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Intelligent Transportation Management

CEE@UCI Affiliates Quarterly Event, Irvine, CA, May 8, 2024

How intelligent are we?

- We spend a lot of time stuck at signals. Do we have more intelligent schemes that we can use and the technology to implement it?
  - Eco-Driving to save time and energy
  - Link-based control

- What intelligent transformations are possible for the transportation systems change in the near future, and over the next few decades
  - Shared and autonomous systems
  - User-exchanges (paying each other!)

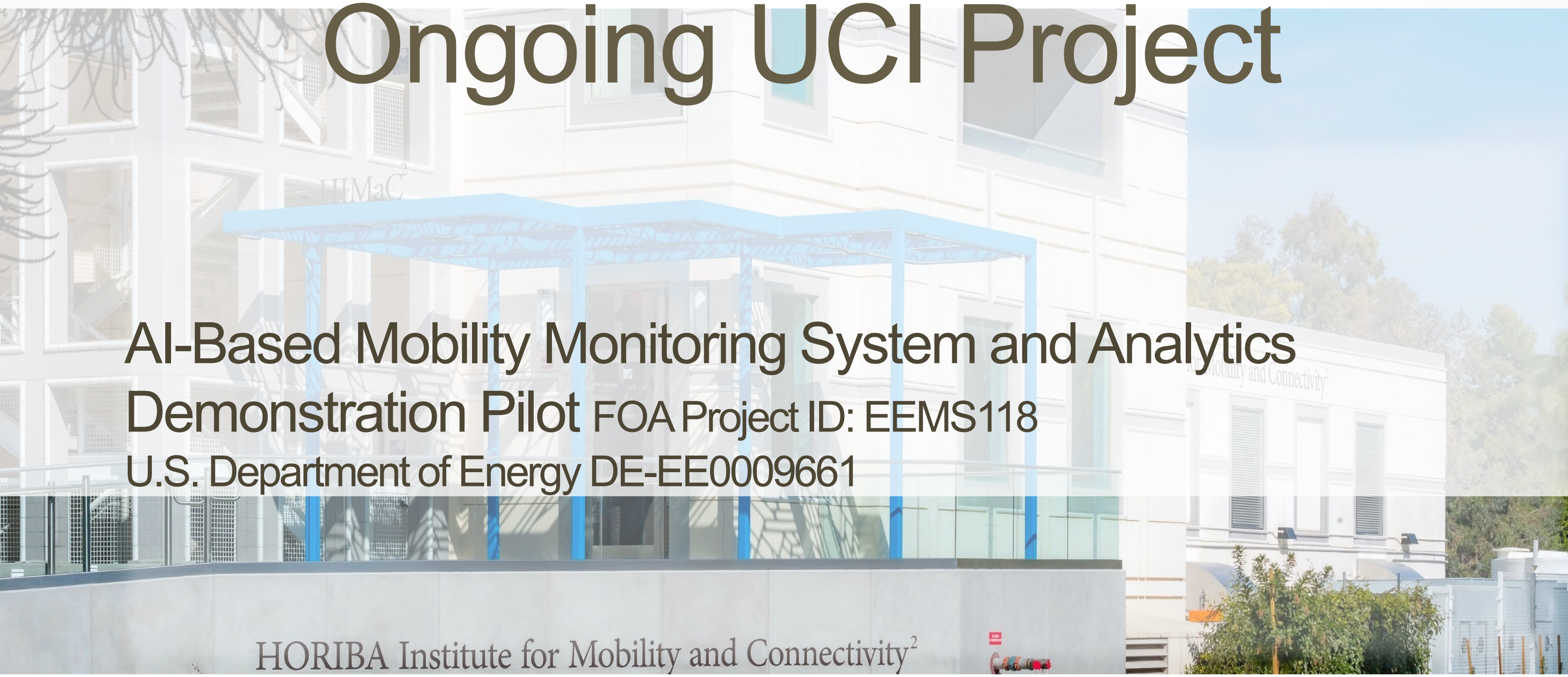
Optimal Use of System Capacity?

Connected/Autonomous Vehicles

California Field Test (PATH AHS, 1992)
– Connected/Autonomous platoon –

Traffic Control, London, 1868

Ongoing UCI Project



AI-Based Mobility Monitoring System and Analytics Demonstration Pilot FOA Project ID: EEMS118

U.S. Department of Energy DE-EE0009661

UCI (Scott Samuelson, Stephen Ritchie, R. Jayakrishnan, Michael Hyland, Blake Lane, Craig Rindt, Pengyuan Sun, Tanjeeb Ahmed, Vojislav Stamenkovic)

ANL (Michael Pamminger, Qian Peng, Felipe de Souza, Miriam Di Russo, Kevin Stutenberg, Thomas Wallner)

