Integrated Collision Warning System for Transit Buses

David Duggins, Jay Gowdy[1], John Kozar, Robert MacLachlan, Christoph Mertz, Aaron Steinfeld, Arne Suppe, Charles Thorpe, Chieh-Chih "Bob" Wang[2]

NavLab, Robotics Institute
Carnegie Mellon University
[1]SAIC Center for Intelligent Robotics and Unmanned Systems (CIRUS)
[2]ARC Centre of Excellence for Autonomous Systems
& Australian Centre for Field Robotics (ACFR)

Transit ICWS

- Integrated Collision Warning System
- Federal Transit Administration (FTA) merged two existing Intelligent Vehicle Initiative (IVI) transit research efforts:
  - Side collision warning system (SCWS, PA)
  - Forward collision warning system (FCWS, CA)

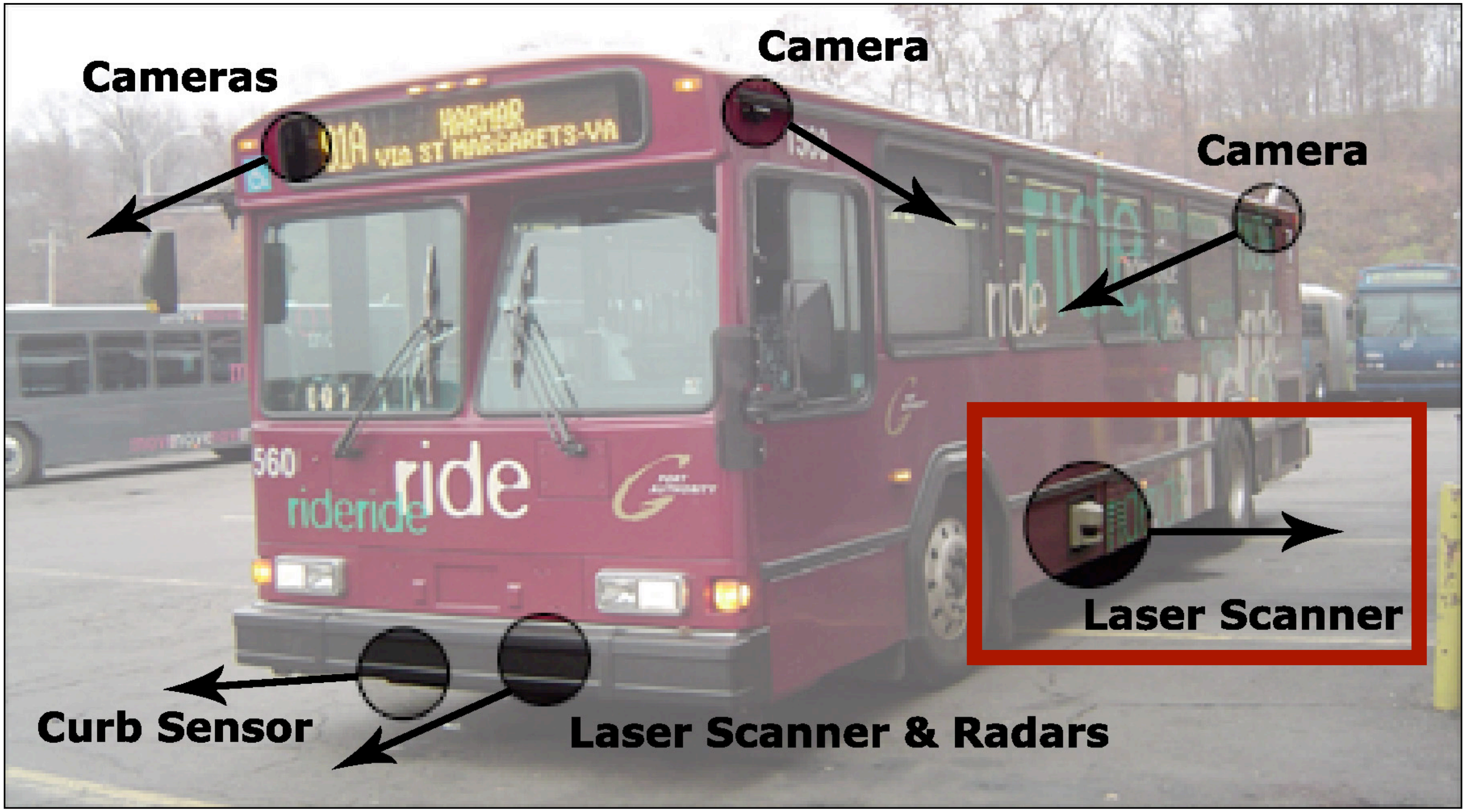
Primary Warnings

- **Alert: Yellow LEDs**
  - Detected a threat with the potential to become more dangerous
- **Imminent Warning: Red LEDs**
  - Detected a threat with a high probability of making contact with the bus unless evasive action is taken

