Making Intersections Safer with I2V Communication

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Why focus on intersections?

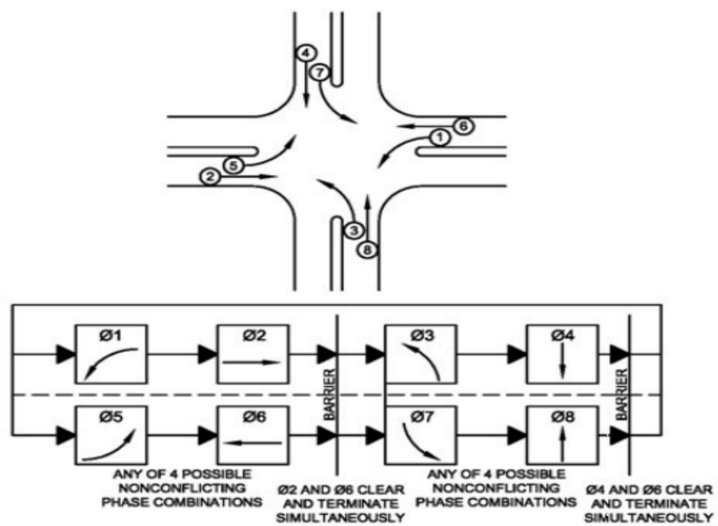
Intersections are small killing fields:

✦2.5M intersection accidents annually: 40 % of all crashes, 50 % of serious collisions, 20 % of fatal collisions.

✦Red light runners cause estimated 165K accidents and 700-800 fatalities.

✦96 % of drivers fear being struck by a red-light runner, 56 % of Americans admit to running red lights.

Two policy prescriptions: Vision Zero and Automated Vehicles.



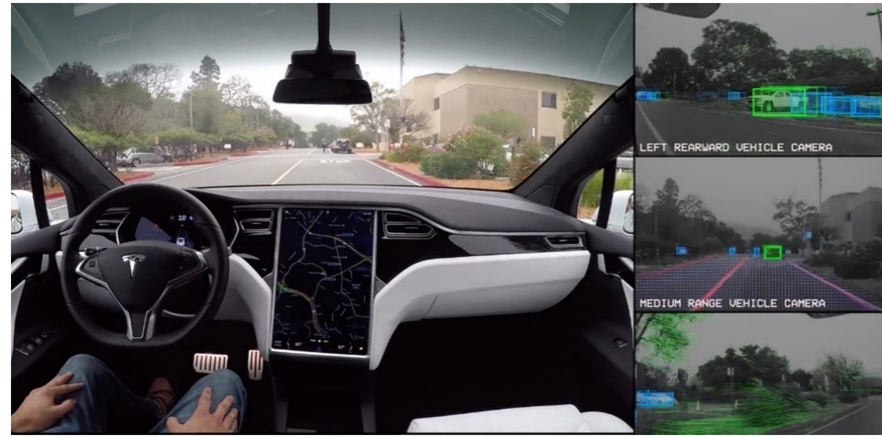
The promise of Automated Vehicles (AVs)

"Every year, 1.2 million lives are lost to traffic crashes around the world … A common element of these crashes is that 94% involve human error … We believe our technology could save thousands of lives now lost to traffic crashes every year" – Waymo Safety Report (2017)

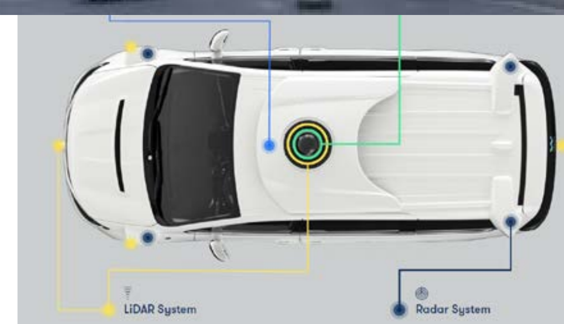
AVs rely on deep learning and simulation

- Elon Musk

  "Once you solve cameras for vision, autonomy is solved; if you don't solve vision, it's not solved … You can absolutely be superhuman with just cameras." TED Talk, minute 14: https://blog.ted.com/what-will-the-future-look-like-elon-musk-speaks-at-ted2017



- Waymo
  - 3.5 M real world autonomous miles driven
  - Predict intentions of other agents
  - Visualize everything we see (XView)
  - Model scenarios (Carcraft)
  - 20,000 simulations per scenario
  - Waymo Safety Report: https://waymo.com/safetyreport