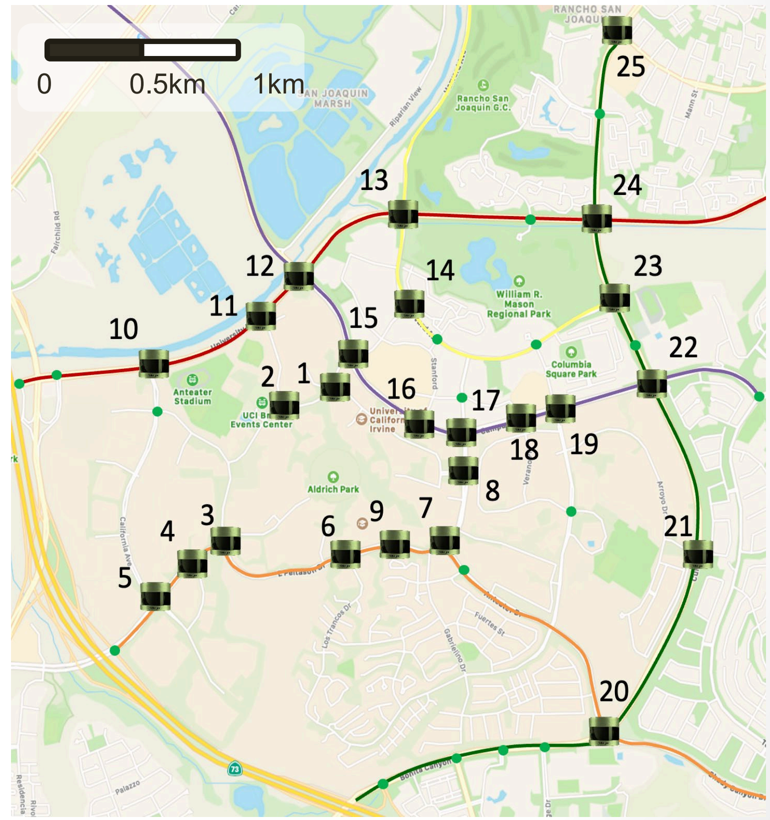
Lidar-Based Intelligent System

LiDAR
+
Artificial
Intelligence
(AI)
on Edge
Box

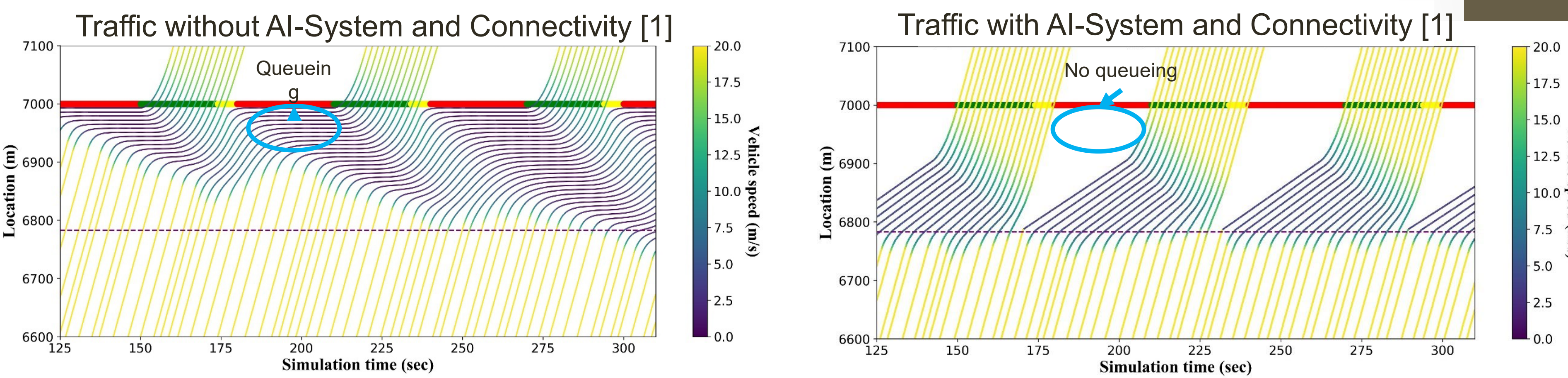
AI-System Installation

AI-Systems being installed on **public roads** both in the City of Irvine and UC Irvine, effectively **two municipalities**

***Public Road Network Platform* 25 Intersections**



Eco-driving V2I Controller for intersection efficiency



[1] Sun, Nam, Jayakrishnan, Jin, 2022. An eco-driving algorithm based on vehicle to infrastructure (V2I) communications for signalized intersections. *Transportation Research Part C,* 144 103876.

Vehicle control methods

A3-c Precise Control: Dynamic Real-Time Trajectory Smoothing Algorithm (DRTSA)

Speed oscillation minimization

$$\min_{\{a_i\}} Z_m = \frac{1}{m}\sum_{i=0}^{m-1}(a_{i+1} - a_i)^2$$

$$\sum_{i=1}^{m} v_i \times \Delta t = x_q - x_p$$

$$v_i = v_p + \sum_{j=1}^{i} a_1 \times \Delta t \, , \forall i \in [1, m]$$

$$v_m = v_q$$

$$v_i \in [0, v_f], \forall i \leq m$$

$$a_i \in [a_{min}, a_{max}], \forall i \leq m$$

Algorithm 1: Dynamic Real-Time Trajectory Smoothing (DRTSA)

For every CAV during the time interval (t_p, t_q):

Initialization:

$m = 2$

Solve $Z_2 = \Theta_{(t_p,t_q)}[a_1, a_2]$, $Z_3 = \Theta_{(t_p,t_q)}[a_1, a_2, a_3]$;

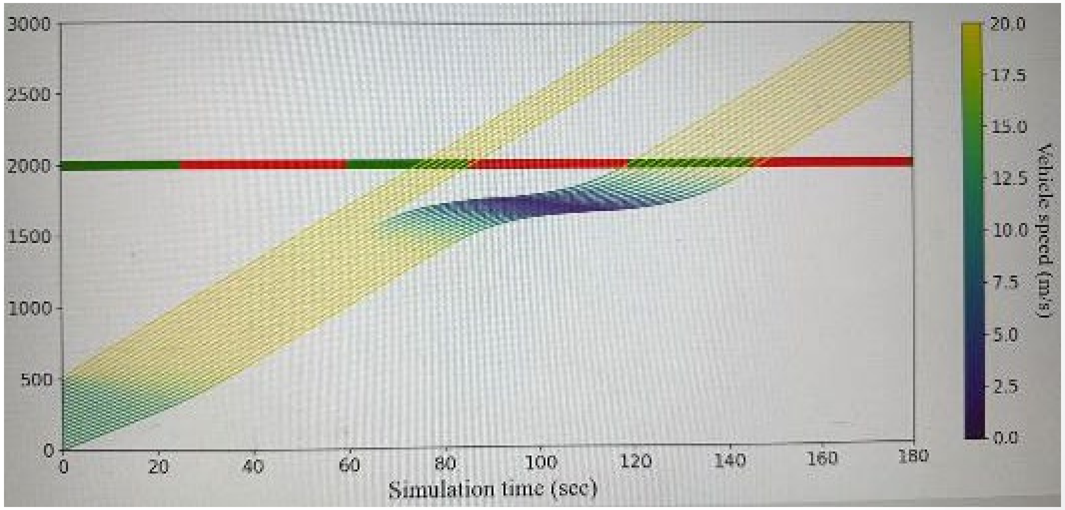
While $|Z_m - Z_{m+1}|/Z_m > \epsilon$ **do**

$m += 1$

Solve $Z_{m+1} = \Theta_{(t_p,t_q)}[a_1, a_2, a_3 \ldots, a_{m+1}]$;

End

Return: Z_{m+1}, $(a_1, a_2, a_3 \ldots, a_{m+1})$



P5: (Forthcoming) Sun, P.*, Yang D. the Dynamic Real-Time Trajectory Smoothing Algorithm for the Vehicle control under various traffic scenarios.