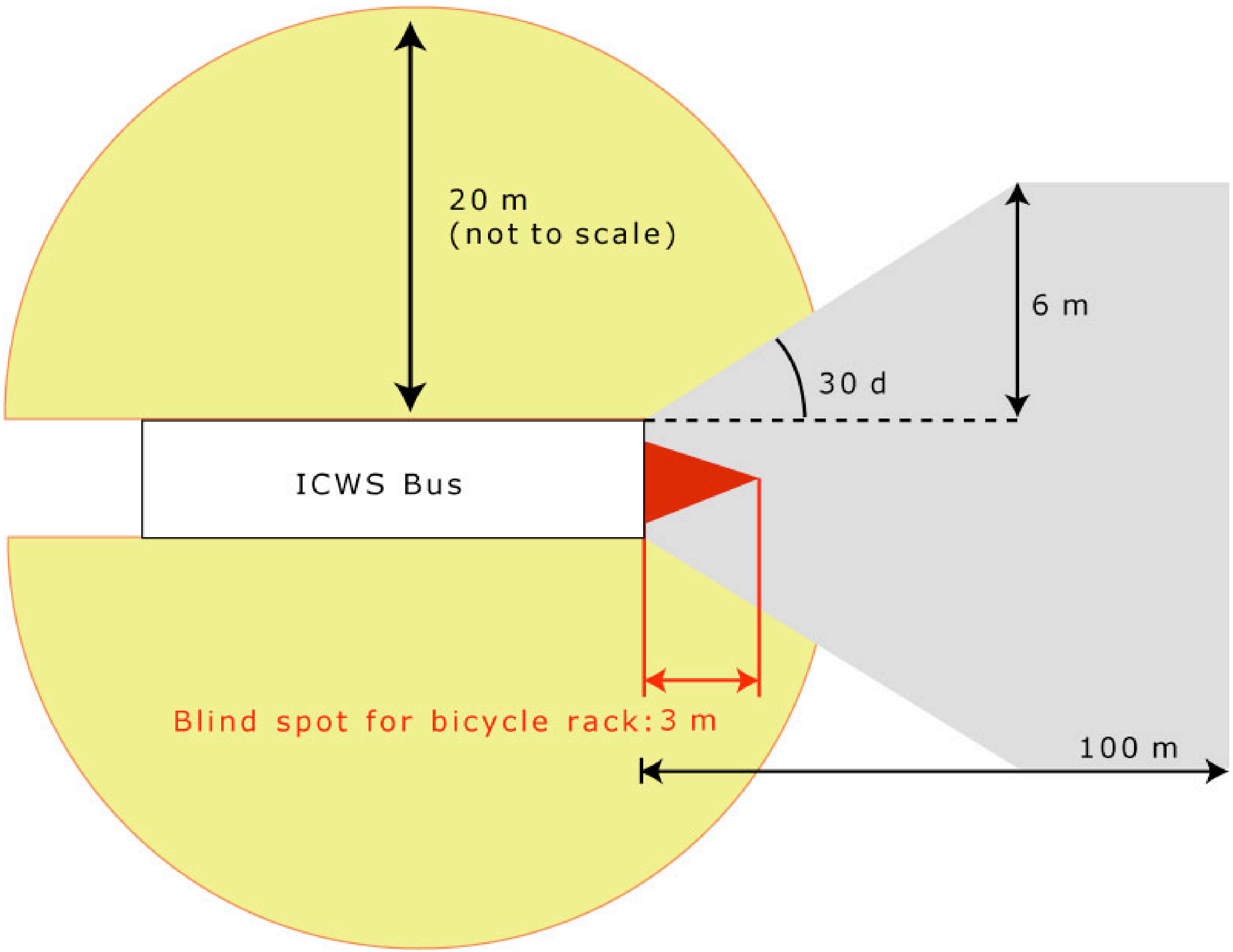
Secondary Warnings

- **Contact: Triangles blink yellow** for the appropriate side
  - Detected a potential side collision
  - Check mirrors and inspect as necessary
- **Under Wheel: Triangles blink red** for the appropriate side
  - Detected a potential pedestrian slipping under the bus
  - Check mirrors and inspect as necessary

Installed External Sensors



Sensor Coverage



Collision Warning

Christoph Mertz

Side Collisions

- Only a very small percentage of side collisions are classical lane change or merge accidents
- Many of the bus accidents involve objects approaching from the side
- The line between safe and unsafe situations is very tight
- In most cases it is not the bus driver who created the dangerous situation

C. Mertz, S. McNeil, and C. Thorpe, "Side collision warning systems for transit buses," *IEEE Intelligent Vehicle Symposium (IV)*, 2000.

Side Collisions (cont.)

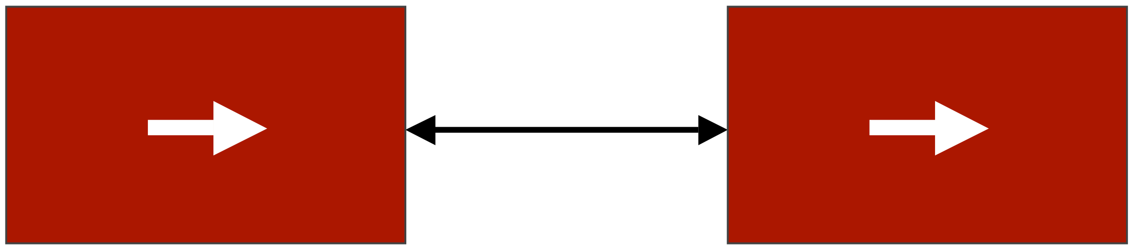
- Many of the most serious accidents involve pedestrians
- In a quarter of all pedestrian fatalities, the pedestrian is partially or completely underneath the bus
- In many cases the bus driver does not notice that a collision with a pedestrian happened

C. Mertz, S. McNeil, and C. Thorpe, "Side collision warning systems for transit buses," *IEEE Intelligent Vehicle Symposium (IV)*, 2000.

Fundamental Question: What should we warn about?

- What is it that makes a situation dangerous?
- Does the driver decide or the engineer?
- Are there different types of dangerous situations?
- Is there one universal measure?
- What about Contact and Under Wheel warnings?

Typical 1D Case

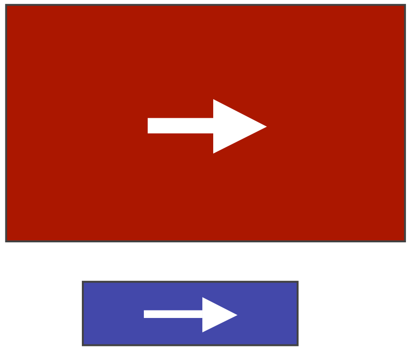


- Warning given if
  - Distance to collision or
  - Time to collision
- is below a given threshold

Details to Consider

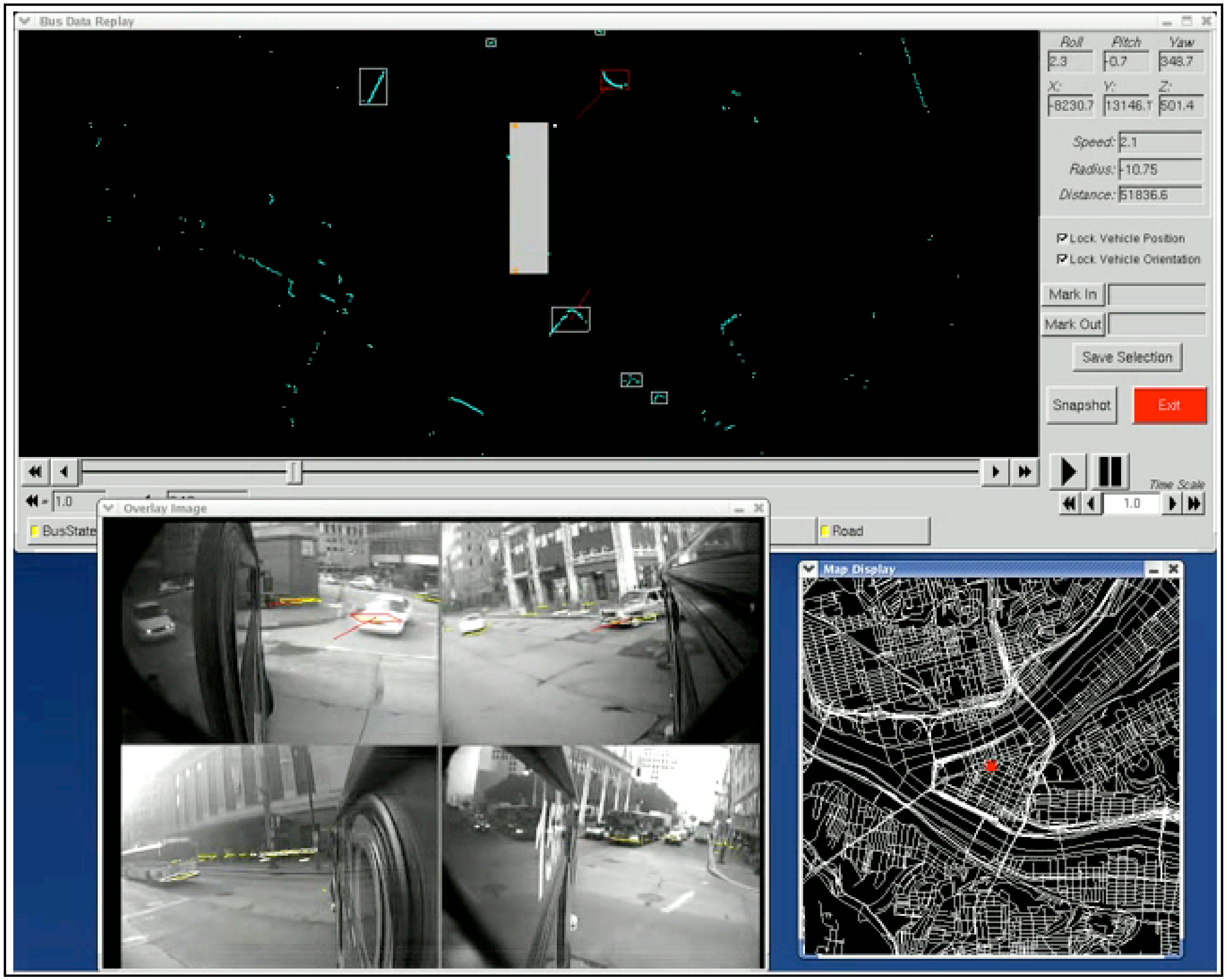
- Assumption about the lead vehicle, e.g. it will come to a complete stop
- Reaction time of driver
- Response time of vehicle
- Maximum deceleration