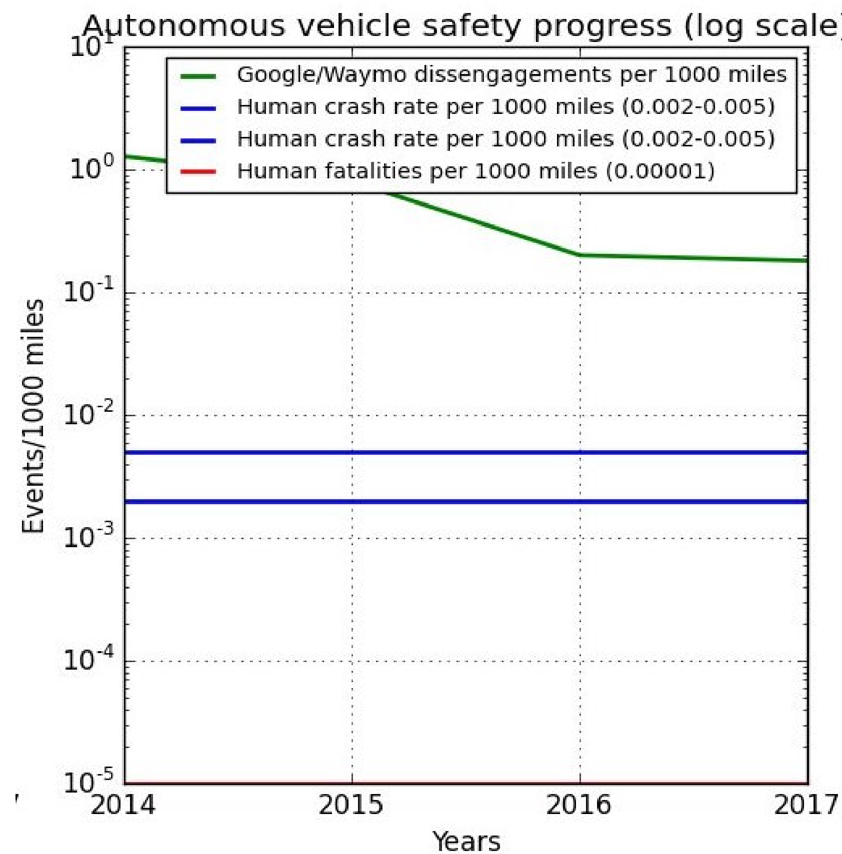
- US statistics
  - 100 M veh-miles per fatality, 1.2 M veh-miles per injury

Safety assessment

Waymo reports disengagement event AV tests if it had "safety significance and should receive prompt and thorough attention from our engineers."

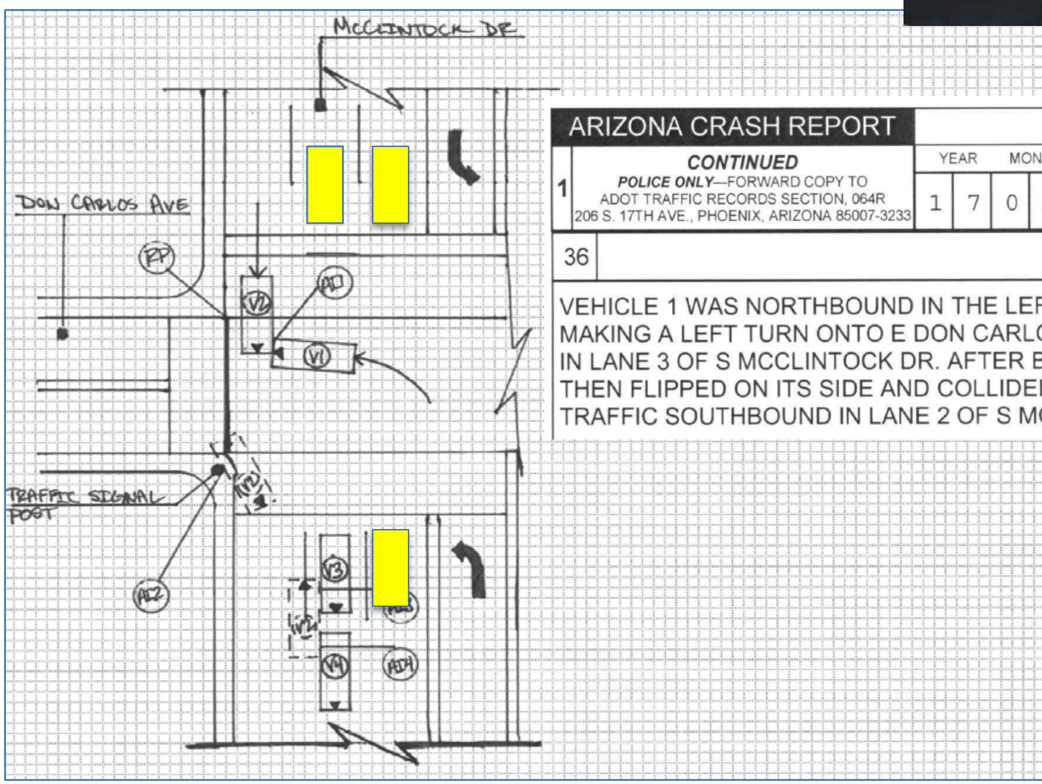
Does this mean a crash was likely without disengagement?

Compare Waymo's 5K miles per disengagement with 200K to 500K miles per accident in U.S.