P3: Sun, P.*, Yang D., and Jayakrishnan, R., 2021. A Dynamic Real-Time Trajectory Smoothing Algorithm for the Vehicles Behind a Moving Bottleneck in Mixed Traffic. Transportation Research Board 100th Annual Meeting. Washington D.C.

Vehicle in the loop (Argonne NL)

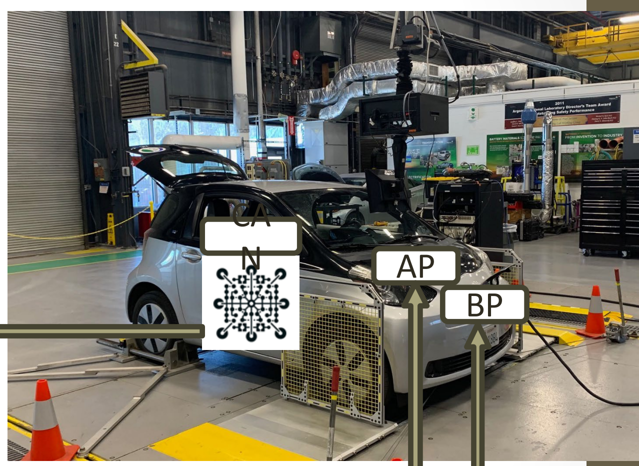
Tools

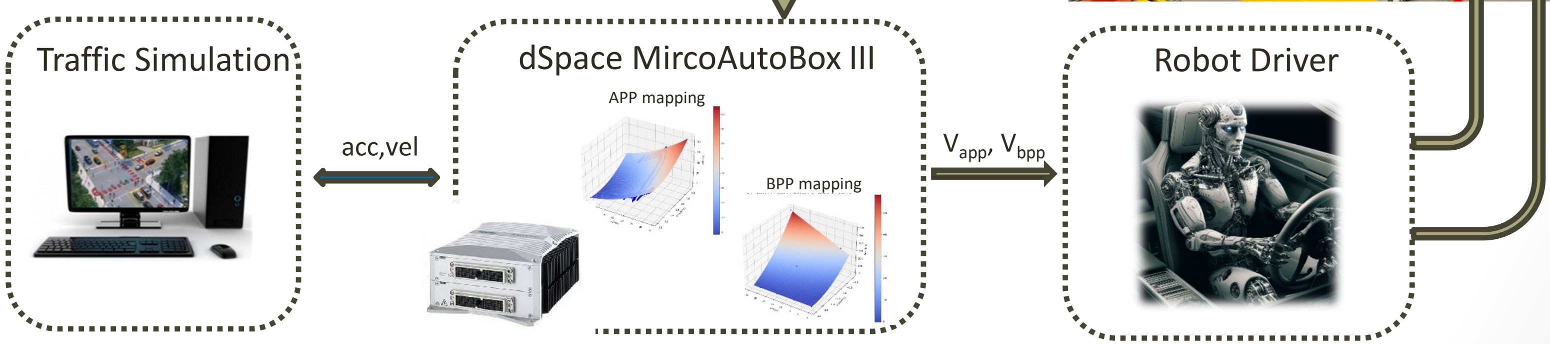
- Vehicle under test: 2012 Scion iQ EV
- Dyno: Simulated road load based on virtual vehicle conditions
- XiL hardware: dSPACE MicroAutoBox III, custom robot driver

Approach

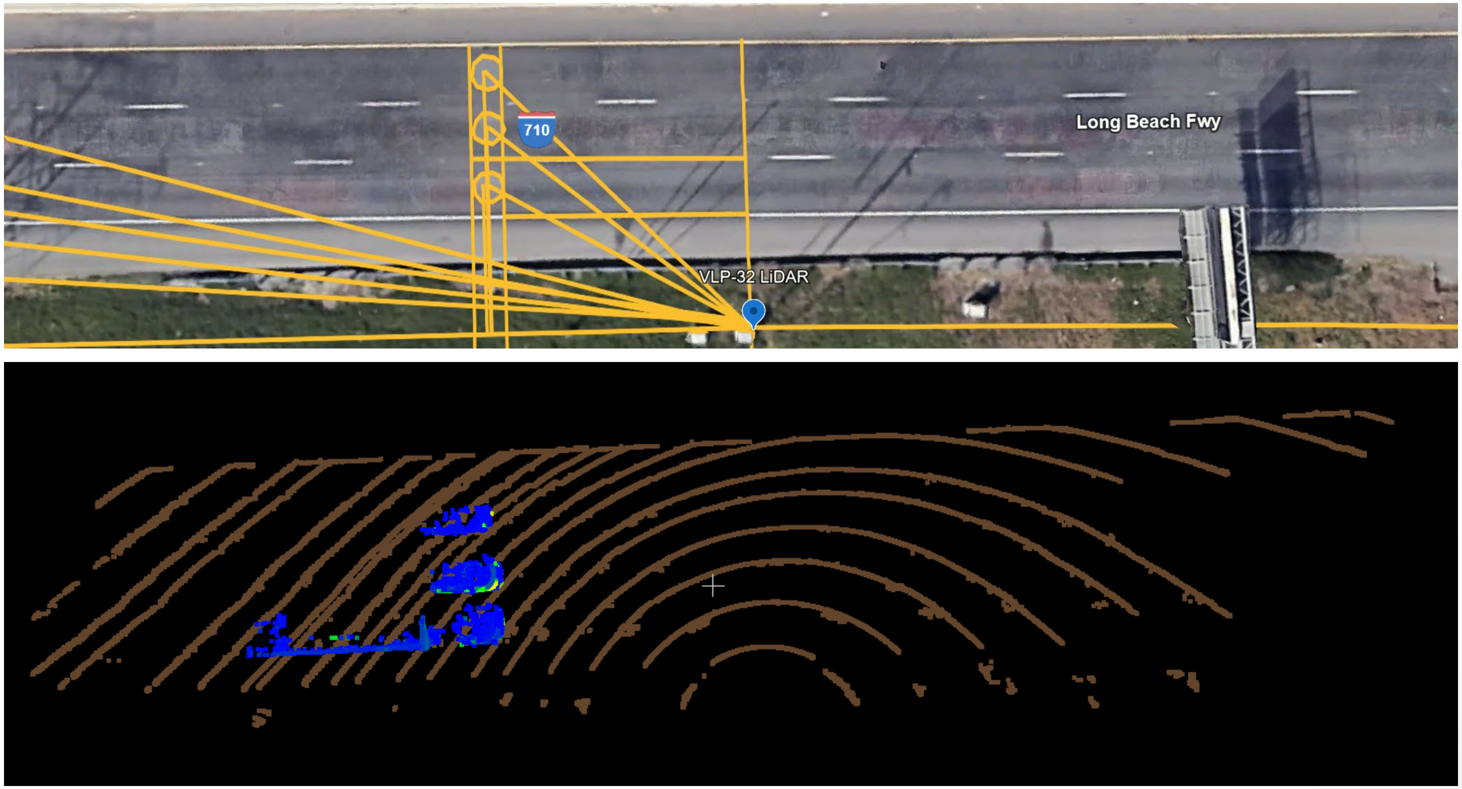
- Tested 12 scenarios in XiL with varying AI-System activation, traffic density, free flow speed, and control speed
- In each scenario, three vehicles were selected for XiL testing
    1. Vehicle with fuel consumption closest to the fleetwide average
    2. Vehicle with the lowest fuel consumption
    3. Vehicle with the highest fuel consumption

