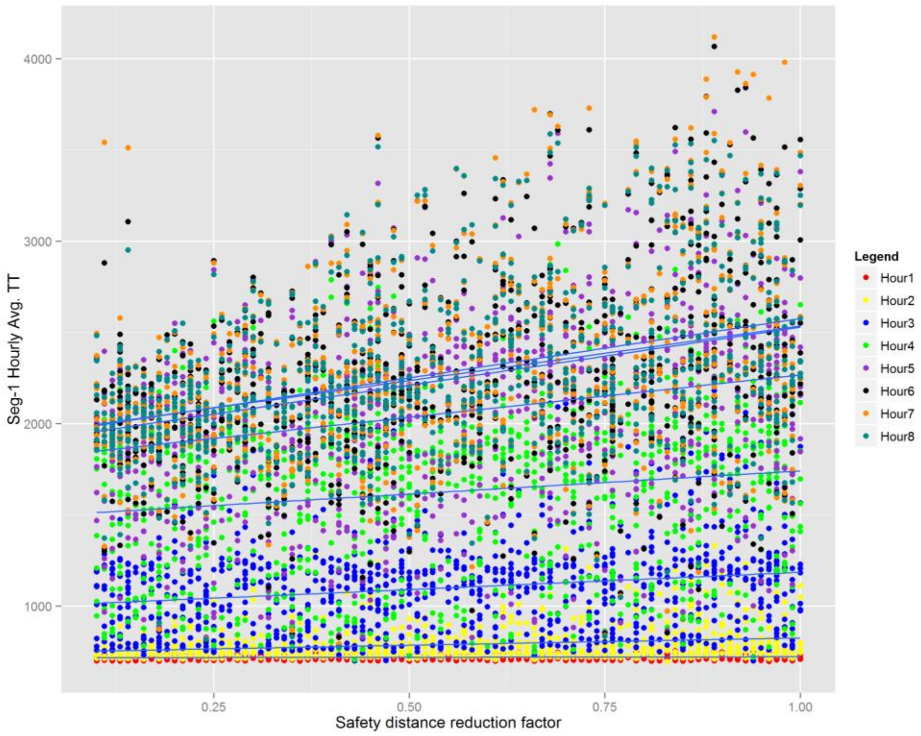
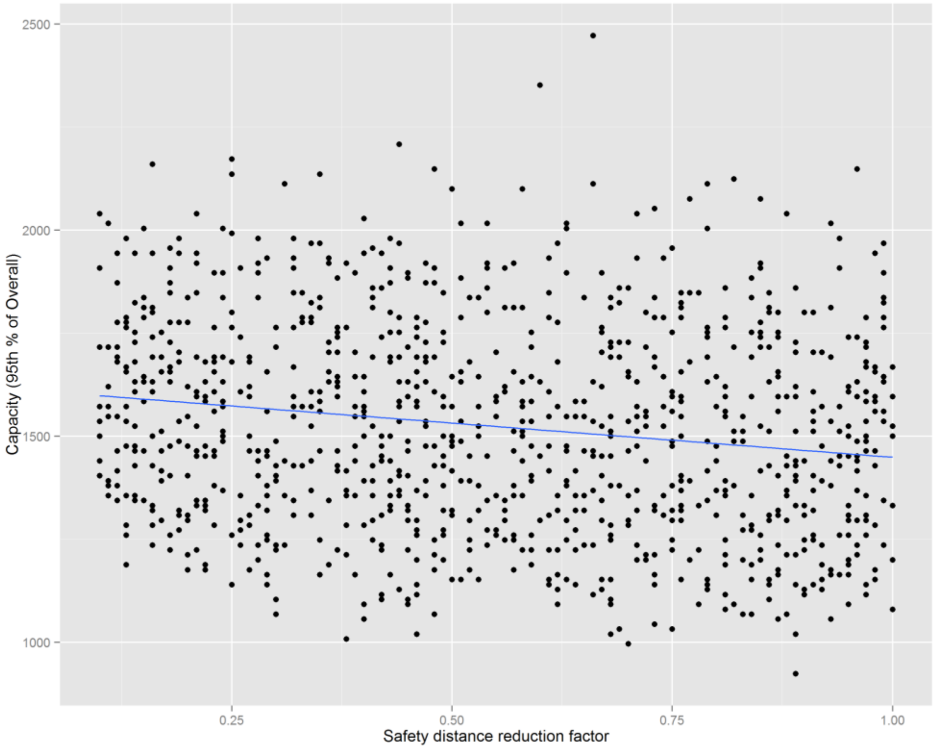
Influence of Safety Distance Reduction Factor on Mainline Travel Times (Left) and 95th Percentile Capacities (Right)





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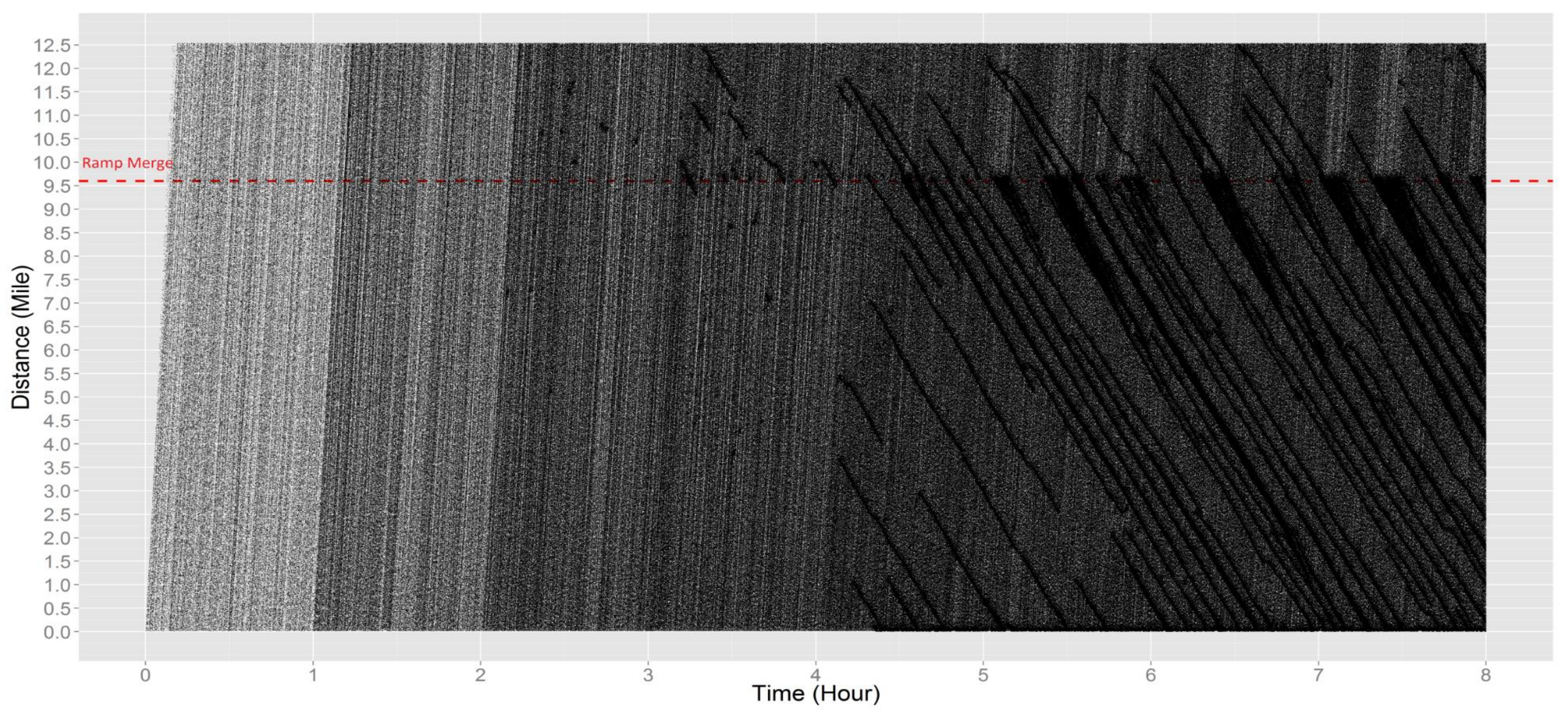
Time Space Diagram of Simulated Mainline Vehicles