Uber AV Crash in Tempe, AZ on March 24, 2017

- Honda (V1) going north made a left turn and collided with Uber automated Volvo (V2) going south at 38 mph in 40 mph zone.
- Police report:



ARIZONA CRASH REPORT

CONTINUED

POLICE ONLY—FORWARD COPY TO ADOT TRAFFIC RECORDS SECTION, 064R 206 S. 17TH AVE., PHOENIX, ARIZONA 85007-3233

	REPORT ID: YEAR		MONTH		DAY		HOUR				NCIC NO.				OFFICER ID NO.					Agency Report Number
1	1	7	0	3	2	4	1	8	2	5	0	7	2	9	2	3	0	7	7	17-34909 961

36 NARRATIVE Describe what happened

VEHICLE 1 WAS NORTHBOUND IN THE LEFT TURN LANE OF S MCCLINTOCK DR WHEN IT FAILED TO YIELD MAKING A LEFT TURN ONTO E DON CARLOS AVE AND COLLIDED WITH VEHICLE 2 WHICH WAS SOUTHBOUND IN LANE 3 OF S MCCLINTOCK DR. AFTER BEING STRUCK VEHICLE 2 COLLIDED WITH A TRAFFIC SIGNAL POLE, THEN FLIPPED ON ITS SIDE AND COLLIDED WITH VEHICLE 3 AND VEHICLE 4 WHICH WERE STOPPED IN TRAFFIC SOUTHBOUND IN LANE 2 OF S MCCLINTOCK DR.

Lessons from Uber crash

Spatial and temporal uncertainty caused 4 non-human errors:

(1) Uber did not know traffic in opposing direction could turn left;
(2) Uber did not predict light would turn yellow before entering intersection;
(3) Uber operator saw the Honda but had no time to react “as traffic in the first two lanes had created a blind spot”;
(4) Honda driver “about to cross the third land and saw a car flying through the intersection, but couldn't brake fast enough to completely avoid collision”.

- Crash may have been prevented by phase prediction (by intersection) to Uber:
  - Phase says left turn ahead permitted; and
  - Green light changing to yellow in 5s, 4s, …
- Blind spot information to Uber:
  - There is a left-turning vehicle (detected by intersection sensors)
- Blind spot information to Honda:
  - There is a through vehicle (detected by intersection sensors)

However, removing spatial and temporal uncertainty requires infrastructure assistance.

Uber Crash Simulated

Other Intersection Crash Scenarios

1: Signal confusion and limited line of sight

2: Delayed reaction to pedestrian crossing

3: Yellow interval dilemma

4: Alert for left turning vehicle

5: Limited line of sight of peds and bicyclists

6: Red light violation

Functions of intelligent intersection

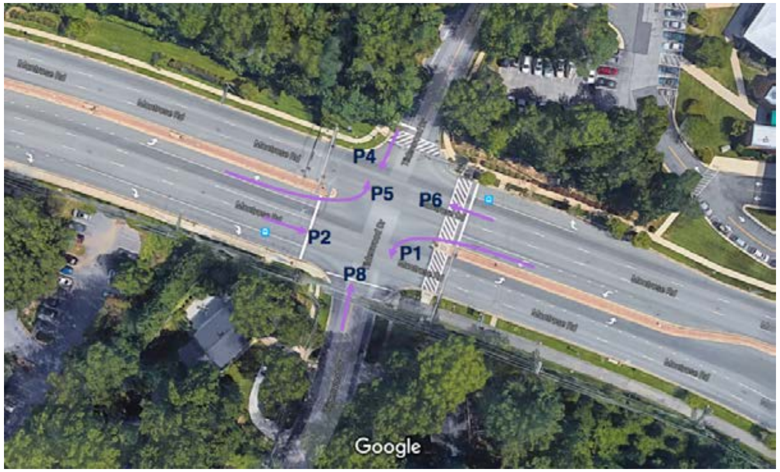
1. Inform vehicle of complete signal phase and predict time of next phase change (SPaT)

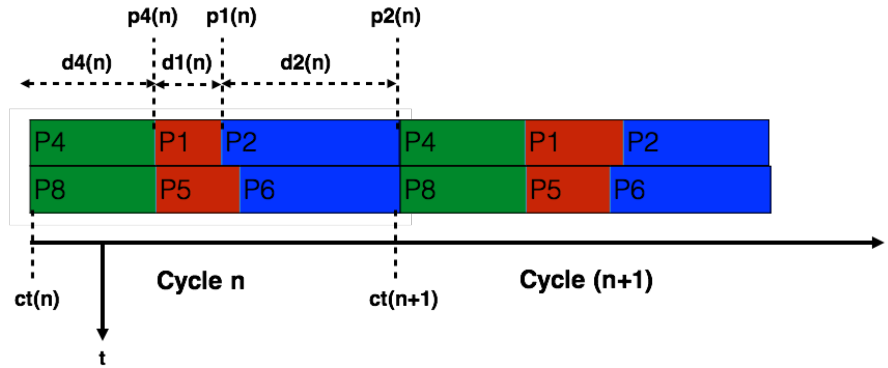
2. Inform vehicle of its potential blind zones