Problem of 2D Cases



- Dangerous or not?
  - Distance to collision is small - dangerous
  - Time to collision is very large - not dangerous
- Slight changes in speed can have large effects on the time to collision.
- Some situations can be very complicated, e.g. several vehicle and pedestrian at an intersection.

Note to Self: This is Hard



Approach: Probability of collision

- Calculate probability of collision instead of time or distance to collision. Calculation includes:
  - 2D
  - physics equation
  - measurement uncertainties
  - bus + driver model
  - object model
  - environment + object + bus + driver model (e.g. If a pedestrian is on the curb, he/she is much more likely to stay on the curb than to step off the curb)

Mathematical Formulation

$$p(t) = 1 - \int_{allX} w(X,t)\,dX$$

where:

$$w(X,t) = \begin{cases} 0 & \text{if a collision occurs between t0=0 and t} \\ w(X,t_0=0) & \text{everywhere else} \end{cases}$$

X = vector of all coordinates

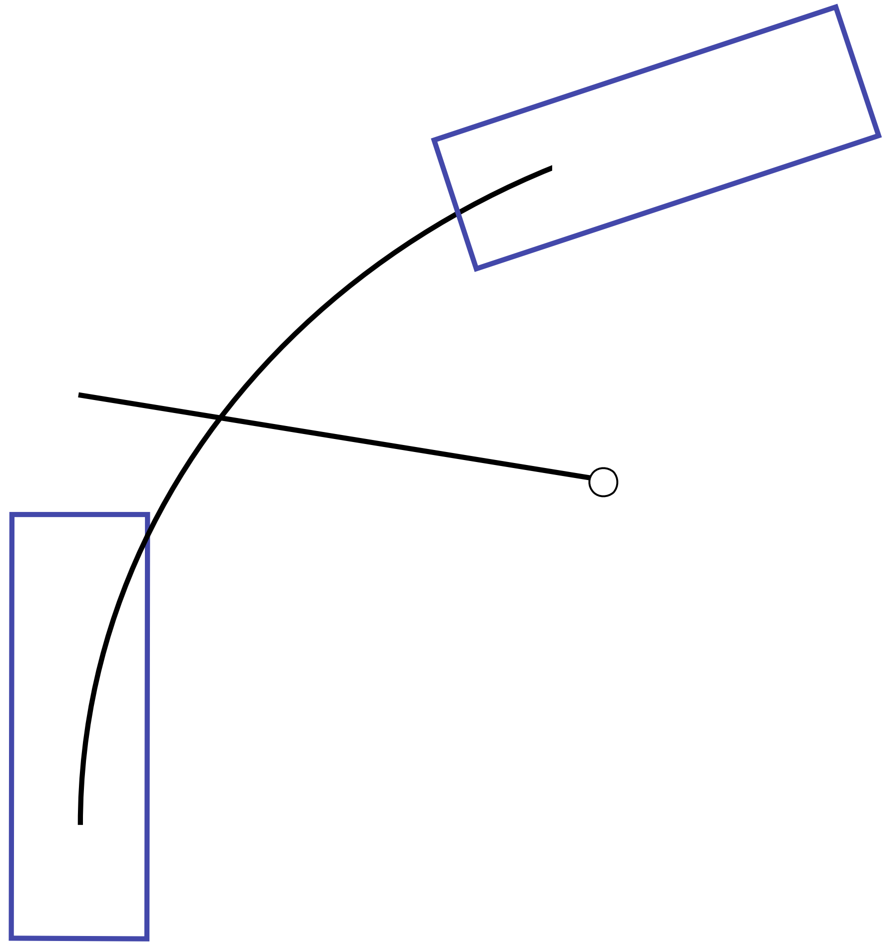
$$w(X,t_0=0) = S_1(a_1,\Delta a_1)\cdot \ldots G_1(b_1)\cdot \ldots H_1(e_1,X)\cdot \ldots$$

S_n = the error function of the measured coordinate a_n
G_n= distribution functions of the unmeasured quantities b_n
H_n = weighting functions taking knowledge of the environment (e_n) into account