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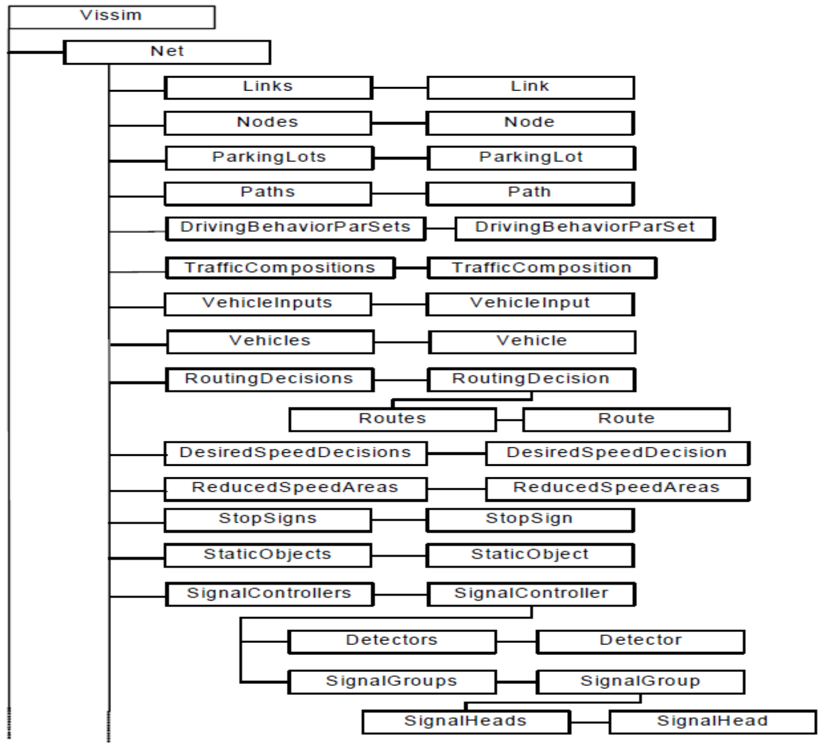
VISSIM COM Interface

- VISSIM offers Component Object Model (COM)
- COM interface defines a hierarchy model of objects, in which the functions and parameters of the simulator may be read, and in some cases manipulated by programming scripts dynamically.
- COM interface provides access to model data and objects during simulation, and allows VISSIM to work as automation server and to export objects and data.

VISSIM COM Interface

COM interface Architecture



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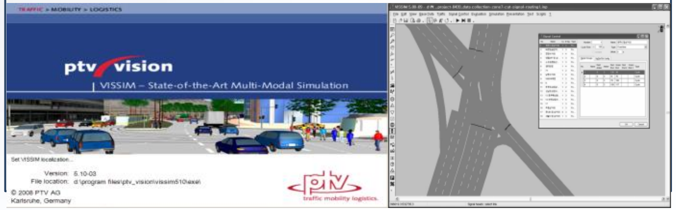
Simulation Analysis Tools

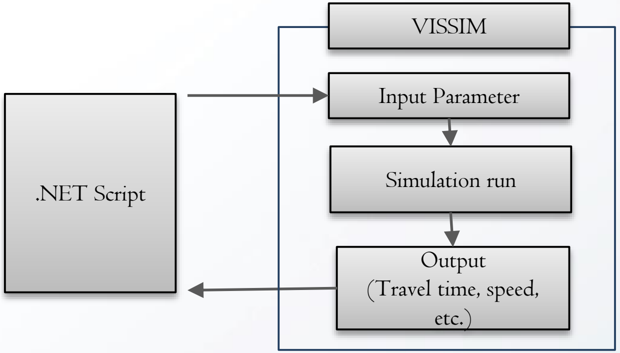
VISSIM

- Microscopic traffic simulator by PTV
- Representation of driver behavior including car-following and lane-changing
- Public transportation, pedestrian, bicycle etc.
- Evaluation of various traffic management strategies: ITS evaluation, work-zone, freeway toll plaza etc.

