"Integrated" Simulation:
What is it, and how is it useful?

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Senior Research Associate

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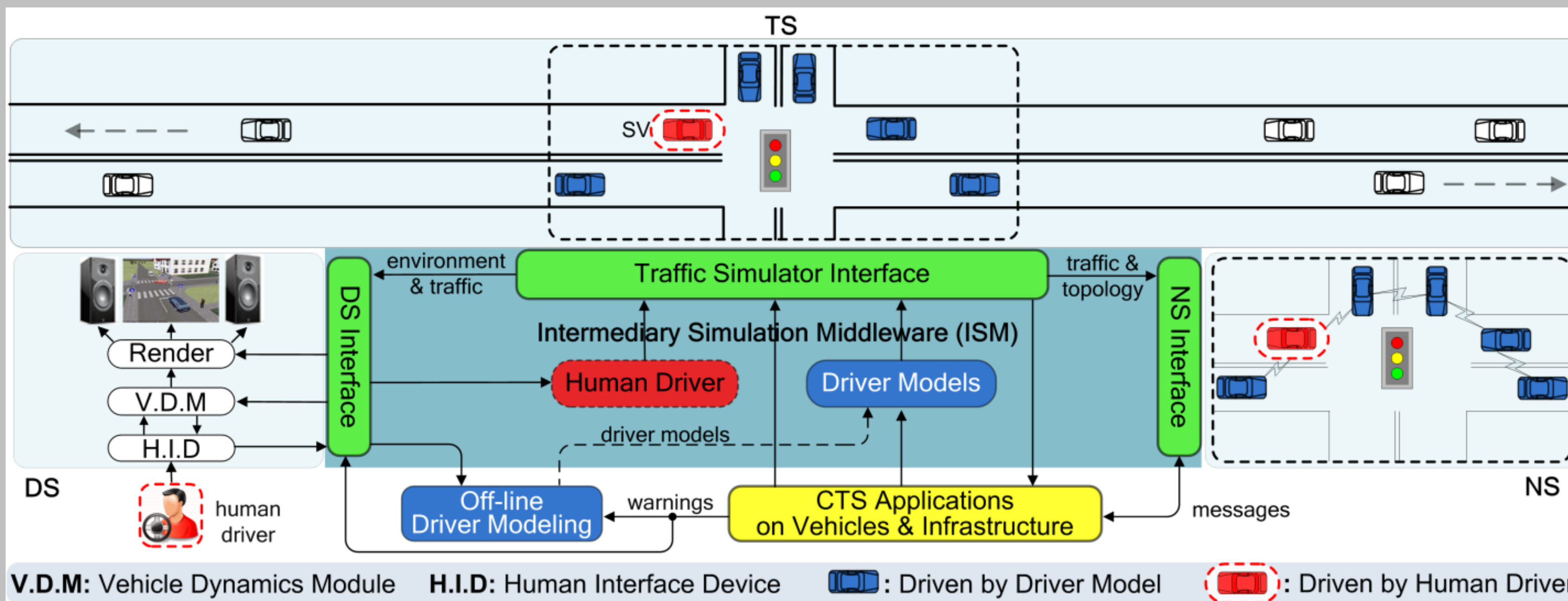
3:00 pm



Funded Research Project

Addressing Design and Human Factors Challenges in Cyber-Transportation Systems

P.I.: Dr. Chunming Qiao

National Science Foundation: Cyber-Physical Systems

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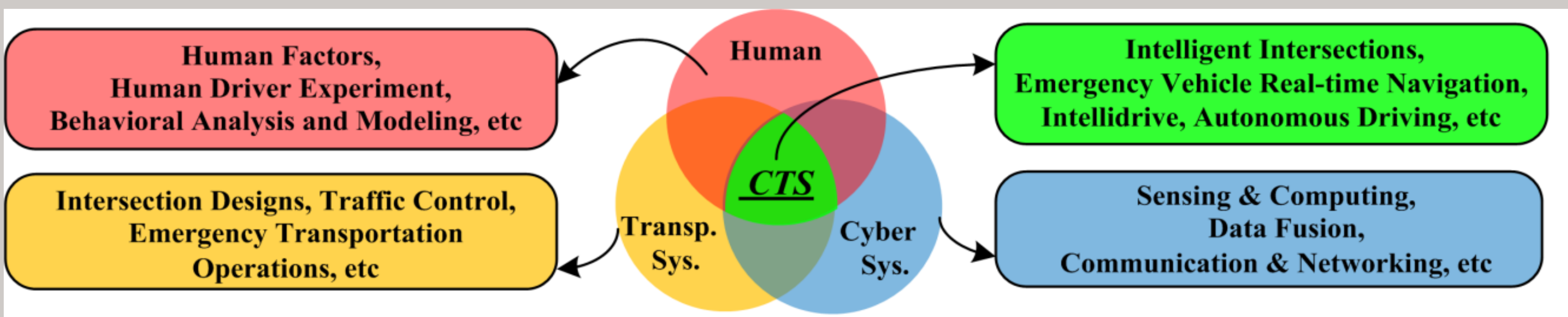
Impetus:

Design and evaluate novel CTS applications related to both traffic safety and traffic operations while taking human factors into consideration



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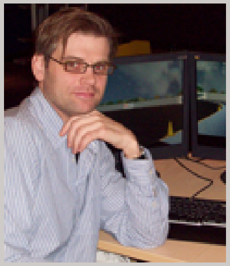
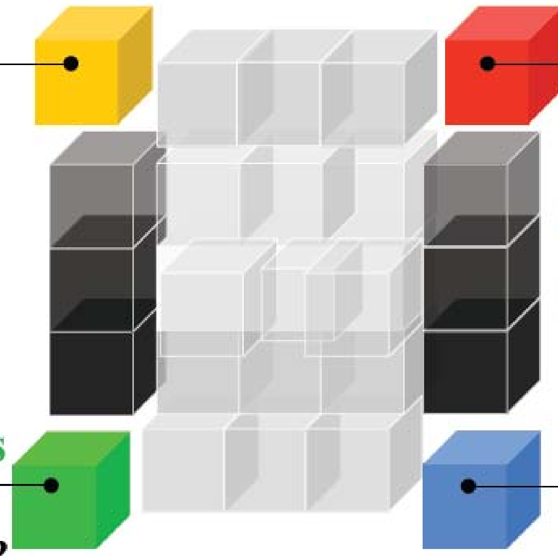


Presentation Overview

- U.S. Transportation Problems
- "Standalone" Simulation
- Integrated Simulation
- Experimental Design
- Preliminary (TS-DS) Integration
- App. #1 Emissions Model
  - Experimental Setup
  - Road Course
  - Results
- Extension #1 – Multiple Simulators
- Summary
- Ongoing Technical Challenges and Future Work
- Q/A

Motivation:: U.S. Transportation Problems

Ground Transportation



Traffic Congestion

- 87.2 billion dollars
- 2.8 billion gallons of fuel
- 4.2 billion hours
- Low quality of life

Traffic Accidents

- 43K deaths/yr or 120 /day
- 10.6 million accidents
- Highest health care cost
- 90% due to driver error