Practical implementation: Monte Carlo integration

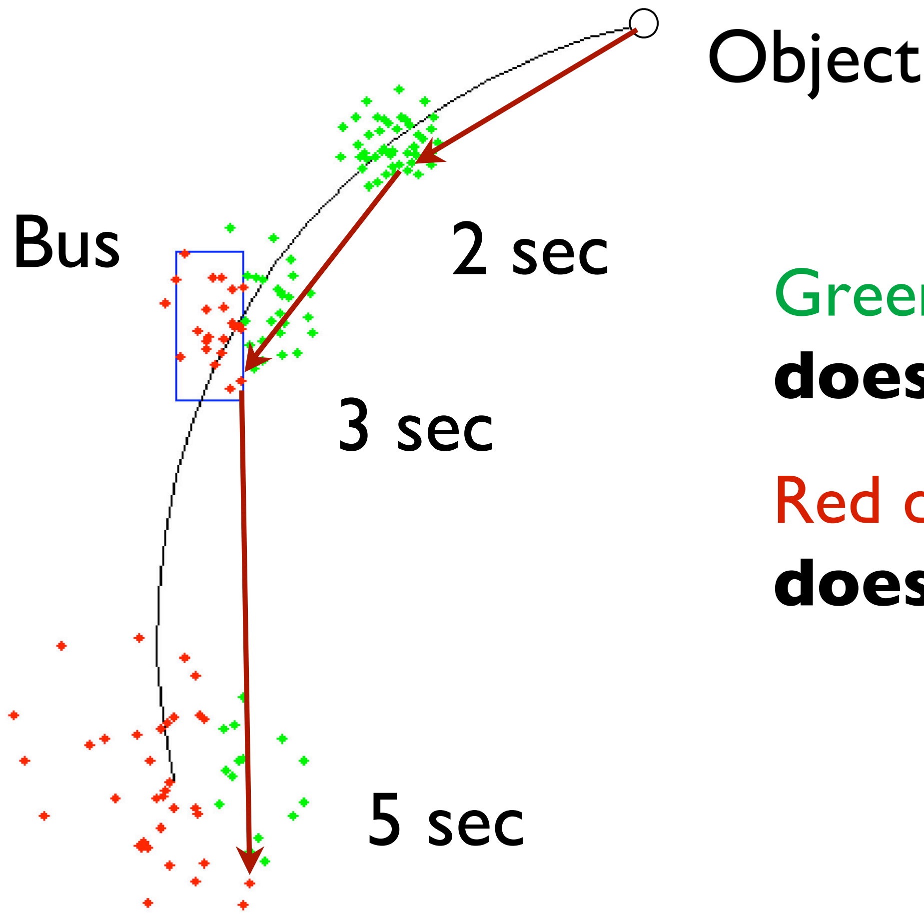
Sample Situation

Bus is turning right while object travels right to left



Calculate Threat

Randomly generated tracks in the frame of the moving bus

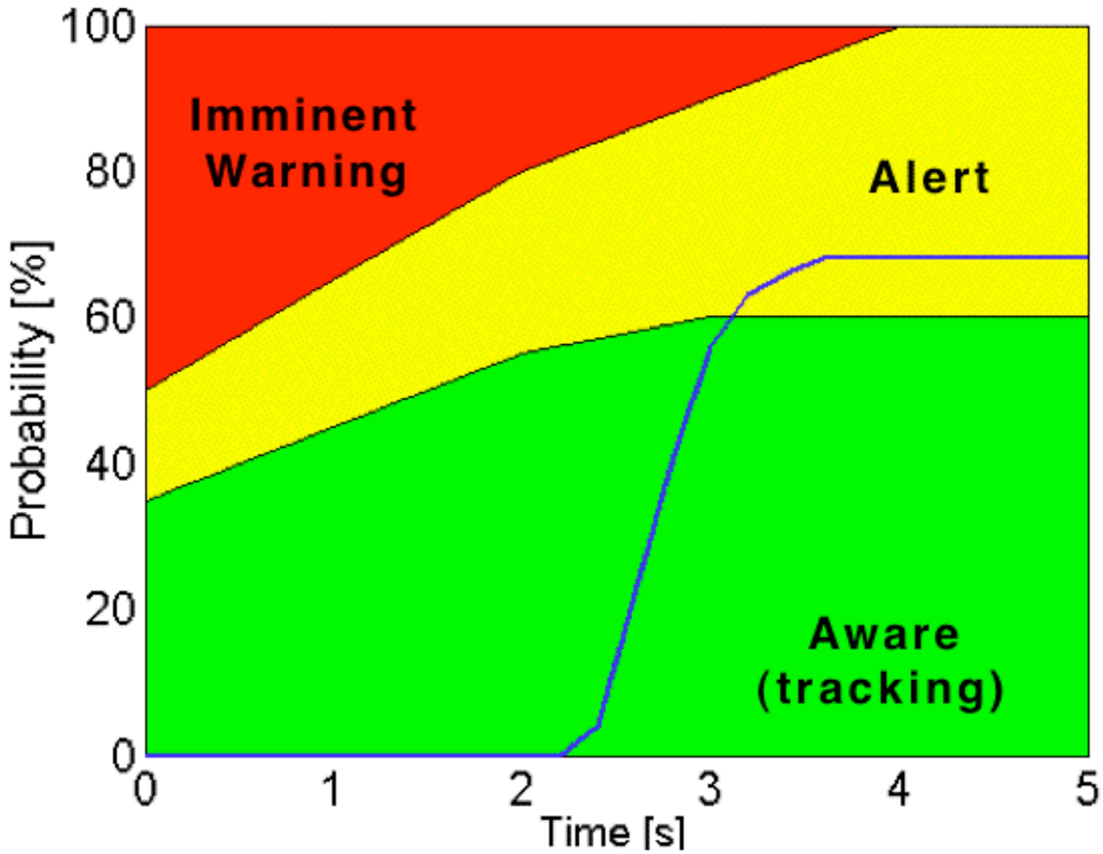


Green dots: Path of object **does not** intersect the bus

Red dots: Path of object **does** intersect the bus

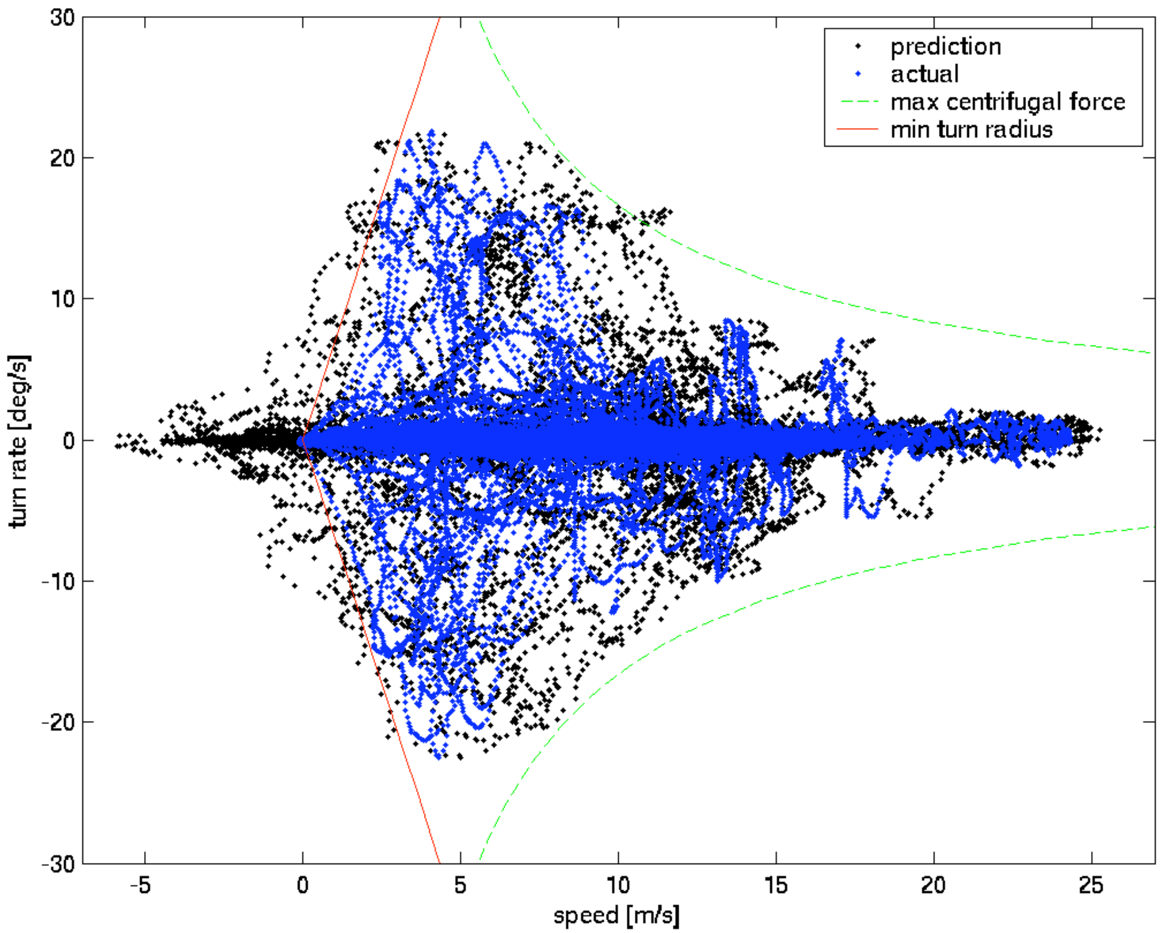
Probability Thresholds

Probability plotted in the aware-alert-warn graph



→ Alert should be triggered