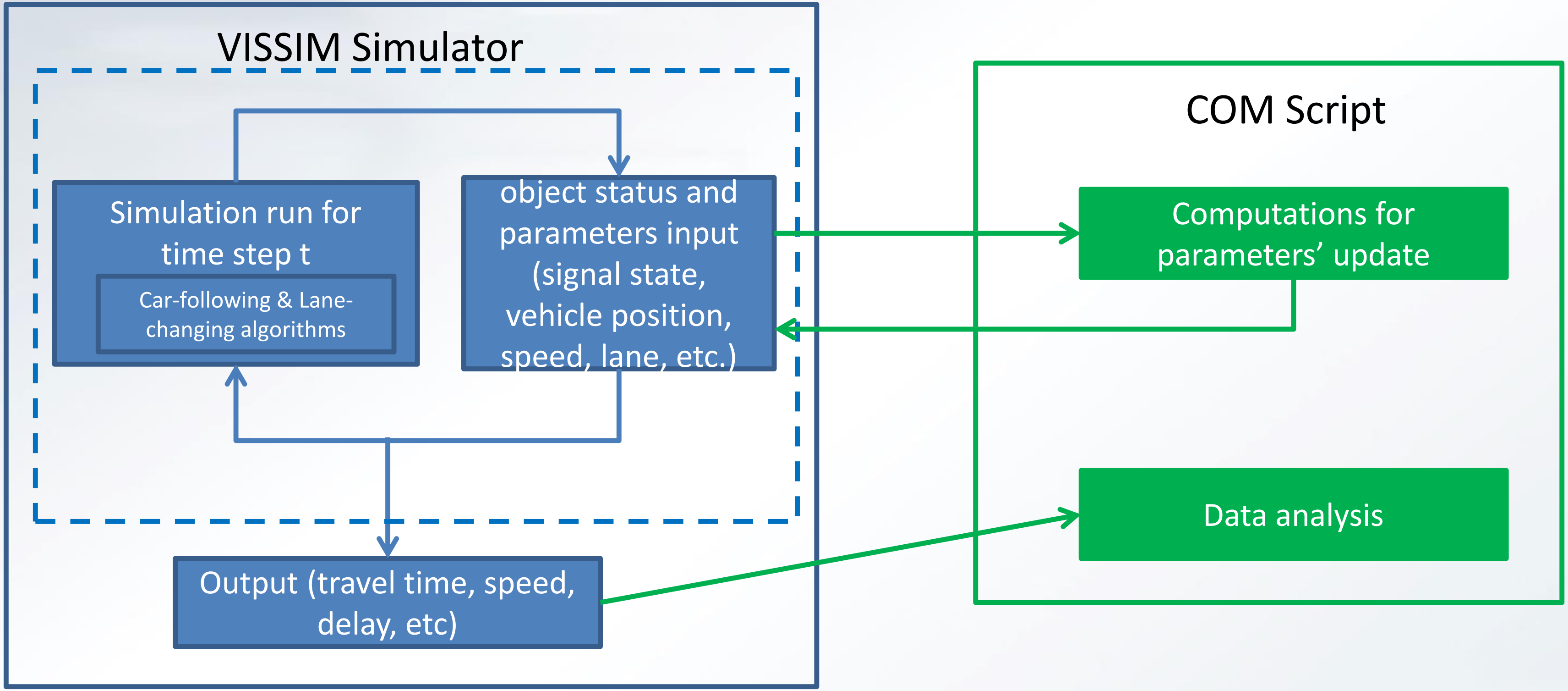


VISSIM COM-Interface

- Control input parameter or receive output at every simulation time-step by external API based on .NET programming



Interactions between COM and VISSIM Simulator



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VISSIM COM Interface

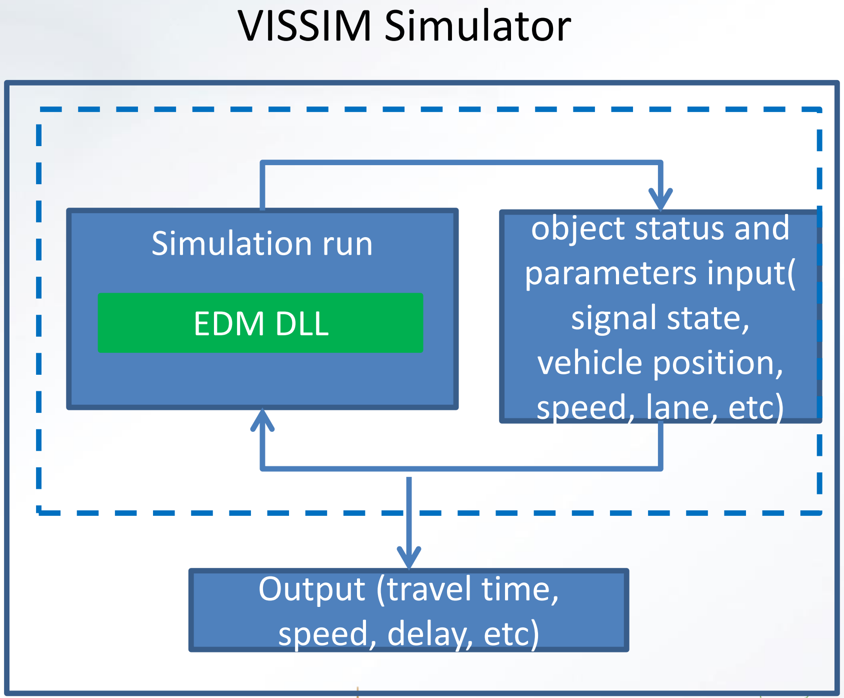
- COM capabilities
  - Generate traffic on desired lane at desired location (more specific and tractable traffic input);
  - Dynamically modify the properties of traffic objects, e.g. vehicle's type, length, color, lane, desired speed;
  - Access arbitrary vehicle by ID (e.g. V2V communication may be mimicked);
- COM Limitations
  - Not all parameters are writable (e.g., acceleration), so it's difficult to gain full control of a vehicle's movement;
  - No trivial way to search for adjacent vehicles, makes it less efficient to find target vehicle for decision-making;
  - Difficult to overwrite the default lane-changing logic;
  - Runtime efficiency issue.

External Driver Model (EDM)

- Introduction
  - External Driver Model DLL interface of VISSIM is an Application Program Interface (API) provided to replace the internal driving behavior with a fully user-defined model.
  - EDM is applied to specific vehicle type separately.
  - The car-following behavior and lane-changing behavior may be fully controlled by EDM’s algorithm. VISSIM is only responsible for passing parameter values to EDM module and retrieving them back to VISSIM simulation.

EDM DLL Interface

- Interactions between EDM and VISSIM Simulator



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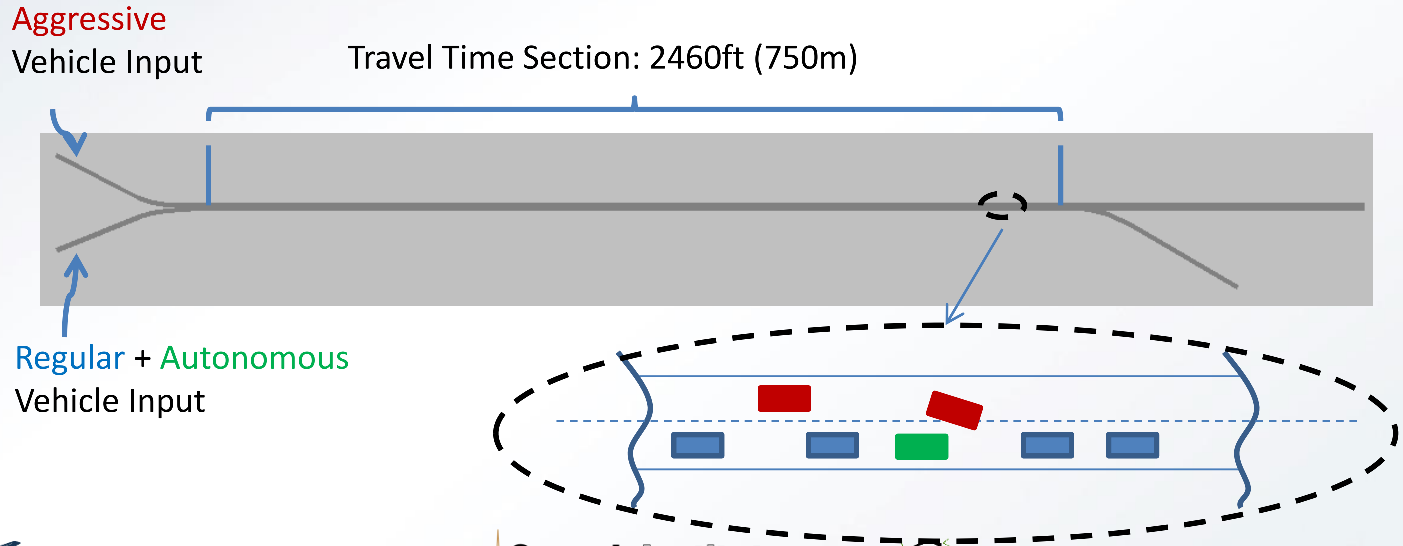
External Driver Model (EDM)