Environmental Impacts

- 1/3 U.S. (28% world) Co2 emissions (2007)
- 51% fuel in 1960 and 72% in 2009

Loss of Functionality

- Extreme events
- Disasters

Components of "Standalone" Simulation

Two types of transportation-based simulators: Traffic (TS) and Driving (DS)

- DS:
  - Hardware: displays, vehicle cabin, pilot controls, motion platform
  - Software: DriveSafety, STISIM, Virtual Driver, in-house
  - Deficiency: traffic is non-intelligent, and does not respond to the actions of human driver, in real-time

- TS:
  - Simulate the movement of individual driver-vehicle units based on car-following and lane-changing theories
  - Software: **TRANSIMS**, Paramics, VISSIM, AIMSUN
  - Deficiency: models lack the level of detail required for safety evaluations: require models that reflect errors in drivers' perception and decision-making

Limitations of "Standalone" Simulation

Limitations:

- TS: Behavioral realism (car-following, lane-changing theories)
- DS: Network realism (accompanying traffic is pre-programmed)

Much potential for integrating these 2 disparate environments:

- To analyze the behavior of special groups within the driver population (e.g. elderly drivers or teenage drivers)
- Human Factors analyses to analyze "driver workload"
- To assess how driver behavior and habits affect fuel-consumption and emissions (i.e. "Eco-driving")
- Way into the future… "Intellidrive"

Broader Impacts to Integrating Simulators

- Wide range of potential applications:
  - Civilian road vehicle applications
  - Military training, strategizing, and education
  - Aircraft, marine vessels, battlefield warfare (e.g., tanks)
  - Transportation safety, and infrastructure design
  - Human factors and driver/pilot behavior

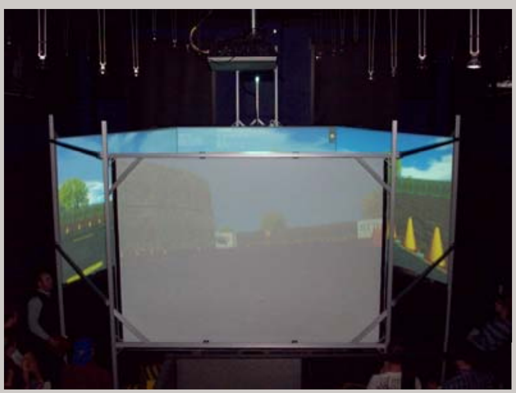
- Extend TS-DS integration to include:
  - Capacity for linked simulators across the Internet
  - Network Simulation (NS) as a third integration component

"The whole is greater than the sum of its parts"

Experimental Design (DS)

<u>Hardware Infrastructure</u>:

- Six D.O.F. motion platform
- 2-seater cabin
- On-board (reconfigurable) controls
- 4-screen VR environment
- 2.1 channel audio system

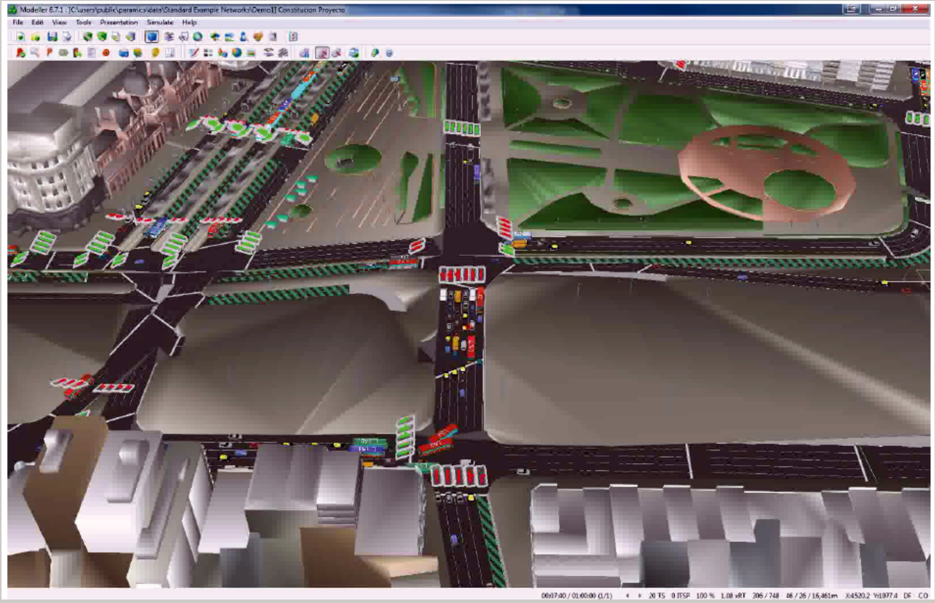


Experimental Design (TS)

PARAMICS (v6.0) was selected

Consists of the following modules:

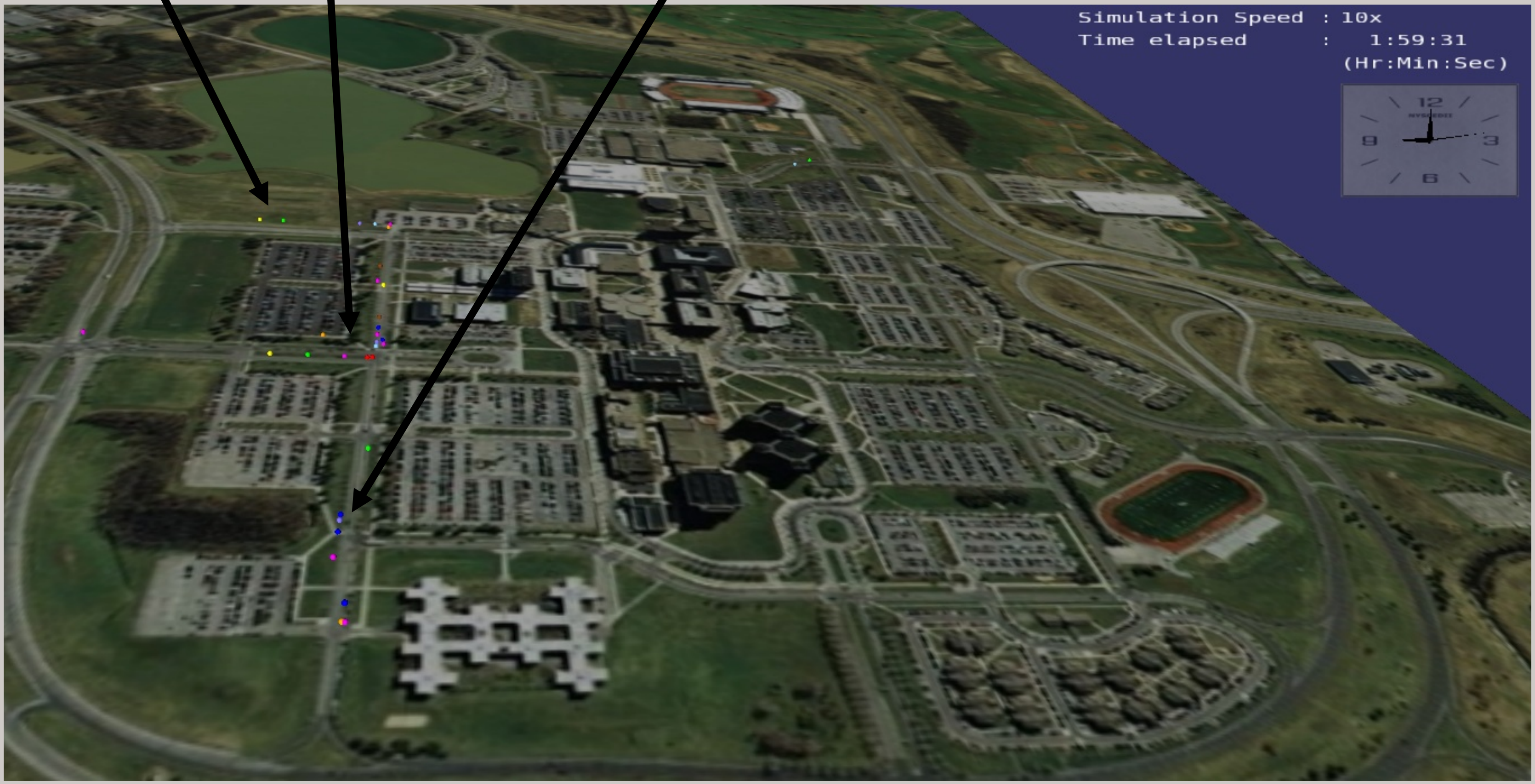
- (1) Modeler
- (2) Processor
- (3) Analyzer
- (4) Programmer (*add-on module*)