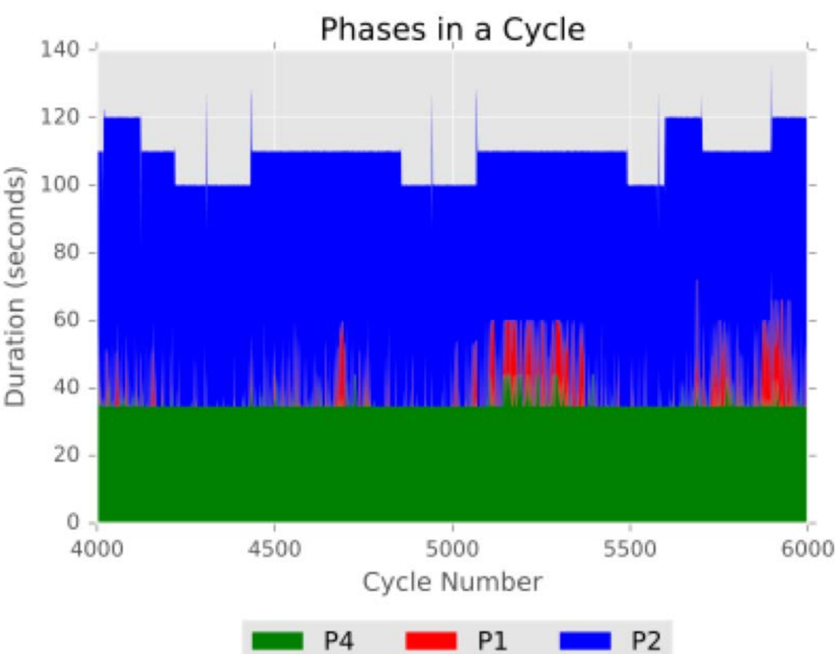
3. Inform vehicle of presence of other vehicles, bicyclists or pedestrians in those blind zones

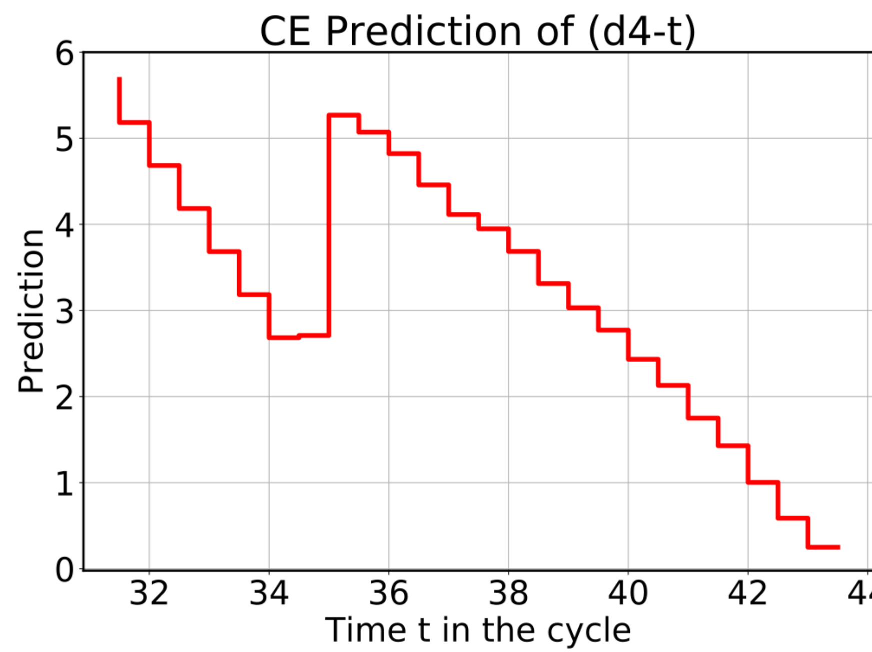
4. Warn vehicles of red-light violators

Signal Phase and Timing (SPaT)