- EDM Capabilities
  - Fully control the movement of a vehicle, i.e. car-following and lane-changing algorithms;
  - Easily communicate with adjacent vehicles with predefined function;
- EDM Limitations
  - Only have access to vehicles within the assigned type, may not track the others by ID;
  - Not network-specific, have no information regarding links, routes, vehicle types of the other vehicles;
  - Information on adjacent vehicles are limited, can read no more than 2 vehicles upstream/downstream;
  - May only dynamically modify subject vehicle

External Driver Model (EDM)

- Run Configuration
  - Duration: Simulation Time = 1 hours
  - Section Length: 2-lane Mainline = 3280ft (starting from merge point to the end of mainline)
  - Output: Travel Time data, Delay Time data, Trajectory plot

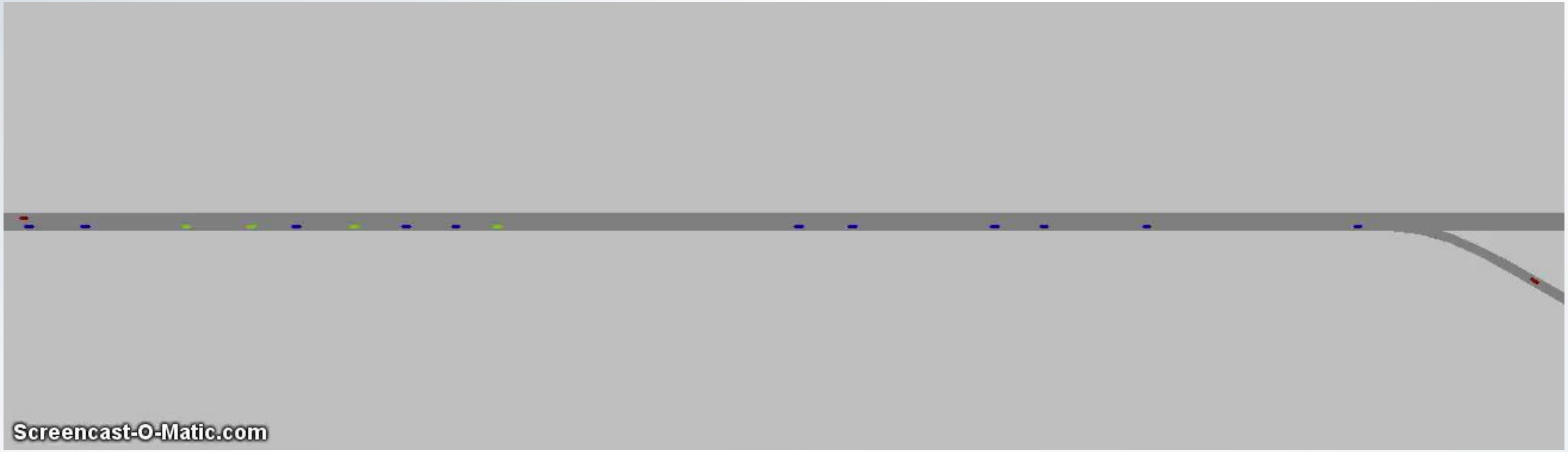


Combinations of COM and EDM

- COM is responsible for tracking target vehicles, modifying vehicle attributes and making lane-change decisions while EDM is responsible for vehicle's movement.

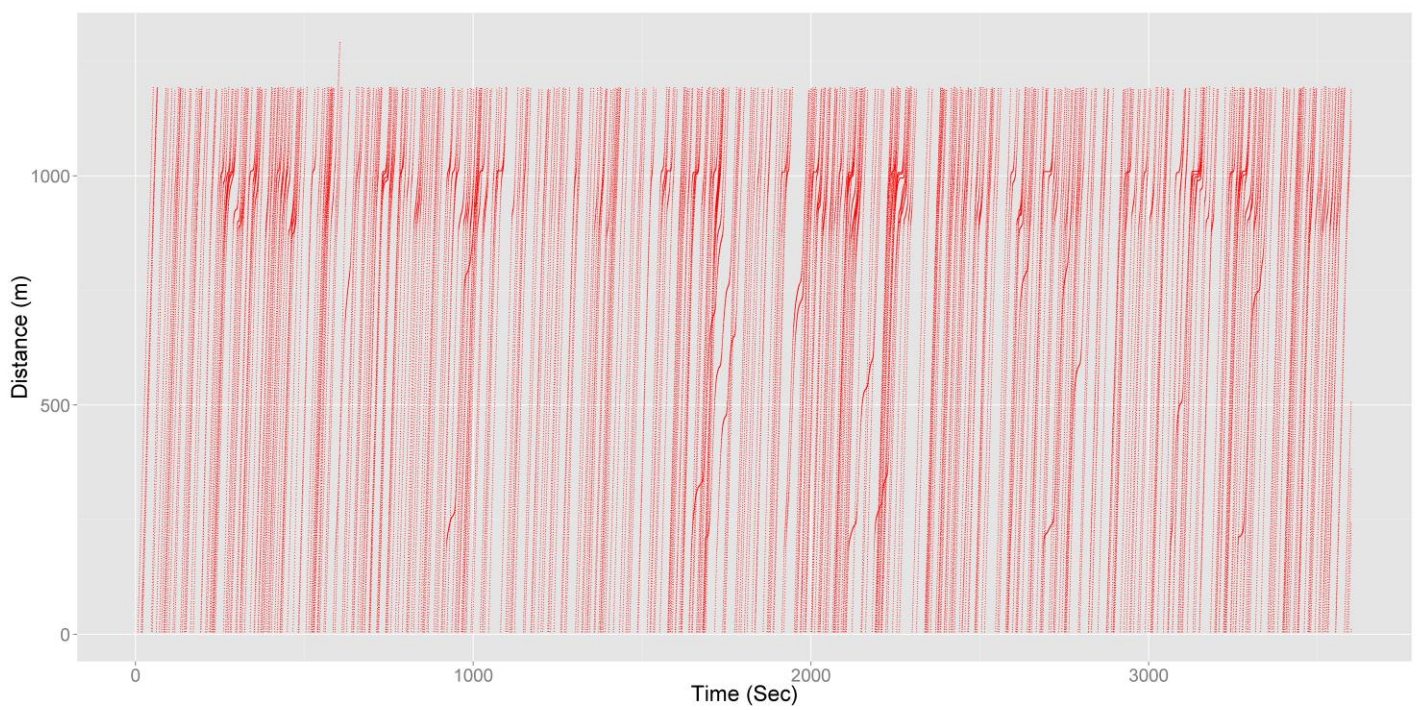
- A concern of combination is efficiency issue.