- Justification for using Paramics:
  - *Programmer* - Application Programmer Interface (API)
  - Retrieve output values and assign input parameters
  - Augment the core simulation with new functions/driver behavior
  - Critical for integrating the TS and DS

{Alternate TS Environment – TRANSIMS}

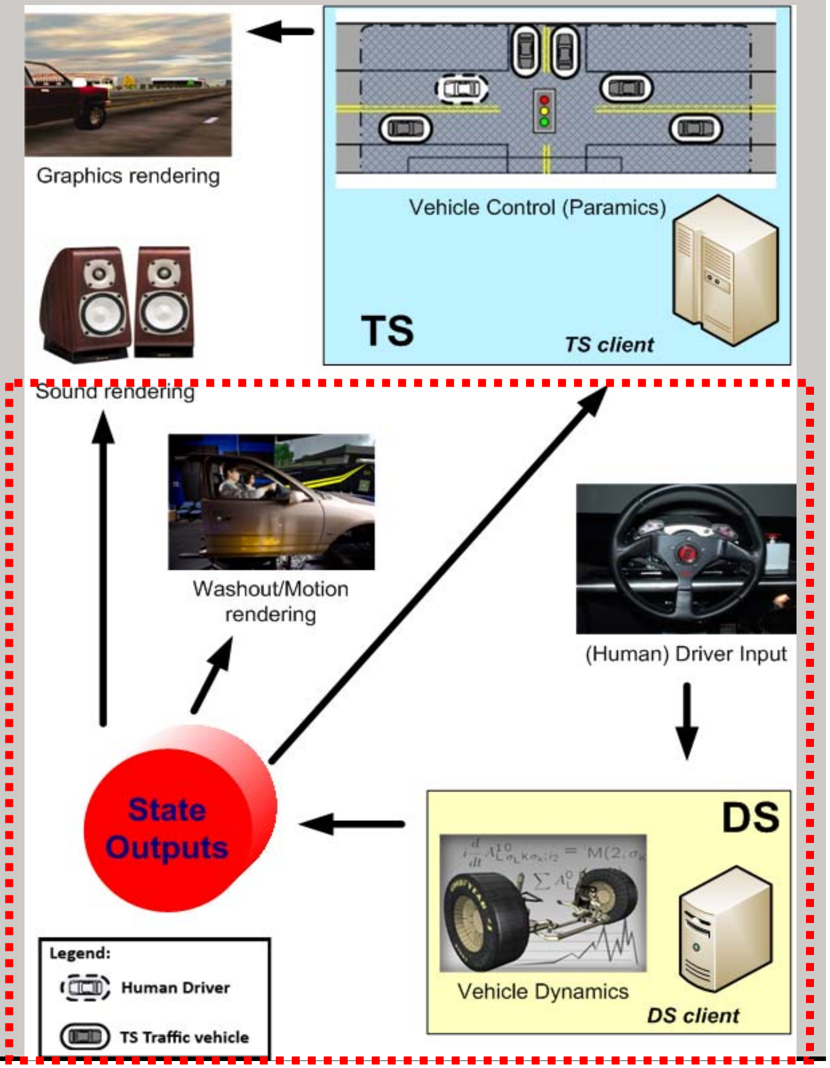
Microscopic vehicle behavior (*vehicles - colored spheres*) mapped onto a Google Maps terrain



Preliminary Integration (TS-DS) overview

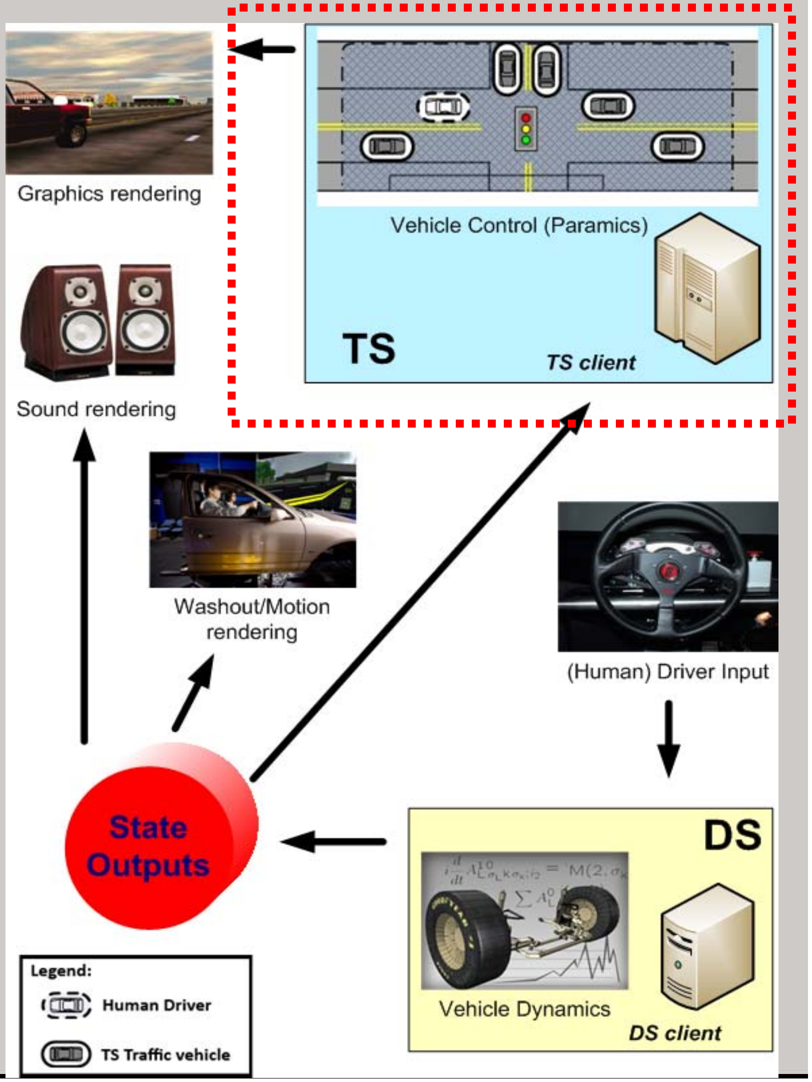
- Step 1: Driver Input (steering, gas, and brake pedals)
- Step 2: DS analysis processing (e.g., vehicle dynamics)