ANL XiL Experimental Setup with Scion iQ EV



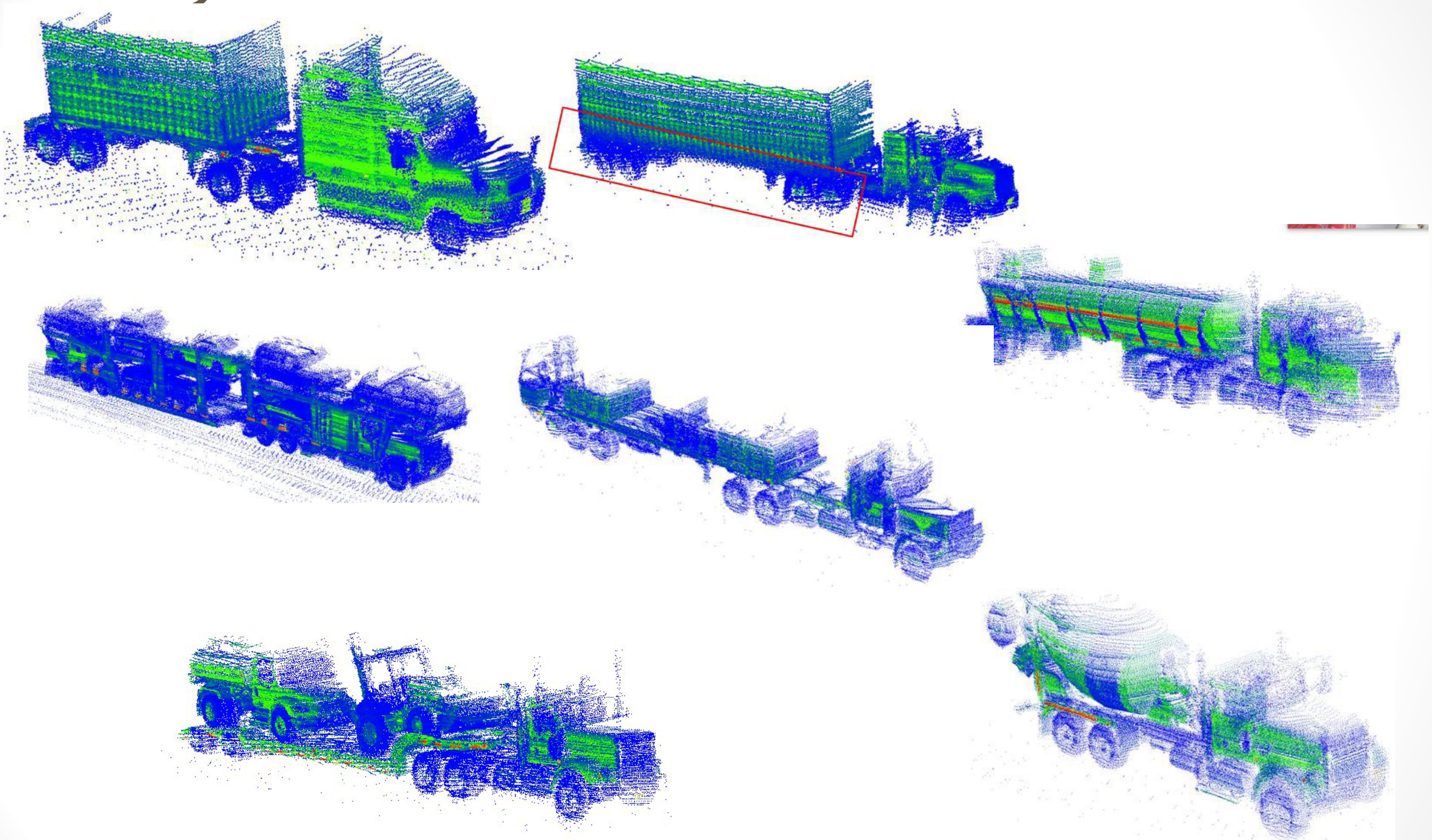


Detection - LiDAR Virtual Loops



Courtesy: Dr. Koti Allu, Prof. Stephen Ritchie, ITS UCI

Object identification



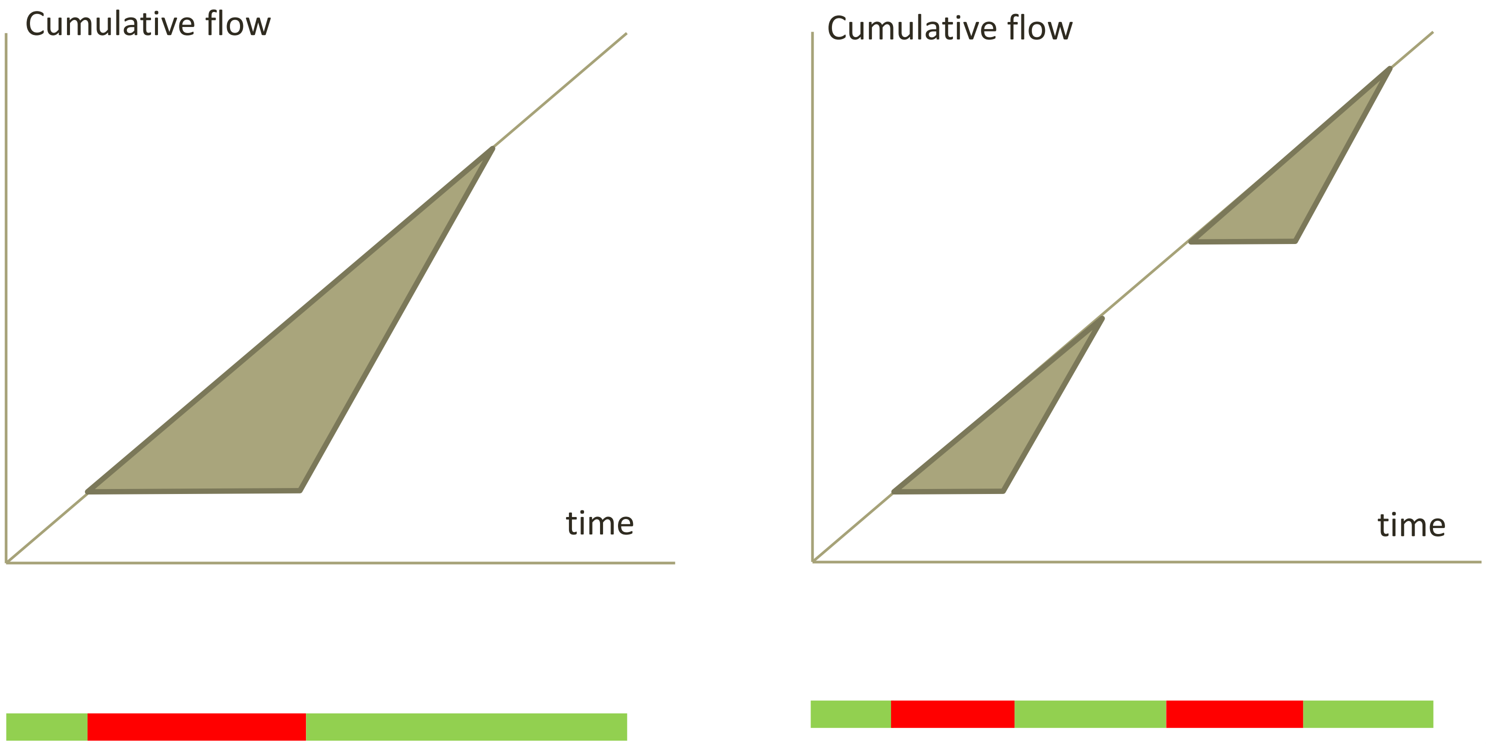
Area-wide detection. AI algorithms can provide individualized speed advisories based on vehicle type the driving pattern from detected trajectories

So what is wrong with traffic control now?

Using red and green lights in cycles,

- Two streams are allowed at a time.
- We do not allow traffic streams with *crossing conflicts* to move at the same time, for safety reasons.
- Some streams of *merging flows* (from right turns) are allowed, unless otherwise specified for congestion reasons (*not safety reasons*)
- ***We assume that merging/through movements are totally safe but crossing/conflicting movements are prohibitively unsafe*.**

Signal Cycle effect we forget

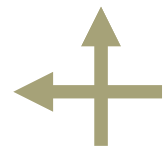


Idealized case. Total queue delay is the triangle area.
Cut the cycle length to half, delays become half.

Intelligent Link-based control