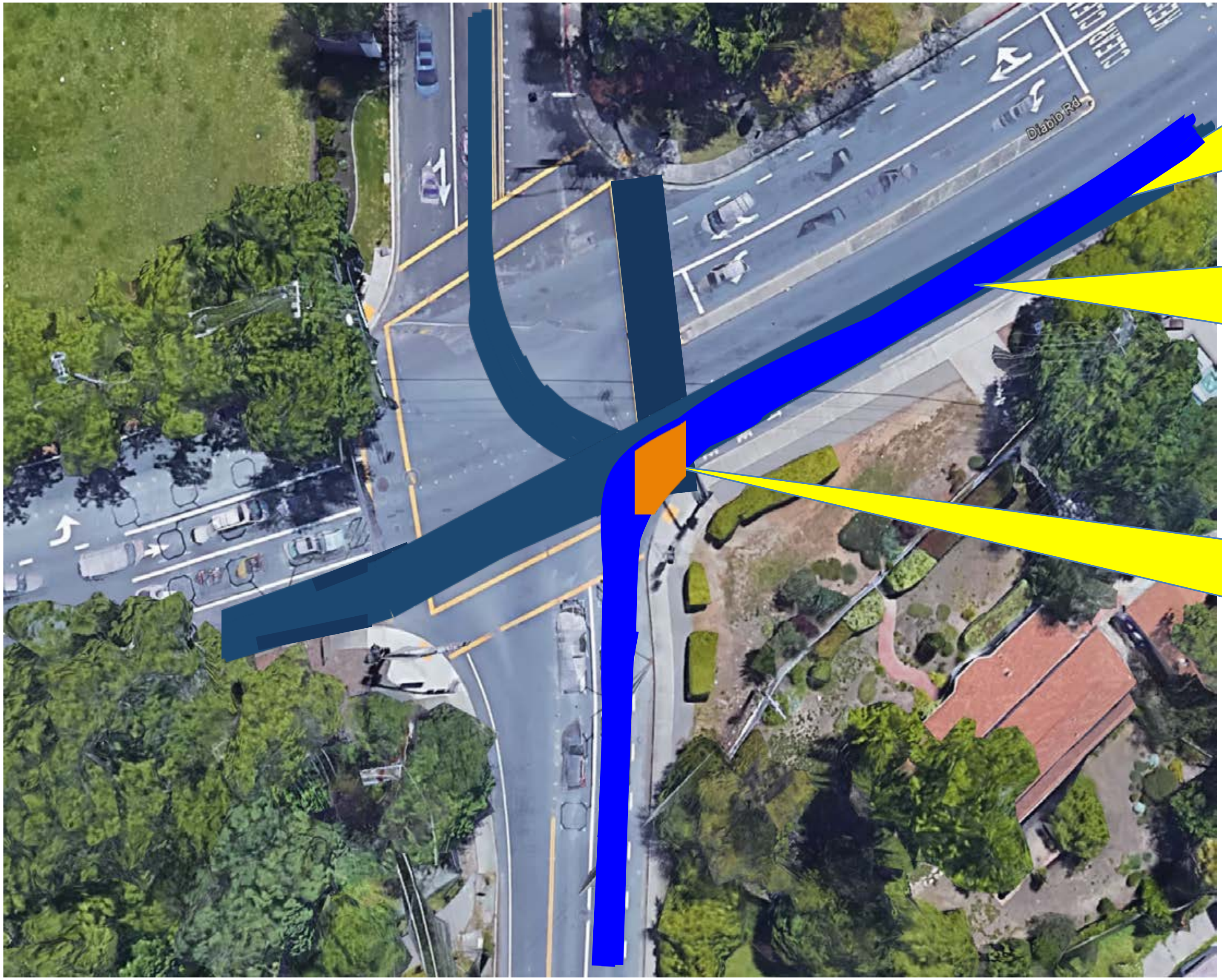






Blind Zone Calculation: Conceptual Approach

- Conflict zone

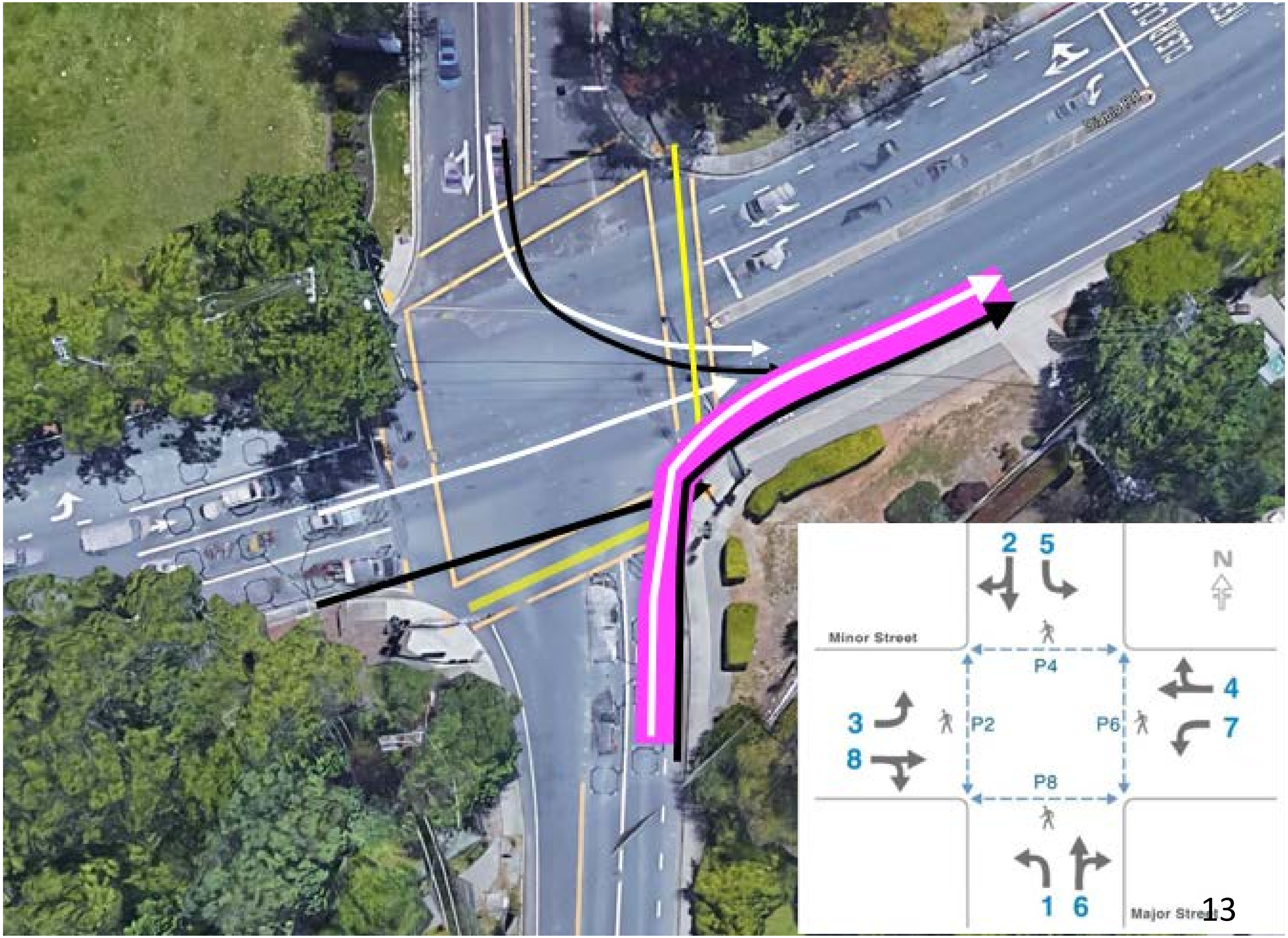


Trajectory is the route of one vehicle.