  State outputs result (e.g., position, velocity, etc.)
- Step 3: Render motion and audio outputs
- Feed outputs to TS



Preliminary Integration (TS-DS) overview

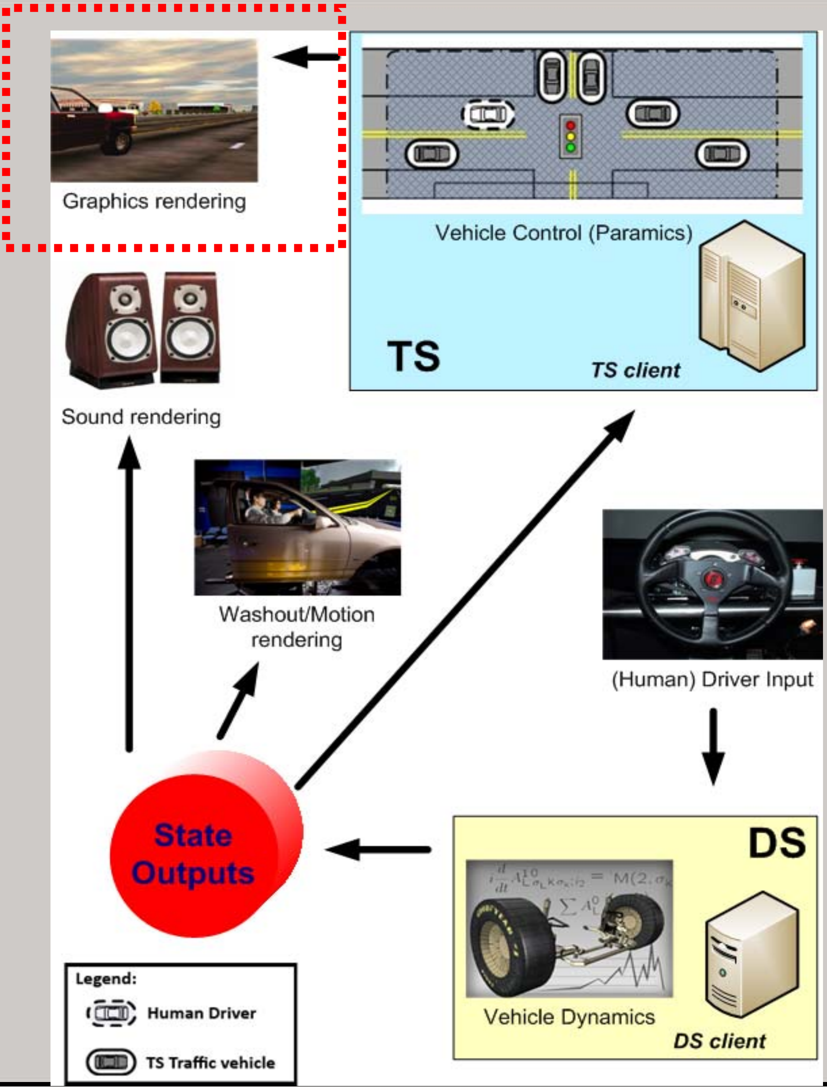
- "Subject Vehicle" (SV) speed, position, orientation are overridden by the actions of the live driver
- SV is surrounded by other traffic vehicles whose behaviors are dictated by the TS
- Background traffic now responds in real-time to the actions of the live driver, <u>a feature often lacking in stand-alone driving simulator implementations</u>



Preliminary Integration (TS-DS) overview

Graphics rendered:

- position/orientation of the human driven vehicle
- position/orientation of the traffic vehicles
- roadway geometry, traffic signals



Application: Emissions Model

Once constructed, how can an Integrated simulator be useful?

- Comprehensive Modal Emissions Model (CMEM)
- Developed: UC Riverside, 2001
- Inputs: second-by-second velocity profile for a vehicle
- Outputs: predict highly time-resolved fuel consumption and vehicle emissions rates

Vehicle Property	Value
Mass (lbs)	3937.50
Coast down power (hp)	17.99
Max Torque (ft-lb)	193.78
Engine speed (rpm)	2953
Engine speed at max power (rpm)	4603
Engine speed at Idle (rpm)	850.0
Engine displacement (L)	3.42
Number of cylinders	4
Engine/vehicle speed (rpm/mph)	33.56
Number of gears	4

Experimental Setup (Summer, 2010 study)

Eco-driving:

- Subtle changes to driving habits
- Reduce fuel consumption/emissions (by up to 15%)

Practices:

- Avoiding rapid acceleration or braking
- Driving at speed limit / constant speed

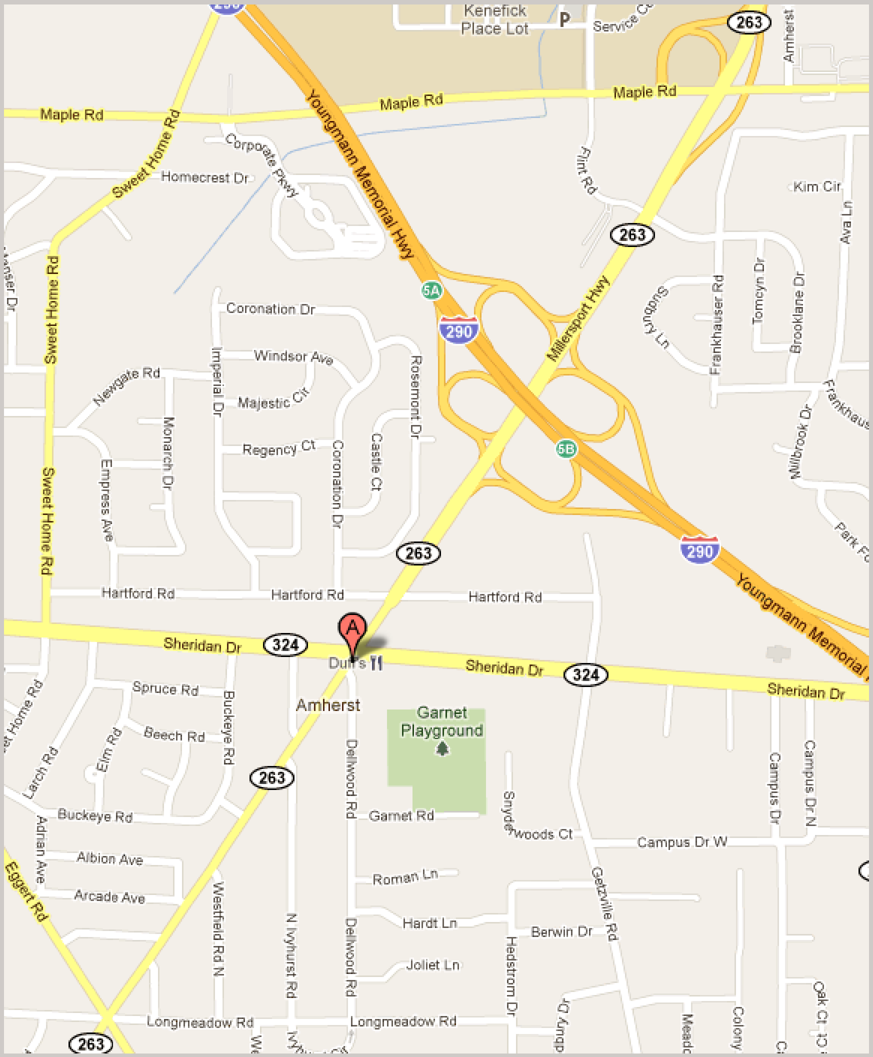
Study Details:

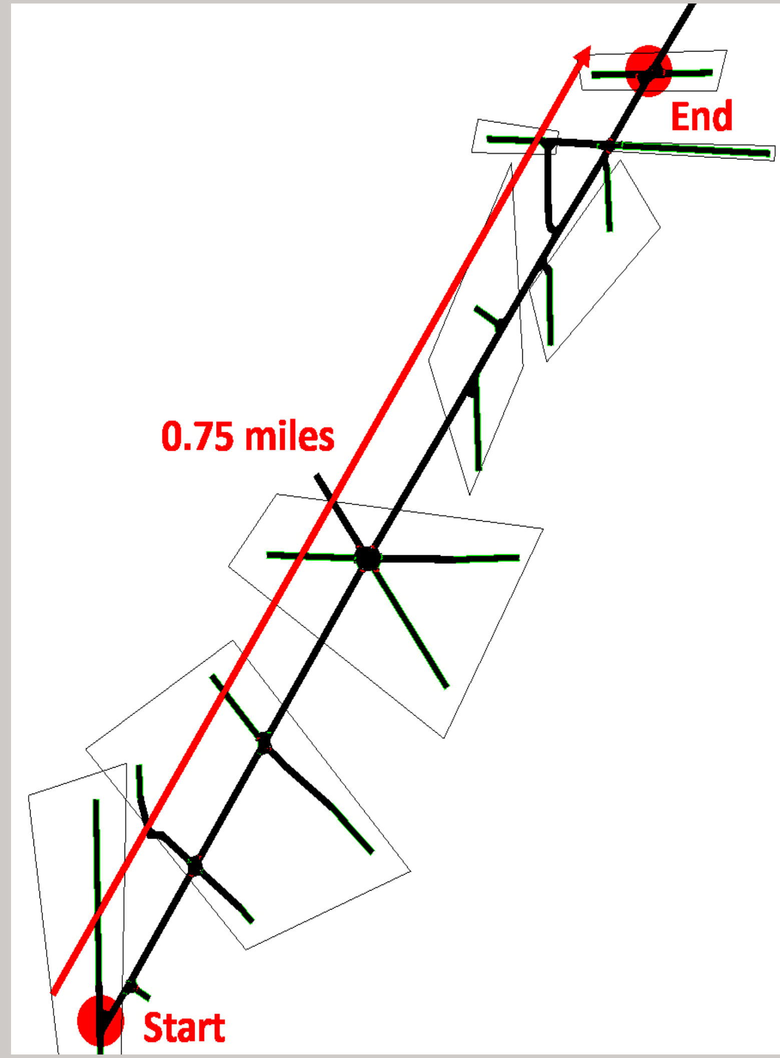
- N=16; avg. age: 27.7; avg. yrs. exp.: 7.5
- 2 drives: i) low, ii) moderate congestion

Objectives:

- Observe performance differences among the different drivers
- Observe impact of factors (driving experience, congestion) on metrics

Road Course (modeled after Millersport Highway)





Results

<u>"Low congestion" condition</u>

- Driver ID, years driving
- Excursion time (sec)
- Maximum and Average speeds (mph)
- Fuel consumption rate (g/mile)
- Tailpipe emissions rate (CO_2), (g/mile)

<u>Facts</u>:

Every liter of gasoline that is burned produces about 2.4 kg of CO2

Responsible > 60% of the enhanced greenhouse effect (*climate change*)

Driver	Time	V_{max}	V_{avg}	Fuel use	T_{CO2}
1-1	160	48.3	16.4	406.7	1129.9
2-7	160	43.4	15.8	318.5	997.9
3-15	215	37.3	11.7	355.6	1075.4
4-0	162	49.5	16.3	460.8	1234.4
5-2	215	43.6	12.4	329.7	1015.2
6-3	163	46.0	17.1	395.9	1010.1
7-10	169	42.1	15.3	356.7	1074.8
8-6	162	43.0	16.5	464.3	1259.0
9-4	172	35.4	14.5	245.0	761.6
10-1	216	37.3	11.6	320.5	1004.6
11-20	213	33.5	11.5	293.7	919.4
12-16	161	77.5	17.9	353.7	902.0
13-6	169	41.4	15.2	334.7	971.8
14-24	161	61.8	21.2	357.0	947.8
15-5	162	40.2	16.2	294.7	906.6
16-0	216	30.7	13.7	221.5	694.7
Mean:	**179.7**	**44.4**	**15.2**	**344.3**	**994.1**
STD:	**24.7**	**11.4**	**2.6**	**66.6**	**147.9**