But, **in a perfect world** with *no vehicle stoppage and no lost times*, **what is the best cycle length**?

As small as we can make it!



- One vehicle per green!
- ~1.8 seconds green time. Or drop green and red signals altogether.

- **Stop fearing crossing movements and conflicts!! Need to use gaps in the cross flow to release one vehicle every 1.8 second.**
  - **Use collision avoidance technology which is not expensive anymore**

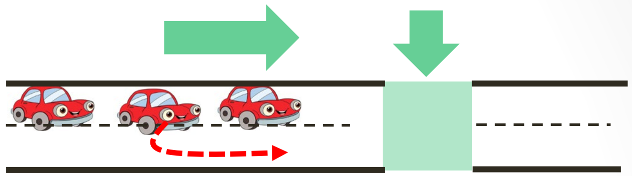
So **stop the cars upstream** and do **timed-release one by one**, to **go through gaps**? (Like Fwy Ramp signals). We create perfect gaps between vehicles, so almost no stops

We call this **Link-Based Control**

Link-based flash-signal control models

B2-d: Time and lane Optimization (TLO):

- find the best order/sequence of the vehicles from the best(optimal) traffic lane



$$t_i^{l,r} = \begin{cases} \text{the exit time} & \text{if } i \text{ leaves } l \text{ from } r \\ 0 & \text{otherwise} \end{cases}$$

$$p_i^{l,r} = \begin{cases} 1 & \text{if } i \text{ leaves } l \text{ from } r \\ 0 & \text{otherwise} \end{cases}$$