Guideway is bundle of vehicle trajectories for a given movement. (eg: Right-turn)

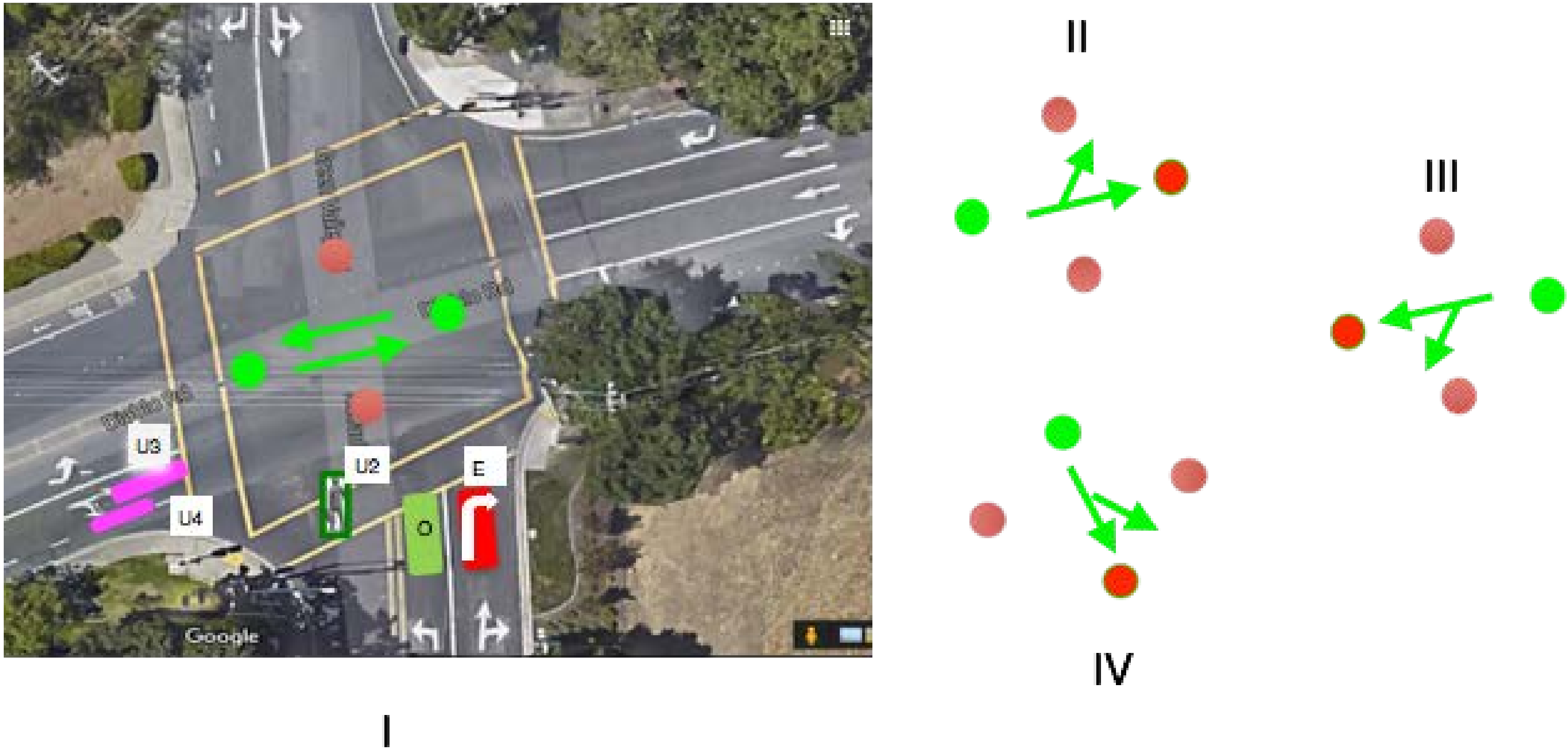
Conflict zone is the area where guideways of conflicting movements cross each other.