Results

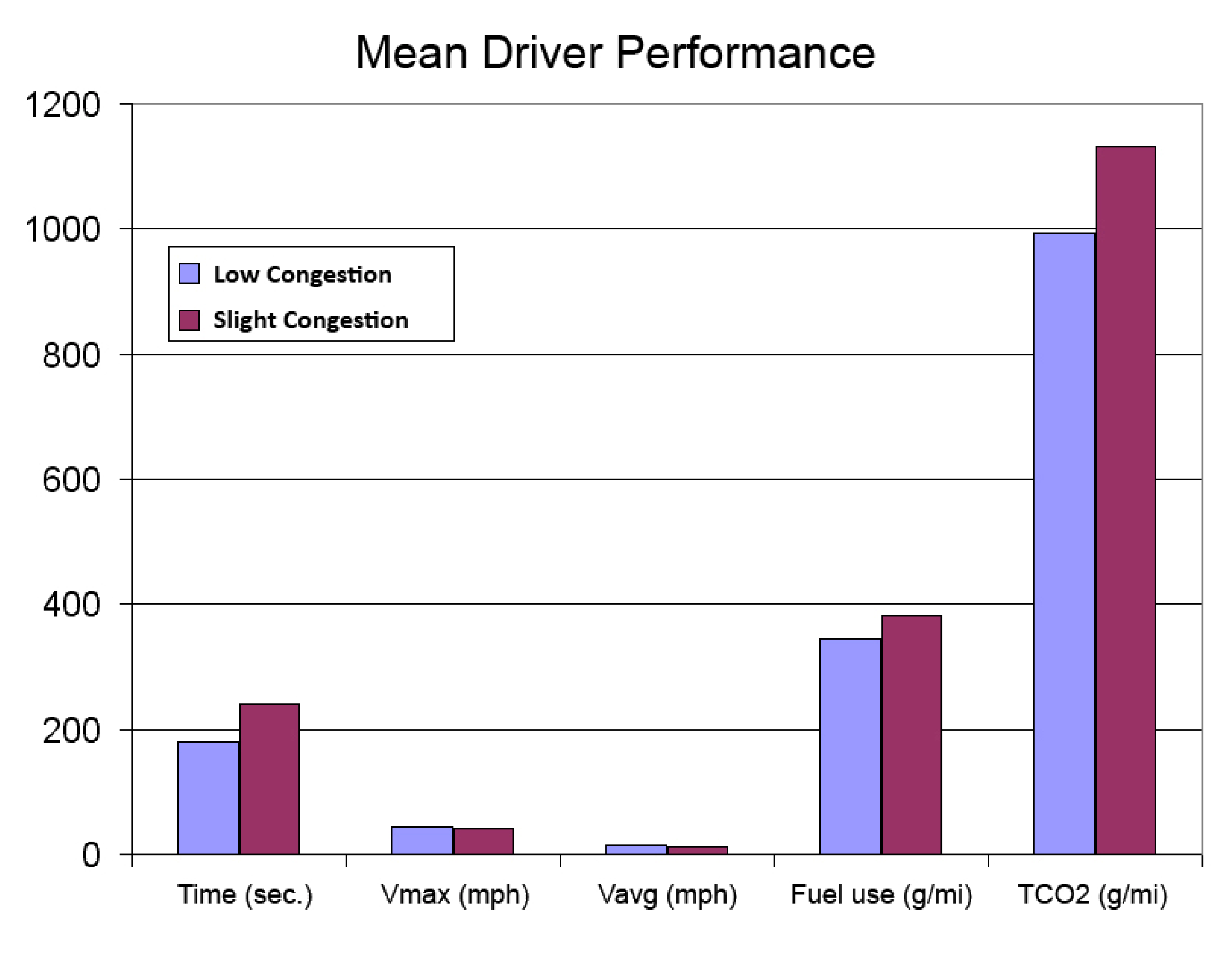
<u>"Moderate congestion" condition</u>

Due to the increased road traffic:

- The mean duration increased by 25% (179.7 to 239.6 seconds)
- Mean max/avg. speeds decreased (by 8.2%, and 25.9%, respectively)
- Mean fuel use (rate) increased from 344.3 to 380.6 grams/mile; (9.5%)
- Mean T-CO_2 rate emissions increased from 994.1 to 1131.5 grams/mile; (12.1%)

Driver	Time	V_{max}	V_{avg}	Fuel use	T_{CO2}
1-1	230	43.2	11.2	439.4	1285.8
2-7	231	40.4	10.7	369.1	1156.9
3-15	286	36.2	8.5	351.8	1031.8
4-0	244	50.1	11.7	517.3	1383.8
5-2	252	42.8	11.0	338.6	1042.8
6-3	230	51.9	14.4	321.0	902.6
7-10	226	38.6	11.0	479.2	1447.9
8-6	286	43.0	8.8	549.9	1649.4
9-4	234	39.5	10.9	320.2	1004.4
10-1	231	40.0	11.1	396.9	1194.0
11-20	232	35.4	11.7	272.8	855.1
12-16	228	47.5	14.2	308.3	912.8
13-6	233	39.3	11.4	373.6	1131.9
14-24	231	44.1	11.4	449.7	1263.0
15-5	232	36.3	10.7	375.6	1132.9
16-0	229	24.2	11.1	226.6	709.4
Mean:	**239.6**	**40.8**	**11.2**	**380.6**	**1131.5**
STD:	**19.1**	**6.5**	**1.4**	**87.9**	**240.3**

Results



Mean Driver Performance
1200
1000
800
600
400
200
0
Low Congestion
Slight Congestion
Time (sec.)
Vmax (mph)
Vavg (mph)
Fuel use (g/mi)
TCO2 (g/mi)

Results

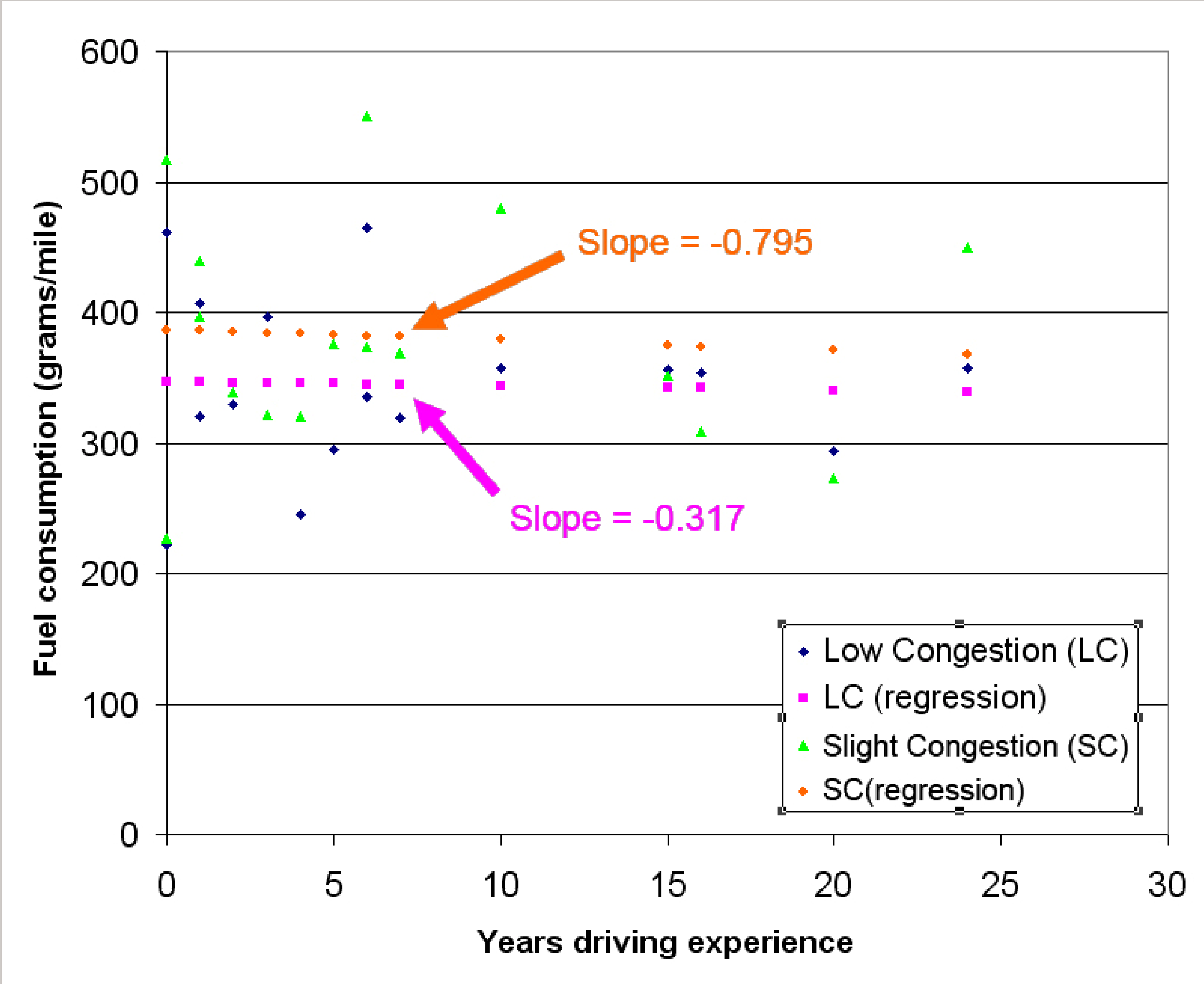
Interesting "human factors" observation:

Trend: A (slight) inverse relationship between both fuel usage and tailpipe emissions versus driver experience

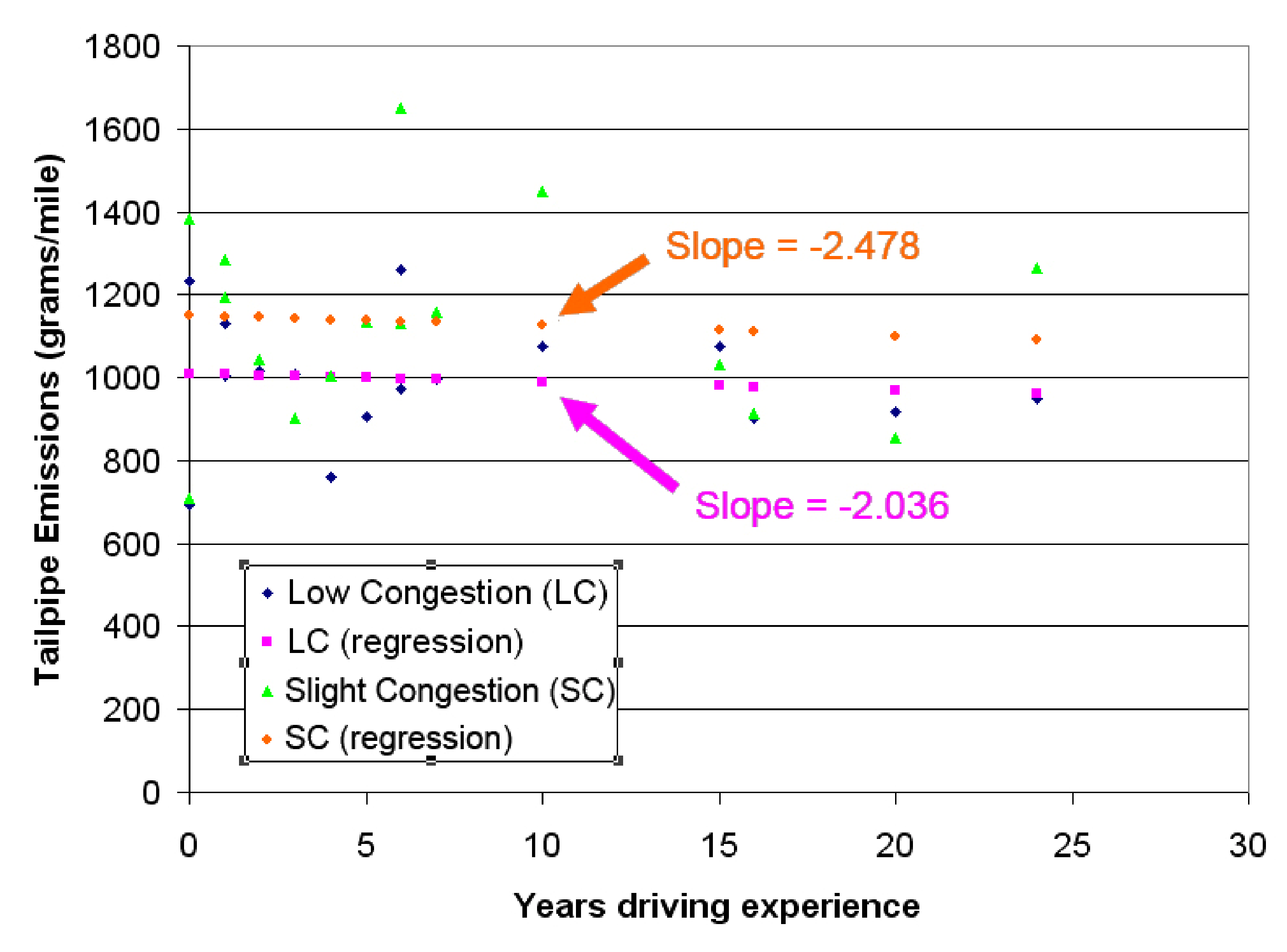
- Although the data has a low correlation coefficient, note the negative values for slope.

- An integrated TS-DS simulator incorporated with a numerical emissions model can be useful for examining these (and other) driver behaviors

Results (Fuel Consumption)



Results (Tailpipe emissions)



Extension #1 – Multiple Driving Simulators

Simultaneous use of multiple driving simulators:

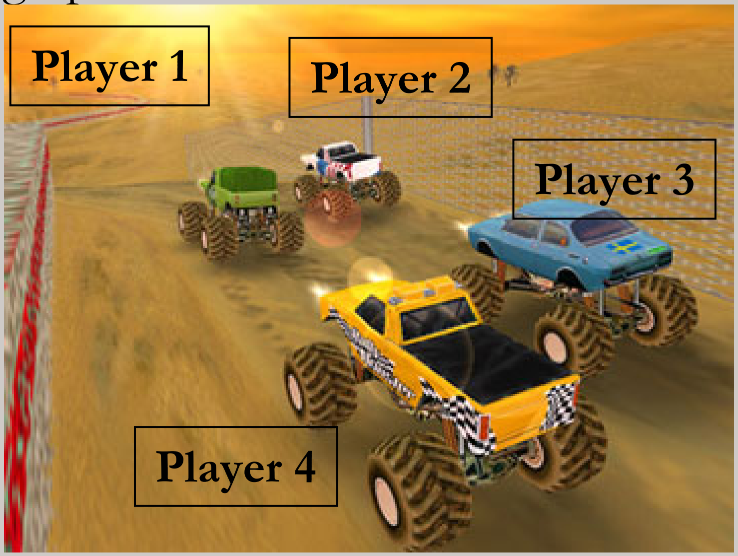
- allow for various human-in-the-loop analyses
- direct vehicle-to-vehicle (V2V) communication and interaction
- demonstrate impact of driver decision-making "down the chain"