Min:

$$\sum_{l} \sum_{i \in l} \sum_{r \in R_i} (t_i^{l,r} + p_i^{l,r} q_i^{l,r})$$

Subject to:

$$\begin{cases} t_i^{l,r} \leq \lambda p_i^{l,r} \\ t_i^{l,r} \geq 0 \\ \forall l;\ \forall r \in R_i; \forall i \in l \end{cases}$$

$$\sum_{r \in R_i} p_i^{l,r} = 1 \qquad \forall l; \forall i \in l$$

$$t_i^{l,r} \geq a_r p_i^{l,r} \qquad \forall r;\ \forall i \in r; z_r \in A$$

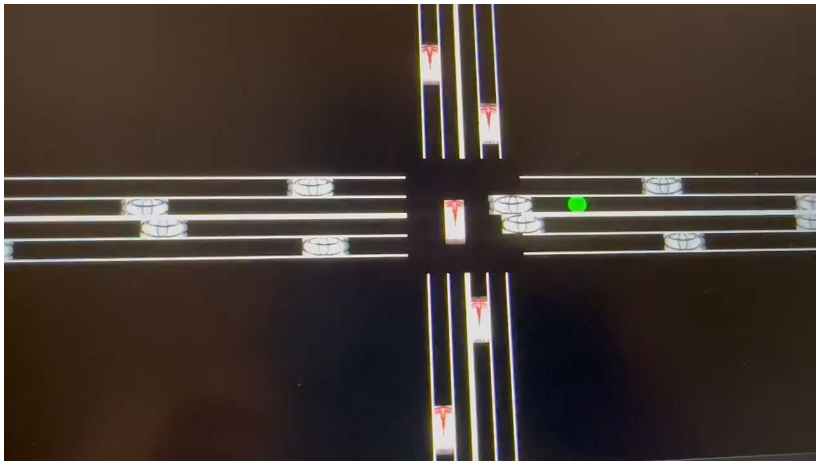
$$v_i^f (t_i^{l,r} - t) - x_i^{l,r} \geq \lambda (p_i^{l,r} - 1) \qquad \forall l;\ \forall r \in R_i; \forall i \in l$$

$$(x_i^{l,r} - x_j^{l,r})(t_i^{l,r} - t_j^{l,r}) p_i^{l,r} p_j^{l,r} \leq 0 \qquad \forall r;\ \forall i,j \in r$$

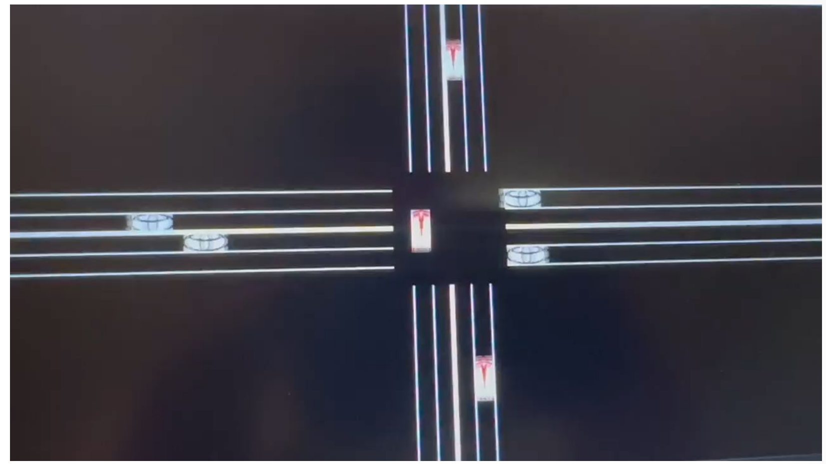
$$\begin{cases} t_i^{l,r} \geq (t_j^{k,s} - \lambda y_{i,j}) p_i^{k,s} p_j^{l,r} \\ t_i^{l,r} \geq (t_j^{k,s} + z_{s,r} - \lambda y_{i,j}) p_i^{k,s} p_j^{l,r} \\ t_j^{k,s} \geq (t_i^{l,r} - \lambda y_{j,i}) p_i^{k,s} p_j^{l,r} \\ t_j^{k,s} \geq (t_i^{l,r} + z_{r,s} - \lambda y_{j,i}) p_i^{k,s} p_j^{l,r} \\ y_{i,j} + y_{j,i} = 1 \\ \forall j \in k; \forall i \in l; \forall r \in R_i; \forall s \in R_j; z_{s,r} \in Z \end{cases}$$

P6: (forthcoming) Sun, P.* and Jayakrishnan, R., (2024). A Link-based Traffic Control Concept with Efficient Vehicle Movements

Link-based control simulation



FIFO, safety buffer = 0.1s



FIFO, safety buffer = 0.5s

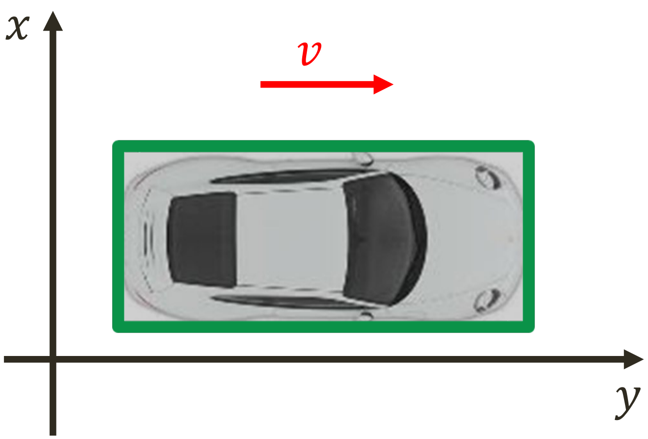
How to evaluate the safety?

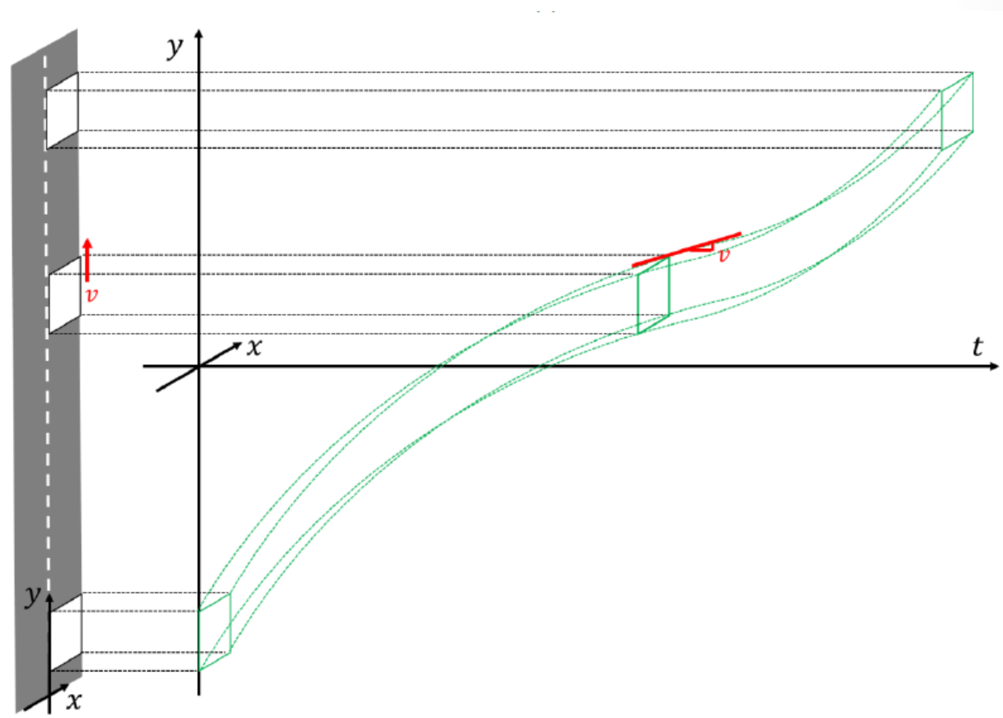
we have: **Vehicle Tube Model**!