Right turn has 7 conflicting movements

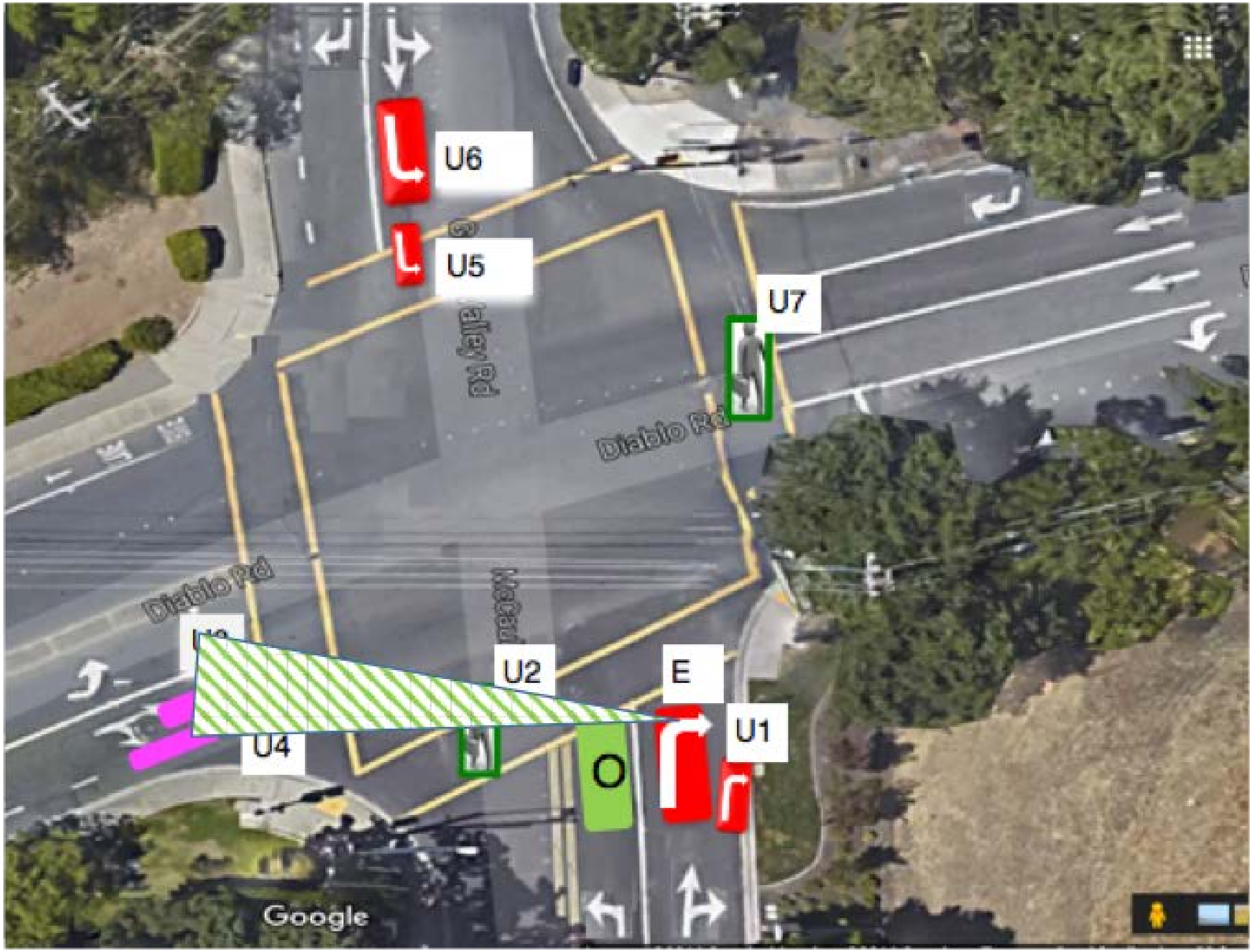


Conflict zones for right turn movement

Resolve conflicts using SPaT message

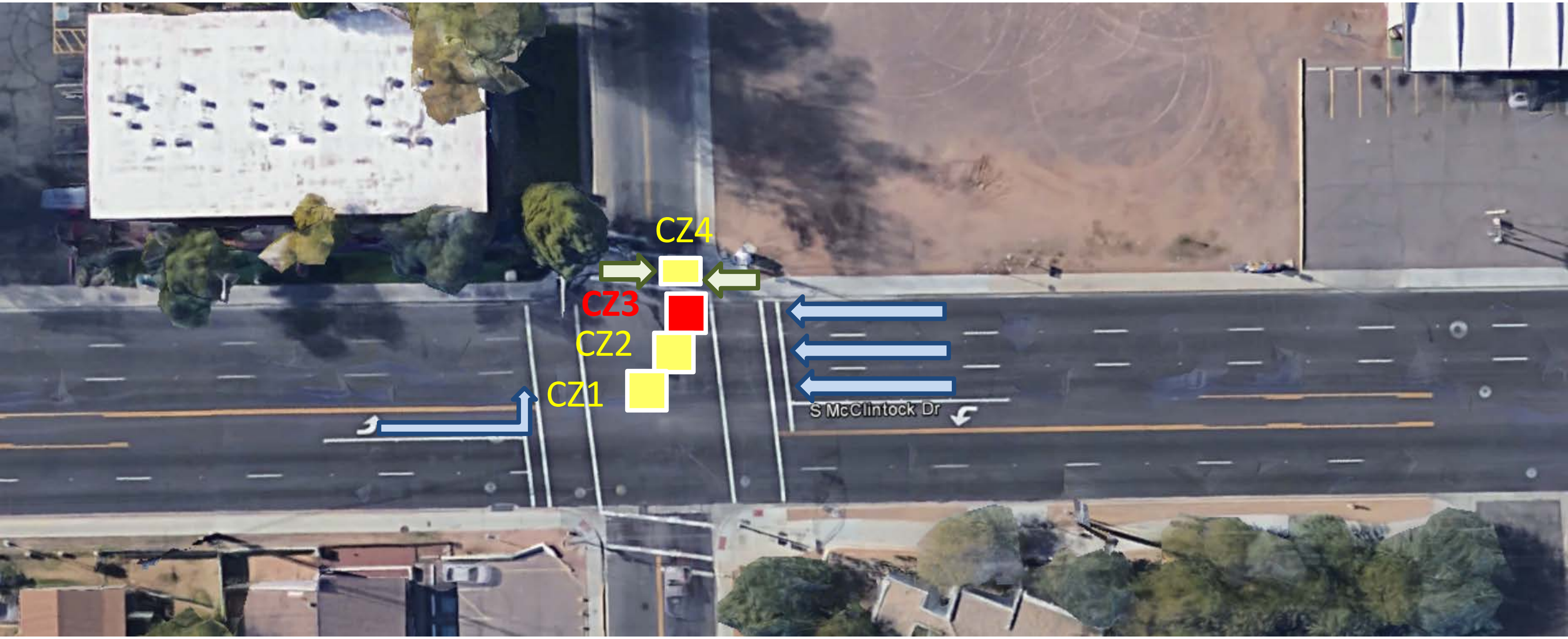