Current Example



Right Lane – 200 vph - Aggressive
Left Lane – 1950 vph – 20% Autonomous, 80% Default

Trajectories Aggressive Drivers



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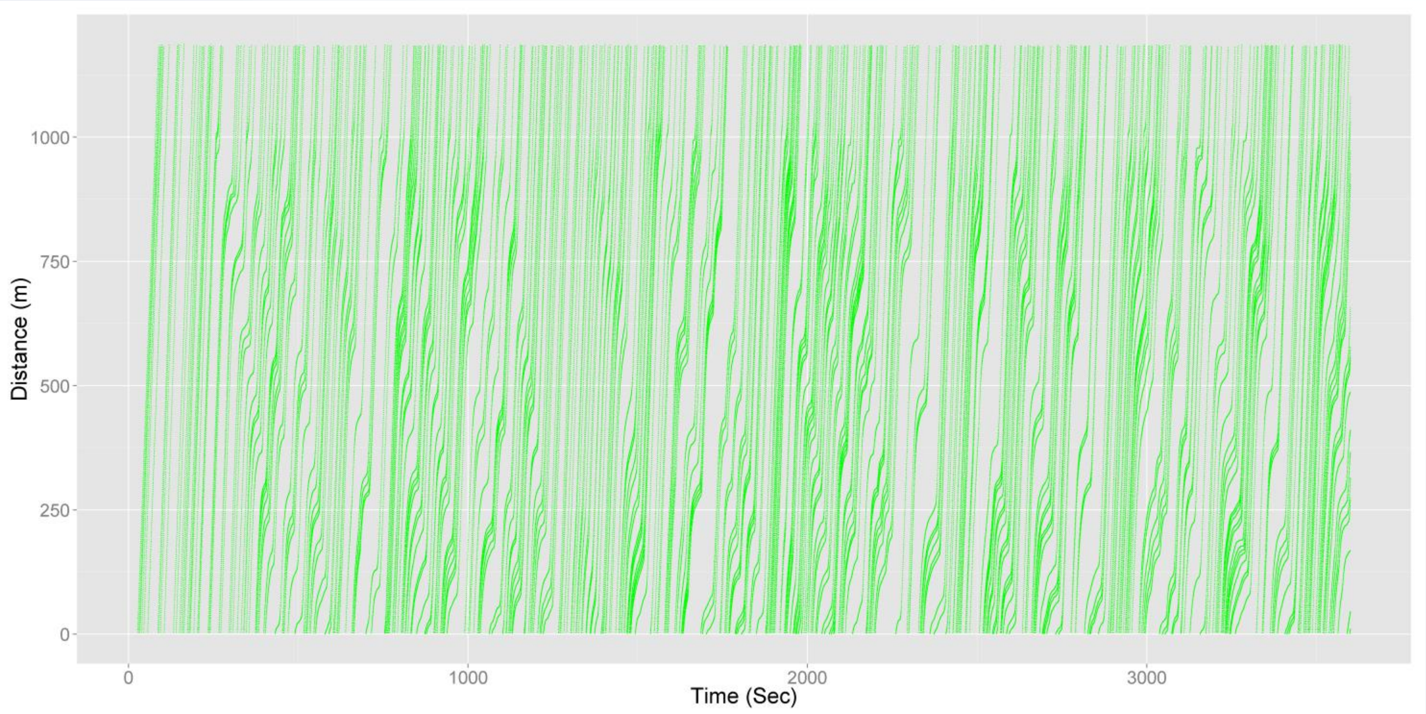
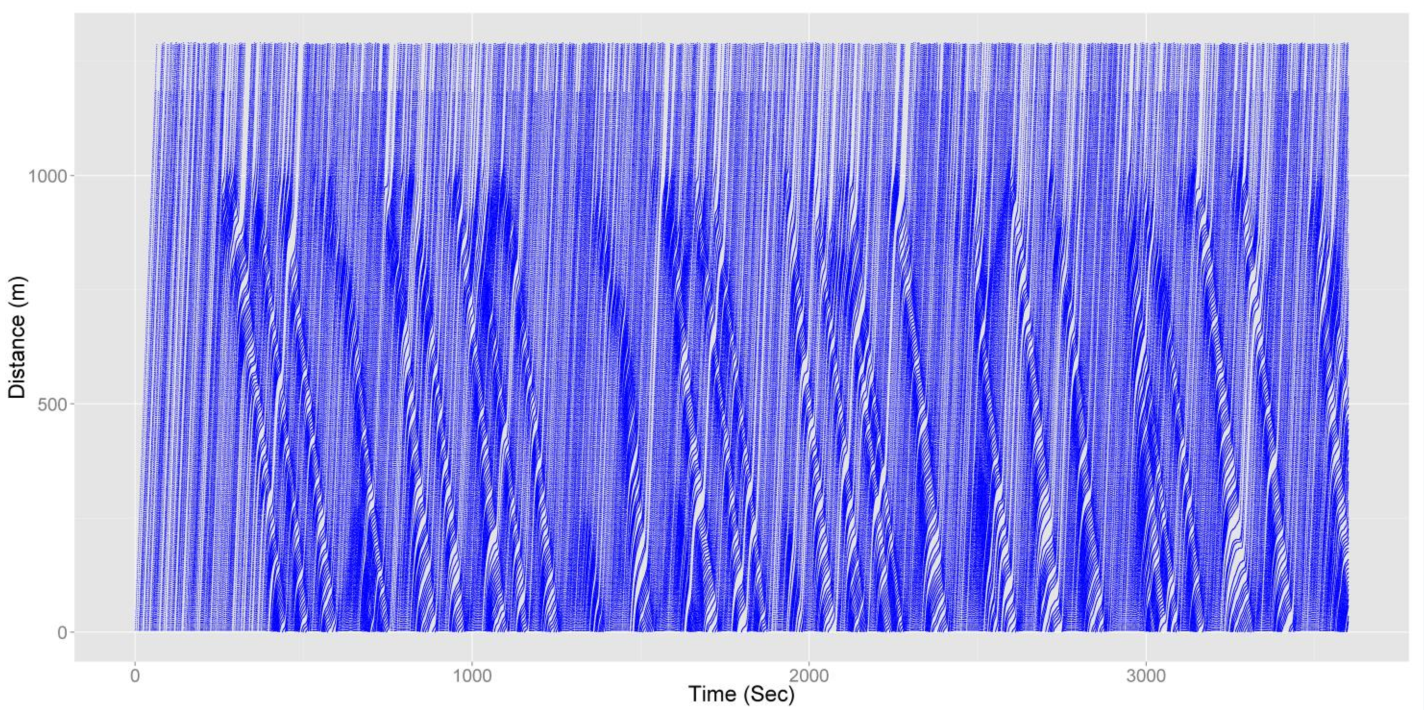
Trajectories Autonomous



Trajectories Other Right Lane



Conclusion – Next Steps

- COM and EDM interface
- Scenario development
- Validation?
- Assumptions, Assumptions, Assumptions