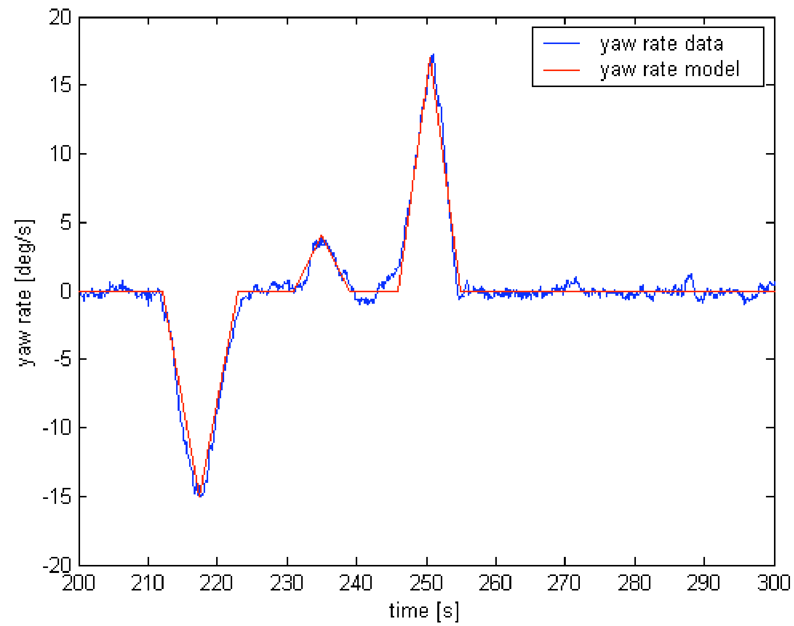
Predict



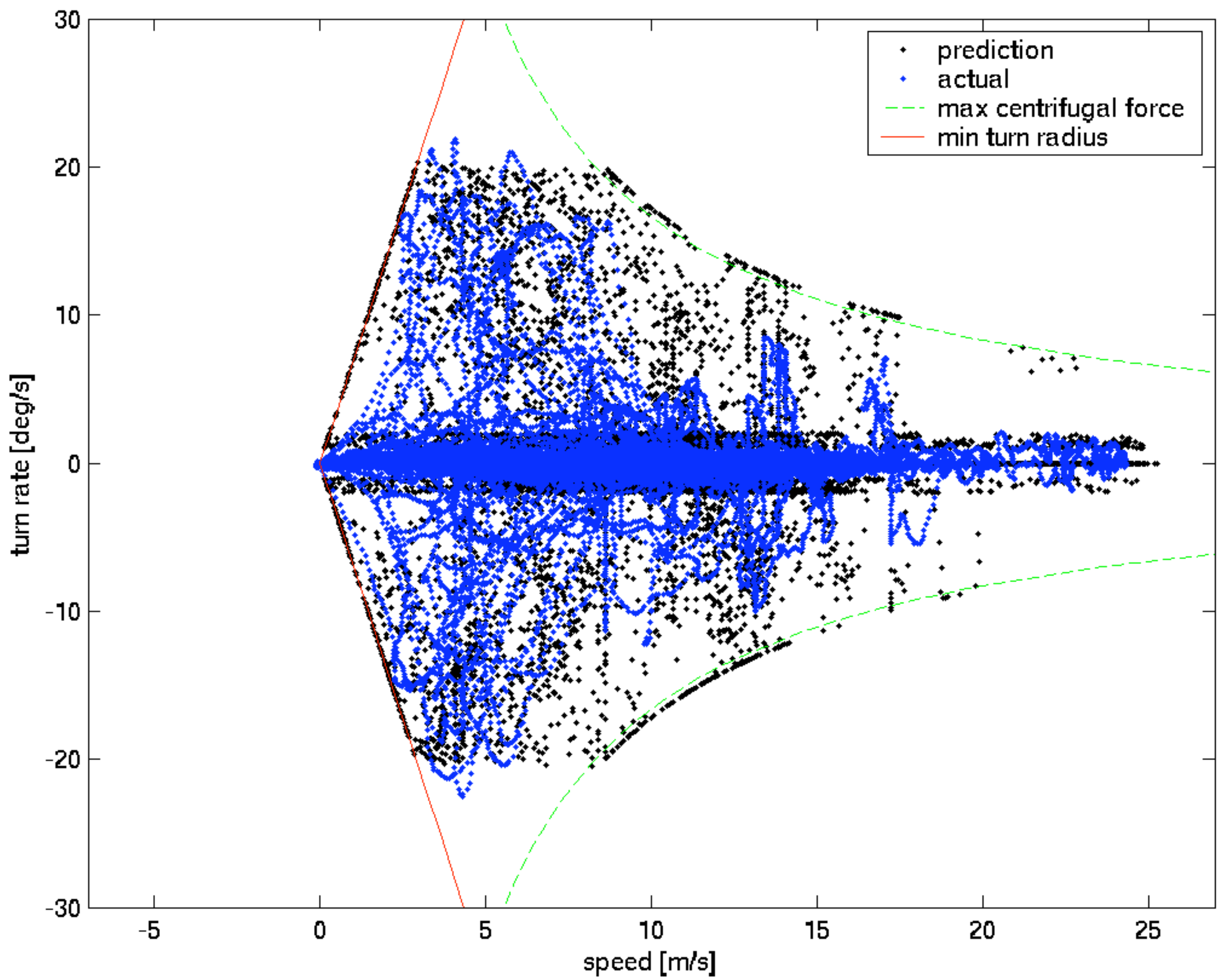
Simple prediction 3 seconds ahead using speed, acceleration, and yaw-rate

Apply Models

- Vehicle Model 1: Limits on the turning rate of the bus
- Vehicle Model 2: Speed is not negative
- Vehicle Model 3: The yaw-rate is characterized by symmetric spikes on top of zero-background.



Improved Prediction

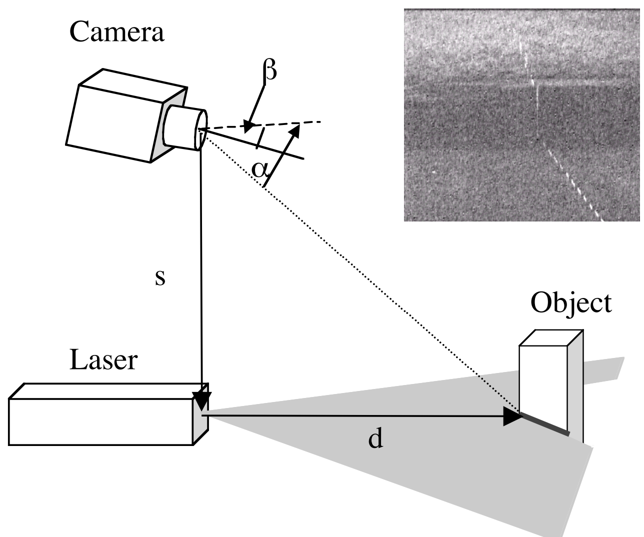


Prediction using
the 3 models,
3 second ahead

10% improvement

Pedestrian Model

(Curb detection)