Concept is frequently used in multi-player P2P (online) video gaming

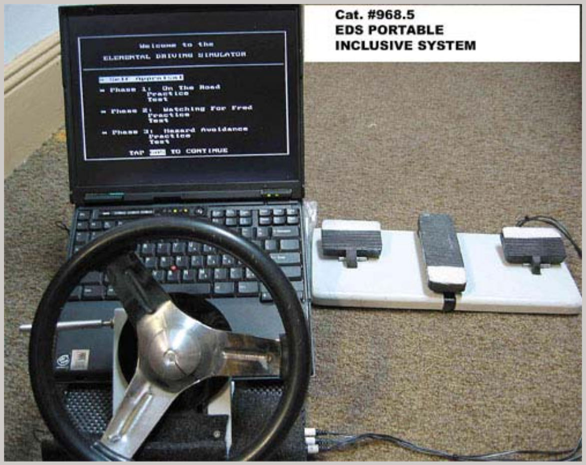
Link <u>multiple driving simulators</u> across geographic distances

Use TCP/UDP (server/client) to update vehicle position(s) and orientation(s) to each simulator

Each linked simulator <u>need not</u> necessarily require motion hardware…

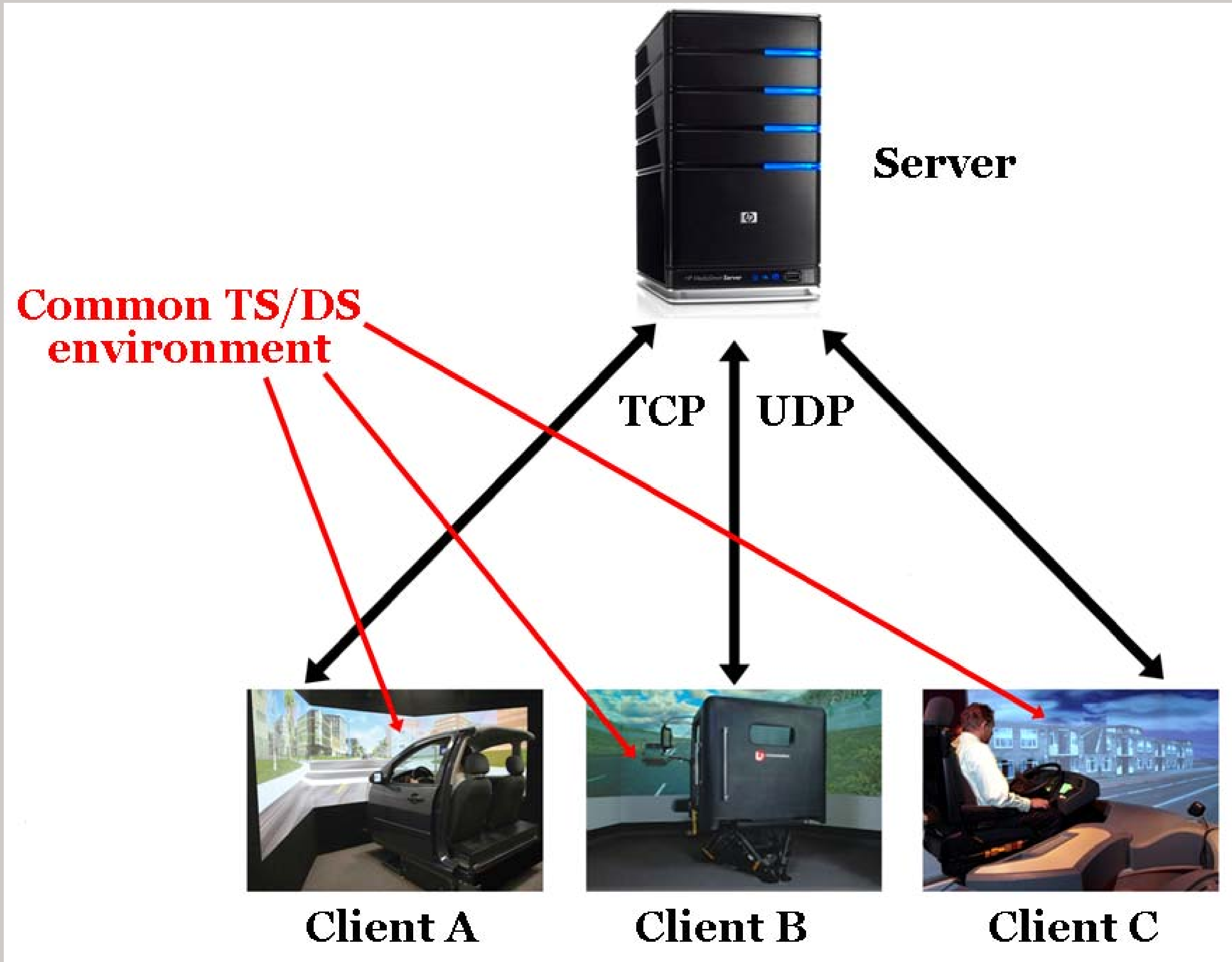


{*recall: Driving Simulator Spectrum*}



Players in networked environment could use ANY fidelity of driving simulator

Extension #1 – Multiple Driving Simulators



Summary

<u>Prototype transportation simulation modeling framework</u>:

- TS-DS integration - override "subject vehicle" within TS by actions of a live human driver
- Implement CMEM software for estimating fuel consumption and vehicle emissions
- Pilot study: 16 human subjects of varying gender, age, and driving experience
- ¾ mile road course: "low" and "slight" congestion
- Data trends: an increase in driving duration implies expected decreases in maximum/average speed, increases in fuel use and tailpipe emissions
- TS-DS Integration useful for examining "human factors"
- Strive for global effort to make driving more "Eco-friendly" practice

Ongoing Technical Challenges

- Location of Graphics rendering is cause for debate
  - as part of the TS, or as part of the DS?
  - use off-the-shelf software, or develop an in-house graphics engine?
  - multiple-screen considerations
  - must consider ease of integrating with motion platform
- Require smoother behavior of vehicles in the integrated simulator
  - interpolation techniques?
- Need to overcome "speed irregularities" for the SV override
  - due to varying vehicle dynamics predictions in the TS and the DS
  - may be due to TS inability to override vehicle behavior in intersections
- SV heading/yaw control needs improvement
  - no true "steering" in current integration– just lane changing capability

Ongoing and Future Work

<u>Expansion of TS-DS architecture to other domains:</u>

- Integration that includes Network Simulation (NS)
  - e.g., Future vehicles send relevant warning messages to the driver
- Create a network of motion simulators
  - e.g., Multiple remote clients within the same virtual environment
- Transportation Safety Research
  - e.g., Communicate with other vehicles & infrastructure (*IntelliDrive*)
- Analysis of Human Factors and Driver Behavior
  - e.g., Rely on human response to partially (or fully?) relinquish driver control in the vicinity of intersections

Questions?