- ***References***

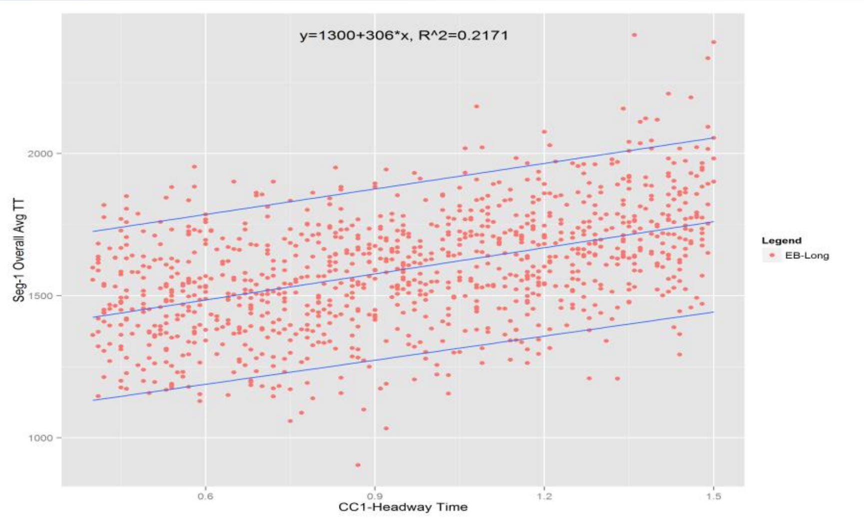
1. Shladover 2008, *Final Report No. CA04-0494*
2. Elefteriadou et al. 2011, *Final Report CMS Project 2009-006*
3. Yeo et al. 2010, *TRR: Journal of TRB* No. 2189: 68-77
4. Shladover et al. 2012, *TRR: Journal of TRB* No. 2324: 63-7
5. The BMW 5 Series Sedan. Owner's Manual. Online Ed. VI/13
6. Van Driel 2007, *PhD Diss.* U of Twente, NL
7. Ford Motor Company. *Traffic Jam Assist.*

Other Potentially usable Slides

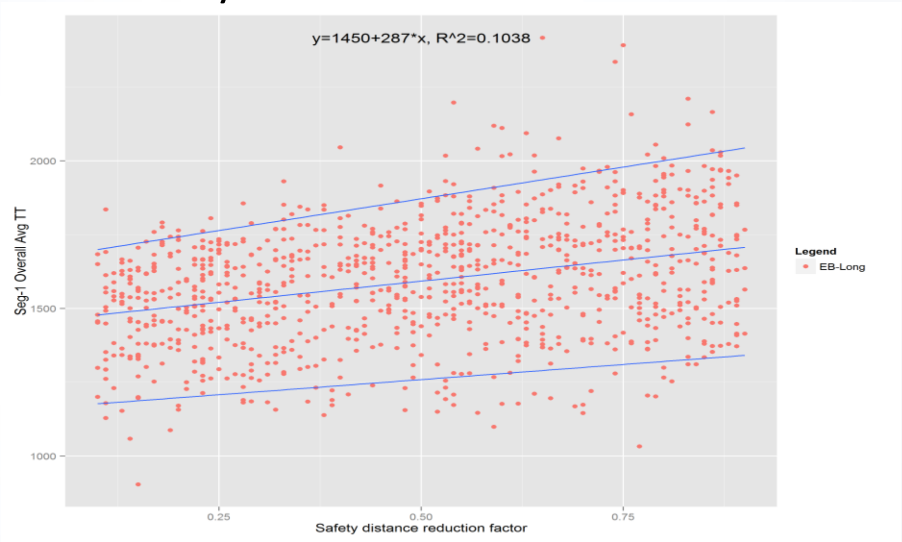
VISSIM Parameter Studies

- Significant Parameters (Average Travel Time as MOE)

CC1-Headway Time



Safety Distance Reduction Factor



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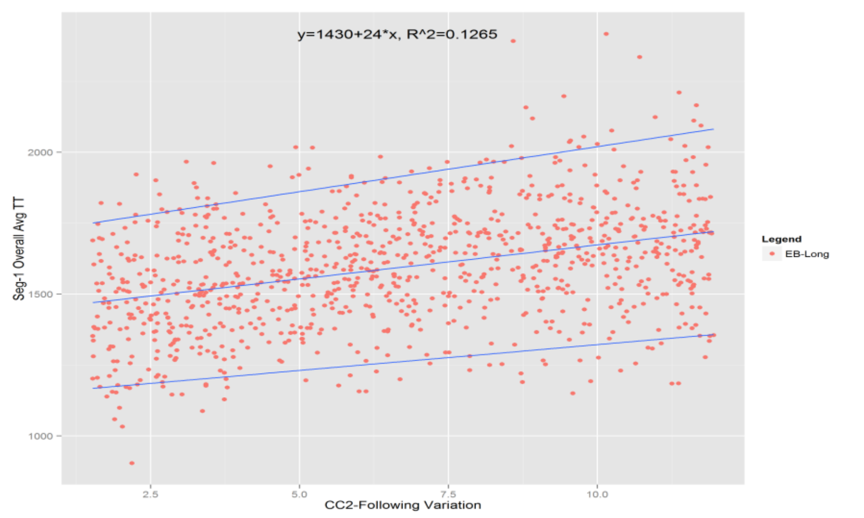
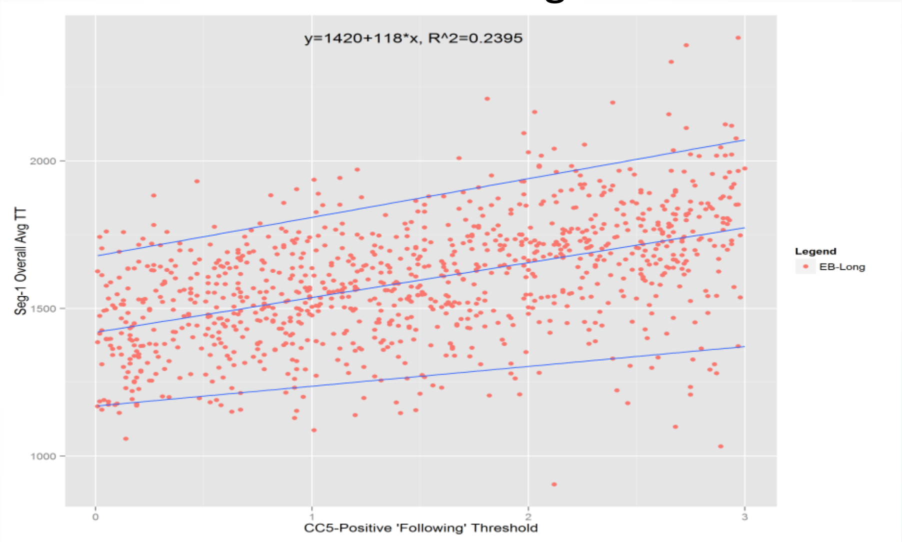
VISSIM Parameter Studies

- Significant Parameters (Average Travel Time as MOE)