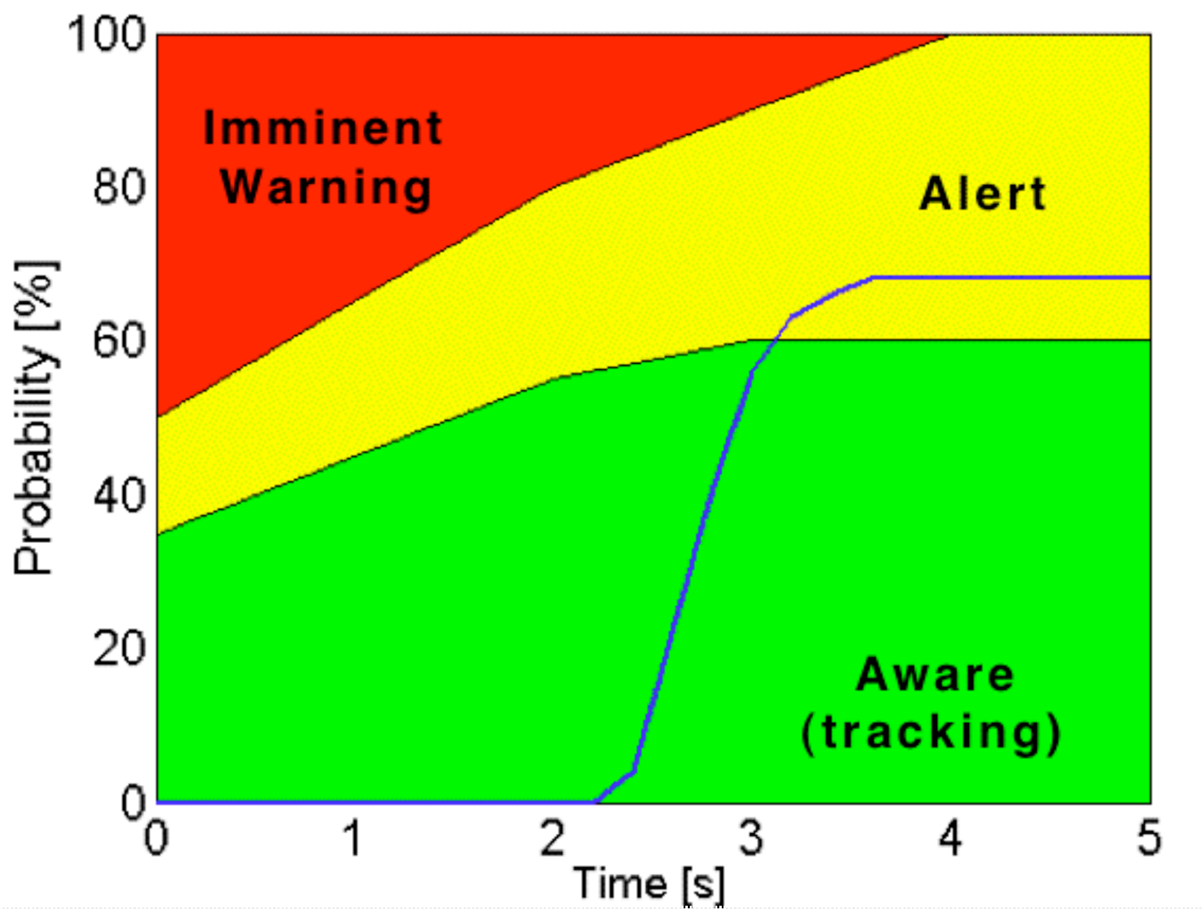


Example: Environment + Pedestrian Model

If a pedestrian is on the curb: *he/she is much more likely to stay on the curb than to step off the curb.*

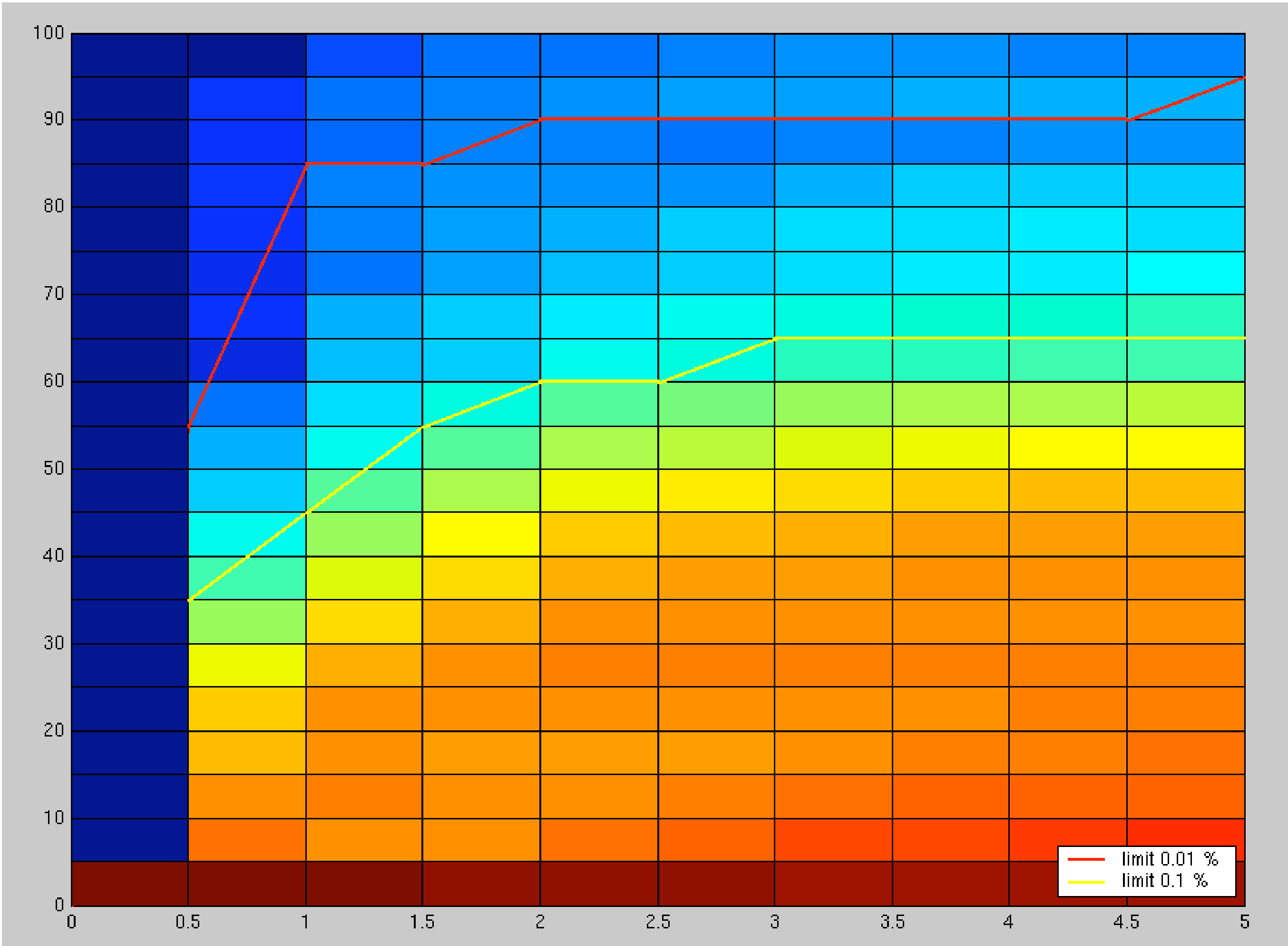
If a pedestrian is off the curb: *he/she is more likely to stay off the curb than to step on the curb.*

Determination of the Limits of Safety Levels



One curve for each object every 0.1 seconds

Distribution of All Curves of All Objects



Limits for 0.1 and 0.01 percentile (shown)