P6: (forthcoming) Sun, P.* and Jayakrishnan, R., (2024). A Link-based Traffic Control Concept with Efficient Vehicle Movements

Vehicle Tubes concept for safety studies

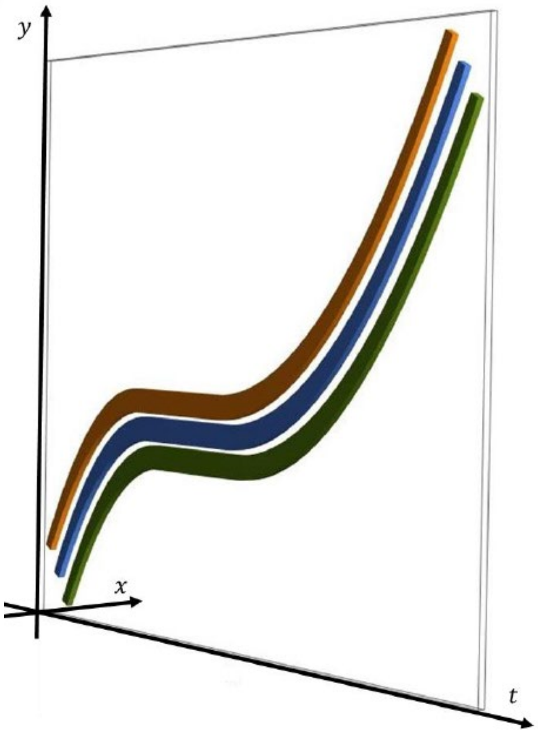
From 2D(x-y) to 3D (x-y-t) space:

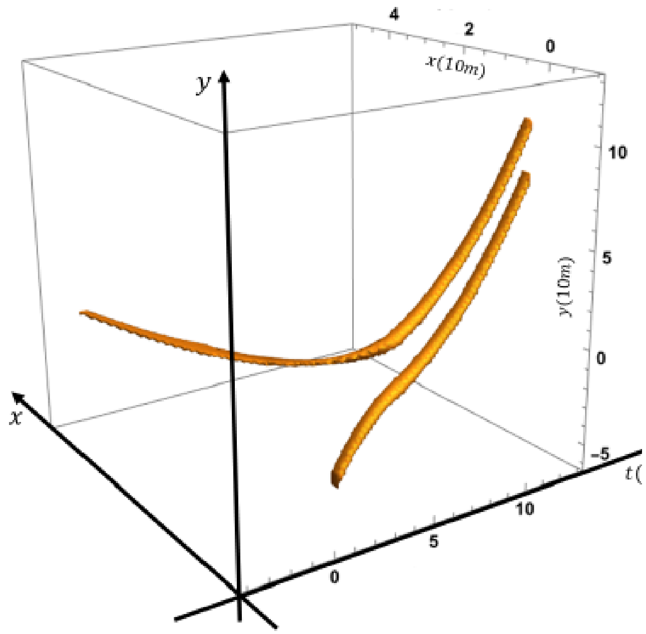


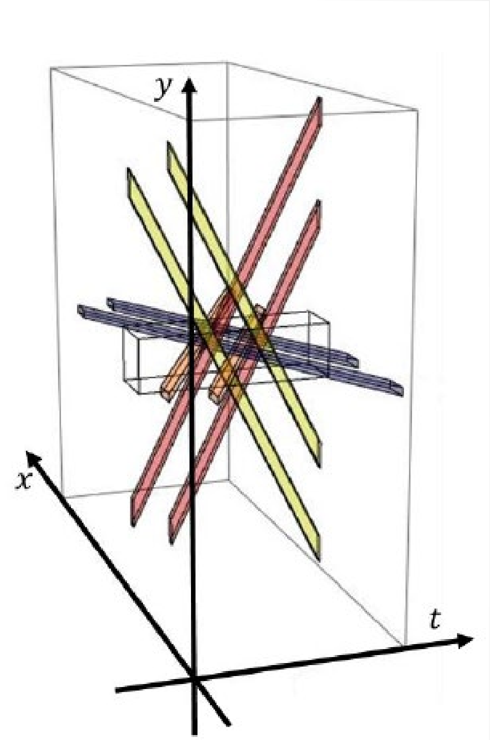


P8: (forthcoming) Sun, P.*, Jayakrishnan, R. The Vehicle Tube Model: A Dynamic Representation and the Theory for Vehicle Accident Analysis.