CC2-Following Variation



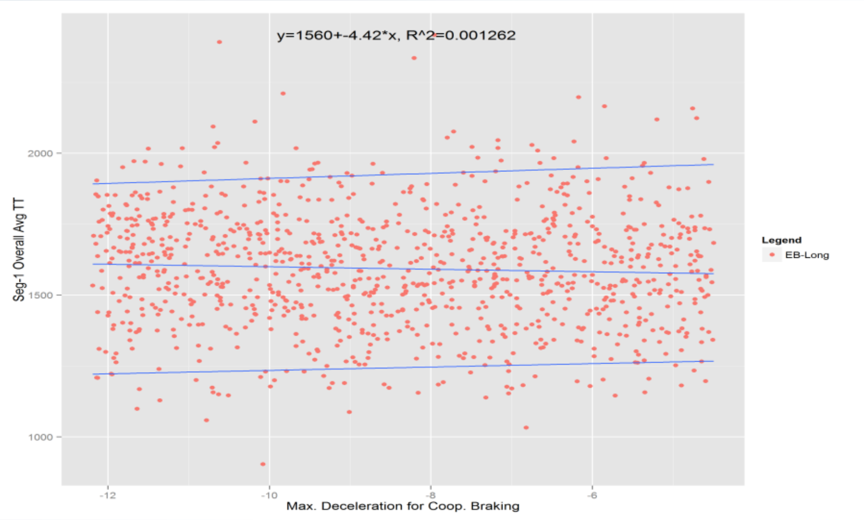
CC5-Positive 'Following' Threshold



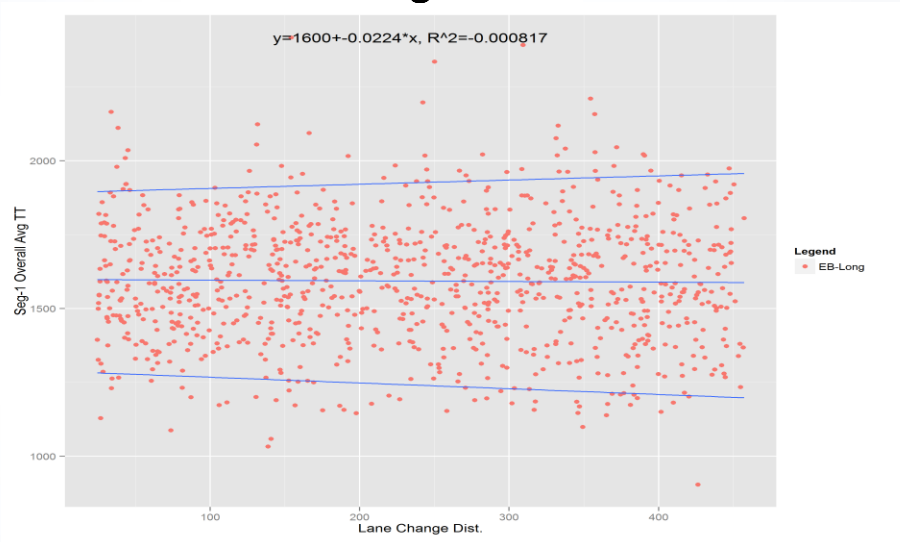
VISSIM Parameter Studies

- Significant Parameters (Average Travel Time as MOE)

Max Deceleration for cooperative braking



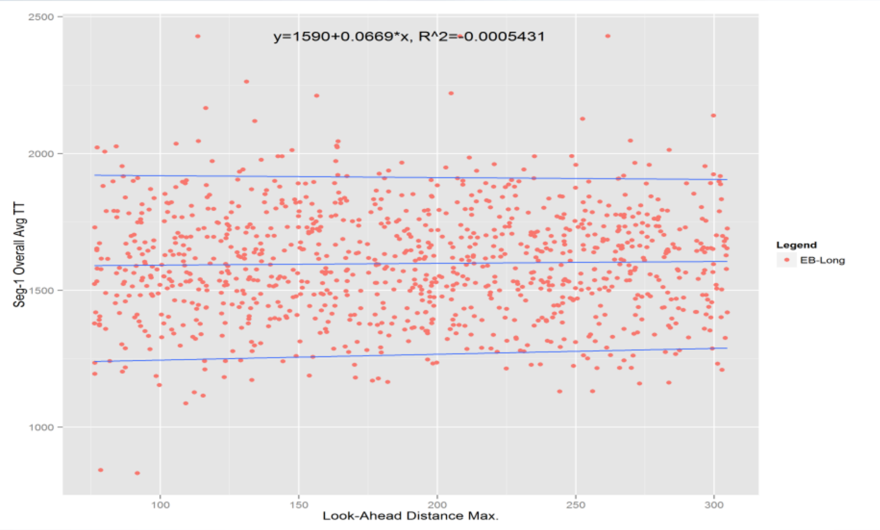
Lane change distance



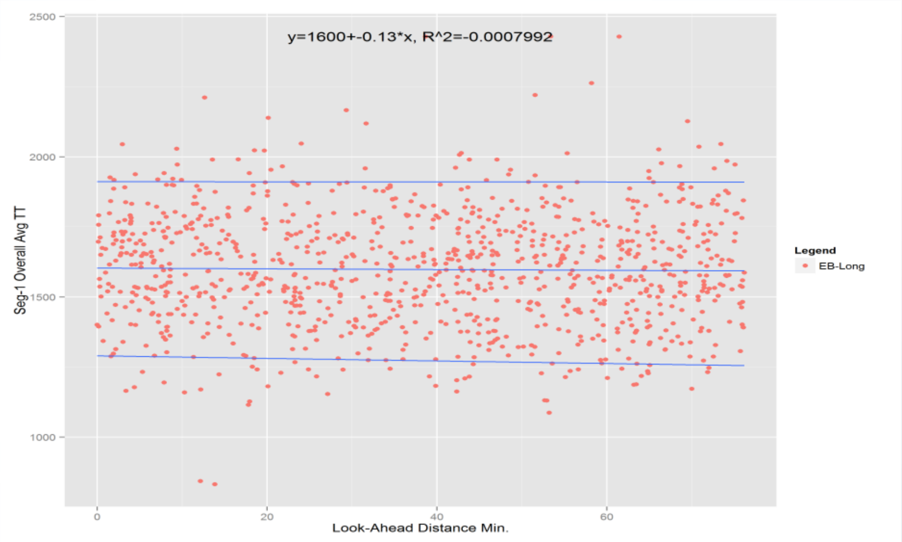
VISSIM Parameter Studies

- Insignificant Parameters (Average Travel Time as MOE)

Max Look-Ahead Distance



Min Look-Ahead Distance



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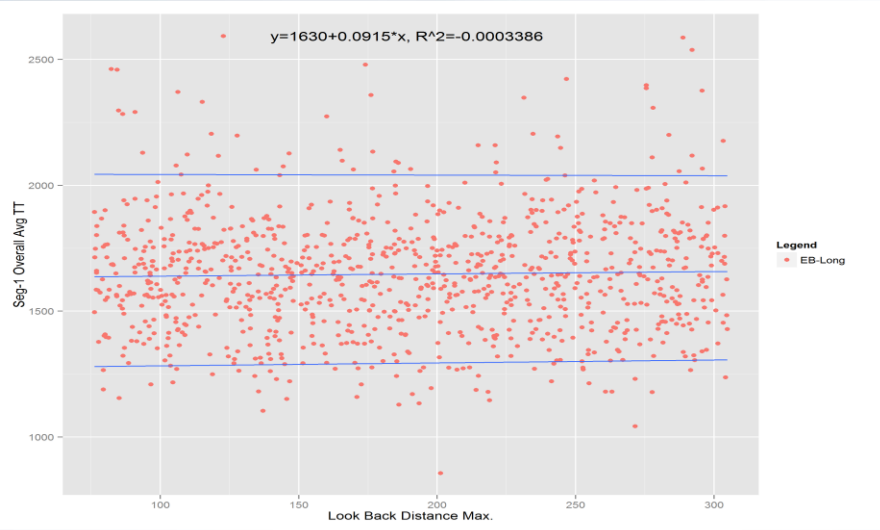
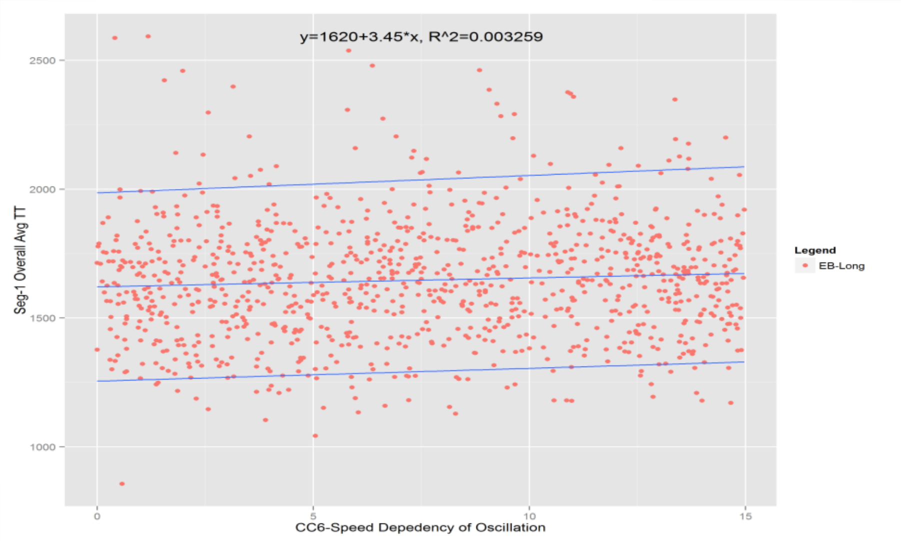
VISSIM Parameter Studies