Contact and Under Wheel

- Contact
  - Object is close to bus (0.5 m)
  - Probability of collision is 100% for 0.5 sec
- Under Wheel
  - Object was close to bus (0.5 m)
  - Object disappears

Driver-Vehicle Interface

Aaron Steinfeld

Interface Paradoxes

1. Drivers agree with the philosophy of **earlier** action rather than harder action yet they would like as **few** alerts and warnings as possible
2. Nighttime drivers prefer **audible** warnings due to concern over glare while daytime drivers tend to focus on **visual** warning options
3. The warning should be salient enough to elicit a **driver** response but should not be readily noticeable by **passengers**

Institutional Concerns

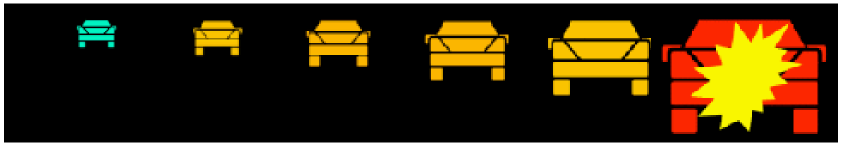
- Union-management relations
  - Monitoring
  - Preventable accidents
- Maintenance
  - Modification, durability, who fixes?
- Fraud
  - Starting gun for falls
- Customers
  - Warning = I'm in danger
  - Isn't PAT broke?

Scott Johnston (PATH)

Prior Work - Cars

- Crash Avoidance Metrics Partnership (CAMP)
  - DaimlerChrysler, Ford, GM, NavTech, Nissan, Toyota, BMW, Volkswagen

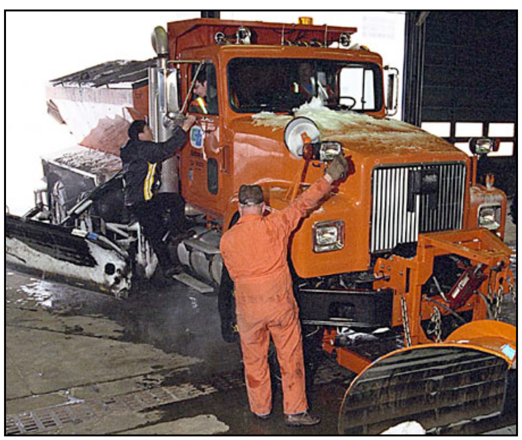
- Automotive Collision Avoidance System (ACAS UMTRI)

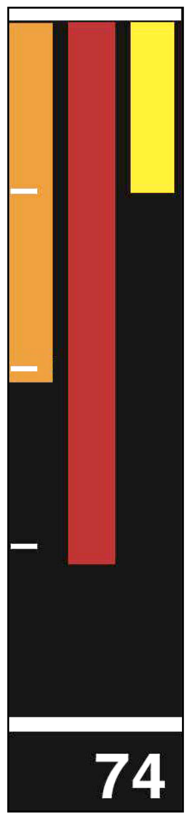


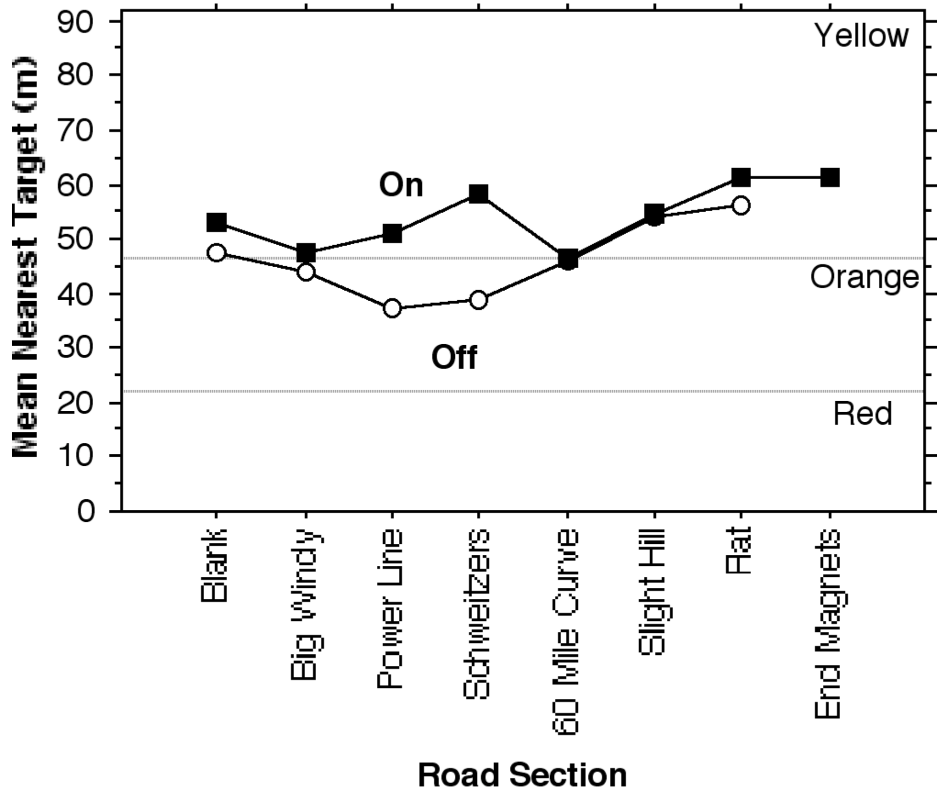
- National Advanced Driving Simulator (Iowa)

Prior Work – Snowplows

- Advanced Snowplow Project, California PATH
  - Downward moving tapes (range) with color change