Vehicle Tubes – safety study







Stop-and-go movement

Turning vehicle

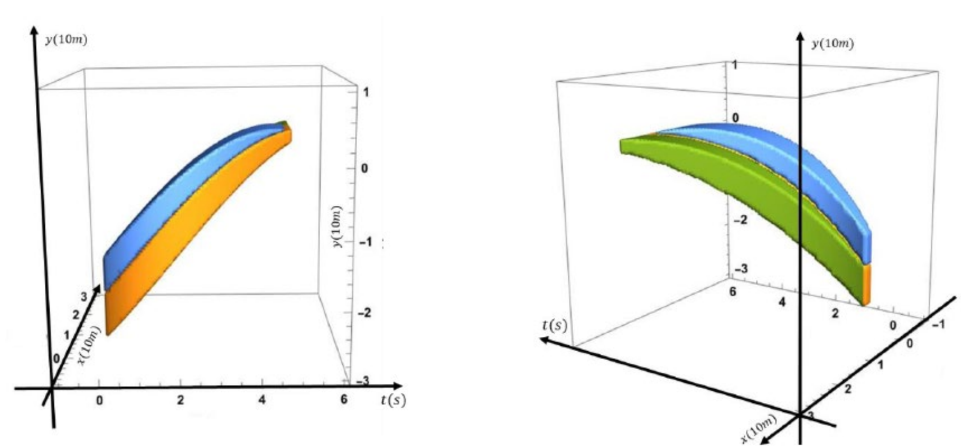
No-stop intersection (Link-based control)

Overlap volume → Risk probability surrogate?

P8: (forthcoming) Sun, P.*, Jayakrishnan, R. The Vehicle Tube Model: A Dynamic Representation and the Theory for Vehicle Accident Analysis.

Vehicle Tube – Accident risk estimation

Make vehicle influence space into tubes and get overlap volumes:



- Risk Probability at a time

$$P_{\lambda}^{n,m} = \begin{cases} 100\% & if \;\; R_m^A \cap R_n^A \neq \emptyset \\ \oiint_{\sigma_1} \rho_n \, dA \oiint_{\sigma_1} \rho_m \, dA + \oiint_{\sigma_2} \rho_n \, dA + \oiint_{\sigma_3} \rho_m \, dA & otherwise \end{cases}$$

- Average Risk Probability over a period

$$\bar{P}_{\lambda}^{m,n} = \frac{1}{T_n^2}\left(\oiiint_{Y_1^{m,n}} \rho_n dV \oiiint_{Y_1^{m,n}} \rho_m dV + T_n \oiiint_{Y_2^{m,n}} \rho_n dV + T_n \oiiint_{Y_3^{m,n}} \rho_m dV \right)$$

P8: (forthcoming) Sun, P.*, Jayakrishnan, R. The Vehicle Tube Model: A Dynamic Representation and the Theory for Vehicle Accident Analysis.

Autonomous Vehicles

- Rides can be matched without spatial proximity of riders.
  - *Because the cars can drive themselves. Travelers' spots not important*
- Parking infrastructure will change –
  - *Because the cars park themselves at cheaper locations*
- Shared Car-ownership & Mobility Portfolios - *a key possibility*
  - *"For Rs. 15,000 a month (1/3rd cost!), get 5 hours a year of a Lamborgini, 200 hours of a Maruti Swift, 200 hours of a Bajaj auto-auto, 50 hours of a 7 seater Innova, 100 hours of shared rides"*
- Lanes can disappear! - Virtual lanes? *Dynamic road-space-slots?*
- Vehicles with "safety bubbles" around it - *Fight for space?*
- Negotiated "mixed-bubbles" flow? - *The smaller the ellipse, the better*
- It pays to pool? - *Have more people in your vehicle. Cheaper to pay others for space for your "vehicle bubble" to move on the road*.

The world finally can catche up with the optimal traffic flow in India!

More possibilities…

So what else can happen in future?

Mobility Transformation in Future

- **Users negotiating with each other or with a facilitating broker**
  - "***I will pay $2 for a green extension at the intersection right now! Can 10 of you cars wait for 15 seconds and get paid?***"

Mobility Transformation in Future

- **Users negotiating with each other or with a facilitating broker**
  - *"I will pay $2 for a green extension at the intersection right now! Can 10 of you cars wait for 15 seconds and get paid?"*

Transportation Research Part B 94 (2016) 22–42

Contents lists available at ScienceDirect

Transportation Research Part B

journal homepage: www.elsevier.com/locate/trb

Envy-minimizing pareto efficient intersection control with brokered utility exchanges under user heterogeneity

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Mobility Transformation in Future

- **Users negotiating with each other or with a facilitating broker**
  - “***Can you change lanes and make way for me to go to the hospital? I will pay you 15 cents…***”

Mobility Transformation in Future

- **Users negotiating with each other or with a facilitating broker**
  - *"Can you change lanes and make way for me to go to the hospital? I will pay you 15 cents…"*

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22nd International Symposium on Transportation and Traffic Theory

Envy-free Pricing for Collaborative Consumption of Supply in Transportation Systems

Roger Lloret-Batlle [a,1], R. Jayakrishnan [a]

[a] Civil and Environmental Engineering Department, Institute of Transportation Studies, University of California, Irvine, USA

Mobility Transformation in Future

- **Users negotiating with each other or with a facilitating broker**.
  - “***Uger says it is cheaper to pick me up before you. Can I pay you $5 to wait for 10 minutes?***”

Mobility Transformation in Future

- **Users negotiating with each other or with a facilitating broker**.
    - *"Uger says it is cheaper to pick me up before you. Can I pay you $5 to wait for 10 minutes?"*

Transportation Research Part E 102 (2017) 60–77

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Using bilateral trading to increase ridership and user permanence in ridesharing systems

CrossMark

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Mobility Transformation in Future

- **Users negotiating with each other or with a facilitating broker**.
  - [Autonomous Car says] "***FemEx will pay me $5 for an urgent package pick-up and drop near your house. Can I give you $2 to wait 10 min?***"

Mobility Transformation in Future

- **Users negotiating with each other or with a facilitating broker**.
  - [Autonomous Van says] "***Can you three small cars move 2 feet each for me to park here? I'll pay $2 to each of you.***"

Mobility Transformation in Future

- **Users negotiating with each other or with a facilitating broker, within a subscription mobility system**.
  - [Autonomous Mobility Service, like your phone company, says] "***You have used up all of your 100 hours on a Hyeondae 4-seater. You can use from the 75 hours from your 2-seater Fjord Focus-mini, or offer your drive-way for our vehicle parking use***."

"Mobility Portfolios" - An Sunghi, PhD Dissertation, UCI, 2022

Concluding thoughts

- **There are plenty of intelligent ideas humans can still come up with.**
- **The reason to look for AI should not be any thinking that our own intelligence has reached a dead-end.**
- **But AI is a reality now. Embrace it, and let us feed better intelligence from us to the machines to learn from.**

THANK YOU!!