- Insignificant Parameters (Average Travel Time as MOE)

Max Look-back Distance



Speed Dependency of Oscillation



What is CVHA?

- Definition

  CVHA systems are systems that provide driving control assistance, or fully automated driving, and are based on information about the vehicle's driving environment that can be received by communication from other vehicles (V2V) or from the infrastructure (V2I), as well as from their own on-board sensors [1].

- Typical Tasks
  - Lateral movement *(lane departure warning, lane keeping assistant, etc.)*
  - Forward movement *(adaptive cruise control, cross-traffic monitor, etc.)*
  - Reverse movement *(rear view camera, cross-traffic monitor, etc.)*
  - Crash avoidance/severity reduction *(forward collision warning, etc.)*
  - Parking *(parking assistant)*
  - Attention monitoring
  - Congestion-driving assistance *(traffic jam assistant, congestion assistant)*

Network Preparation

- Network

Scenario Development

- various traffic conditions

Simulation Analysis

- Extract individual vehicle trajectory

MOE Derivation

- MOEs for each scenario
- operational efficiency,

Effectiveness Evaluation for Advanced Driver Assistance Systems

Step 1. Network Preparation

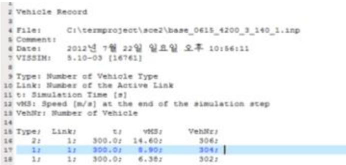
- ✓ Network

Step 2. Scenario Development

- ✓ various traffic conditions

Step 3. Simulation Analysis

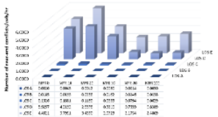
- ✓ Extract individual vehicle trajectory

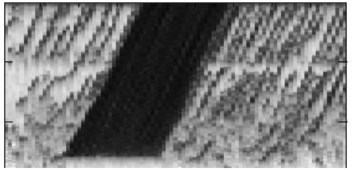


```
Vehicle Record

File:      C:\termproject\sce2\base_0615_4200_3_140_1.inp
Comment:
Date:      2012년 7월 22일 일요일 오후 10:56:11
VISSIM:    5.10-03 [16761]

Type: Number of Vehicle Type
Link: Number of the Active Link
t: Simulation Time [s]
vMS: Speed [m/s] at the end of the simulation step
VehNr: Number of Vehicle

Type;  Link;      t;     vMS;     VehNr;
   2;     1;  300.0;   14.60;       306;
   1;     1;  300.0;    8.90;       304;
   1;     1;  300.0;    6.38;       302;
```

Step 4. MOE Derivation

- ✓ MOEs for each scenario
- ✓ operational efficiency





Network Preparation

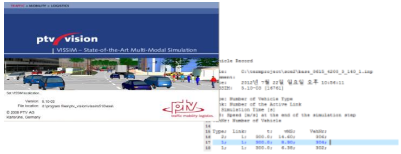
- network

Scenario Development

- traffic

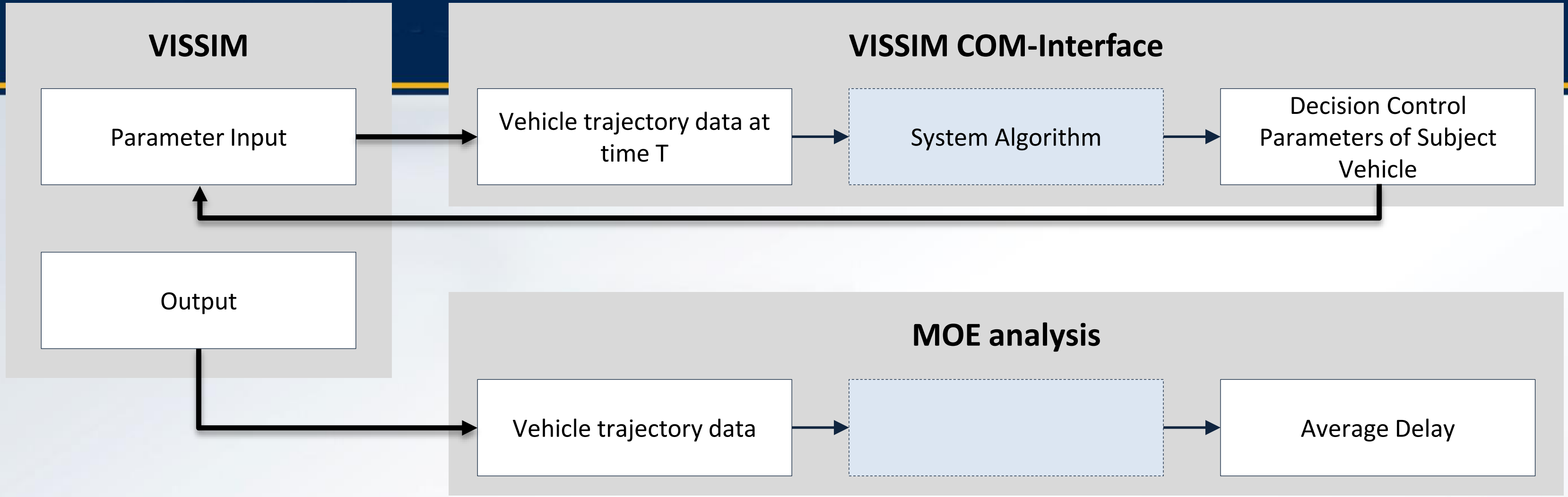
Simulation Analysis

- Control vehicle maneuvering
- Extract individual vehicle trajectory



MOE Derivation

- MOE for operational efficiency
- MOE for safety


VISSIM
Parameter Input
Output
VISSIM COM-Interface
Vehicle trajectory data at time T
System Algorithm
Decision Control Parameters of Subject Vehicle
MOE analysis
Vehicle trajectory data
Average Delay