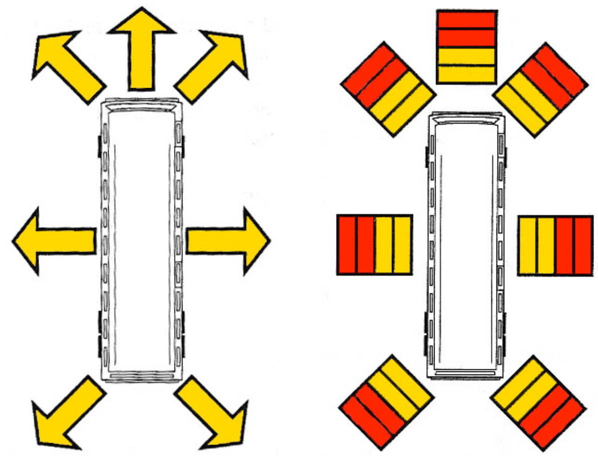






Prior Work – Buses

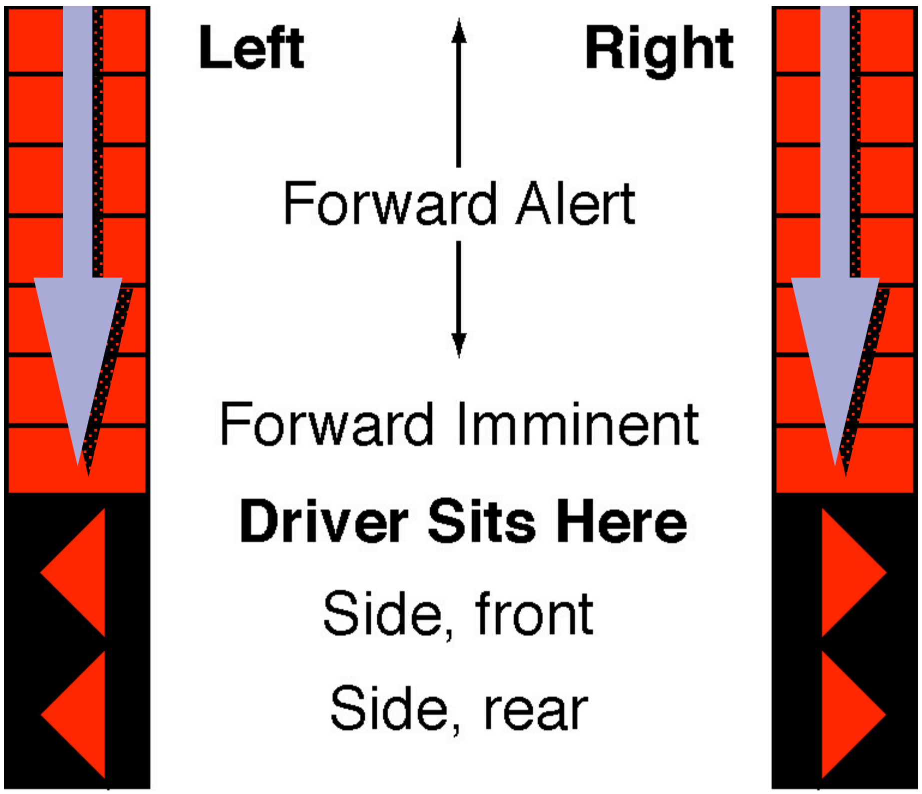
- Greyhound & PAT Phase I
  - Driver acceptance critical
- IVI SBIR (Foster Miller, top)
  - HUDs are a bad idea
  - Center console rarely used
- Blind Spot (Clever Devices, bottom)
  - Peripheral mounts are good
  - Status light is important
  - Non-invasive sounds

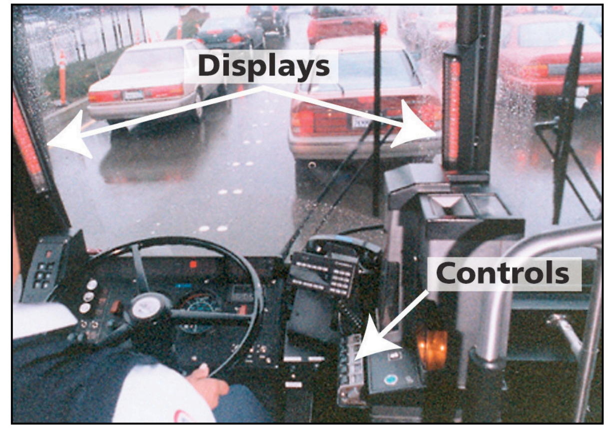


Design Rationale

- Spatial conventions
  - Downward moving tapes (looming effect)
  - Peripheral displays (promote mirror use; help vs. primary)
  - Plan view layout (positions relative to driver)
- Driver conventions – Need driver buy-in
  - Sensitivity control (Paradox 1)
  - Volume and brightness control (Paradoxes 2 & 3)
  - Status lights

Driver-Vehicle Interface

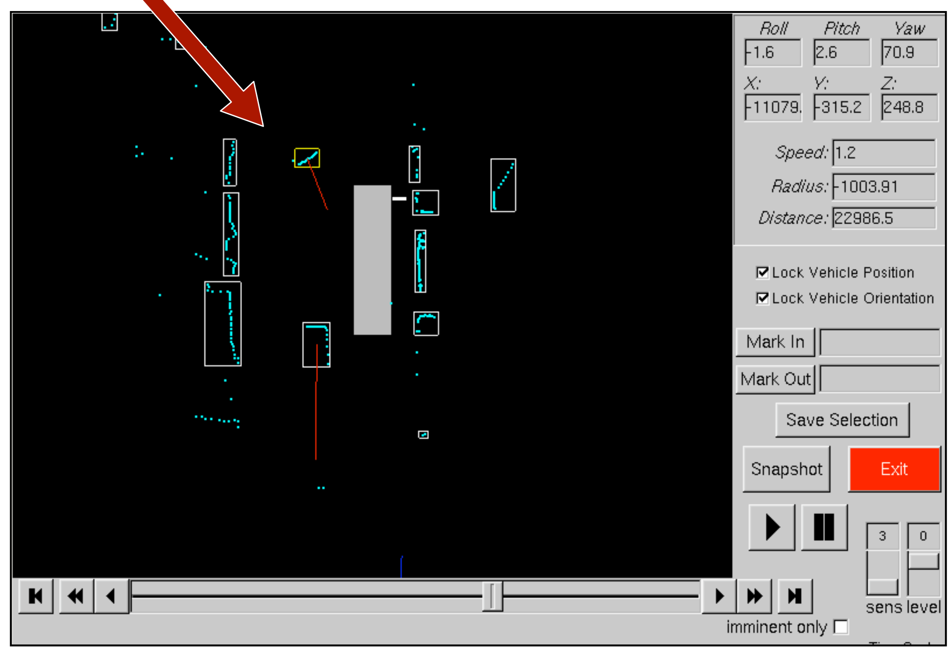




Example Data

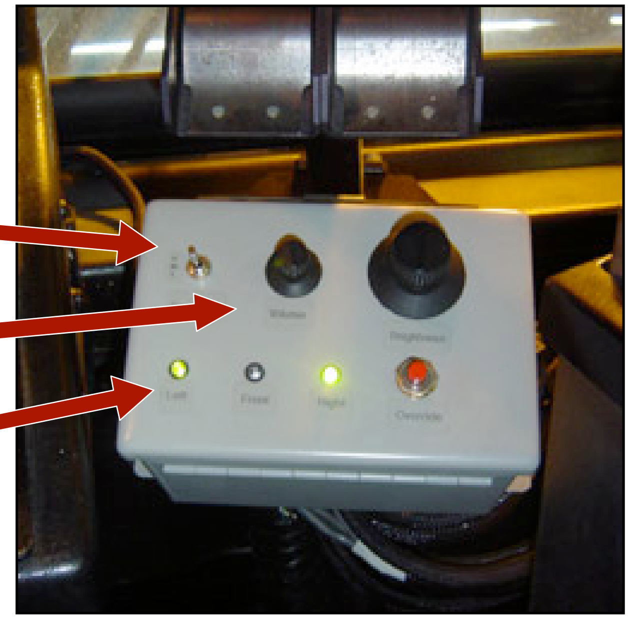
Alert warning, Right-rear

DVI LED bars



Driver Control Box

- Bounded by space
- Sensitivity
- Volume & Brightness
- Status lights
- Intentionally out of reach while driving



Field Research Hazards

- Auto retraction of side lasers
  - Durable, but also somewhat expensive
  - Bus wash infrastructure

- Harsh environment for all components
  - Hardware failures
  - Electronics failures

Auto Retraction

Data Collection

- To date (10/04): ~ 2 terabytes of data

	PAT	SamTrans
km	7,000	8,100
Hours	213	280
Runs	127	250

- Will continue through the winter

Finally...

- You need a partner in the transit agency
  - Dan DeBone and Robin Rochez, Port Authority Transit (PAT) of Allegheny County
  - Frank Burton, San Mateo County Transit District (SamTrans)

- cmertz@andrew.cmu.edu, steinfeld@cmu.edu
- http://www.ri.cmu.edu/labs/lab_28.html