Resolve conflicts visually: Blind zones



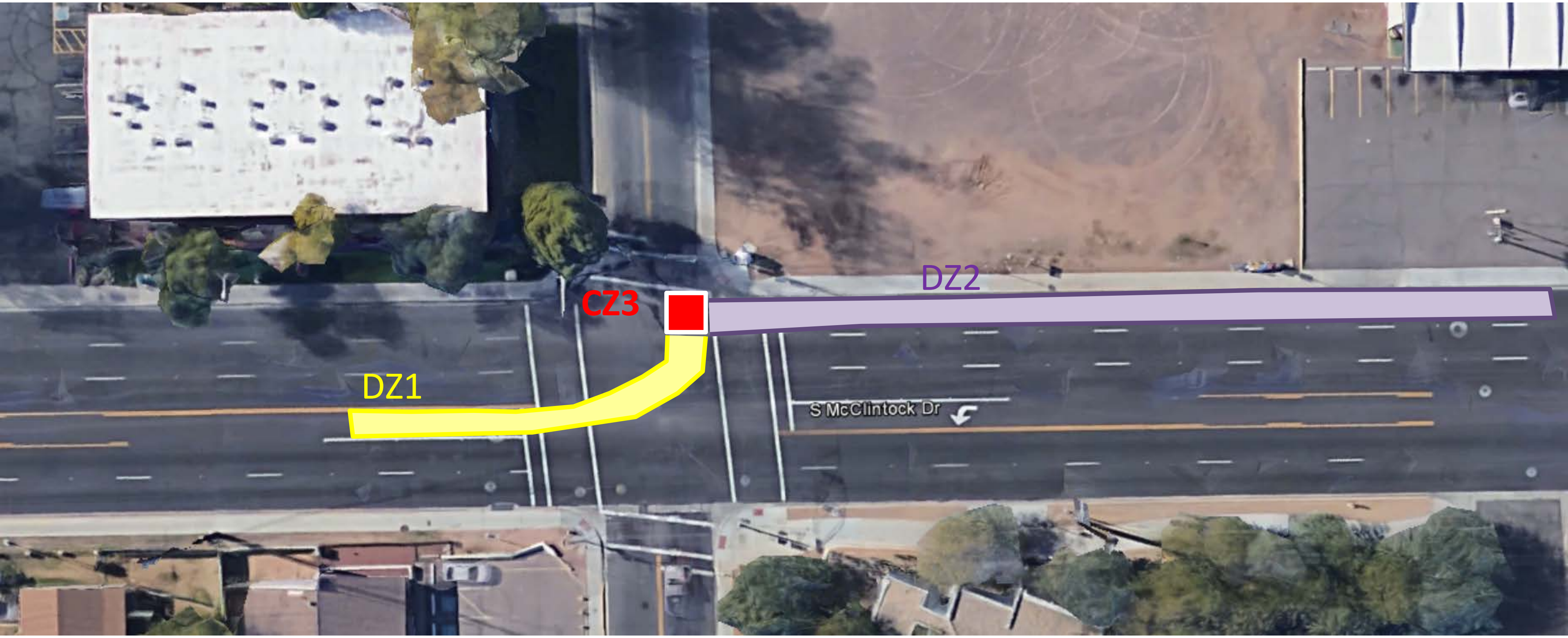
Uber Crash Case

Blind zone corresponds to conflict zone. Focus on CZ3 where Uber crash occurred.



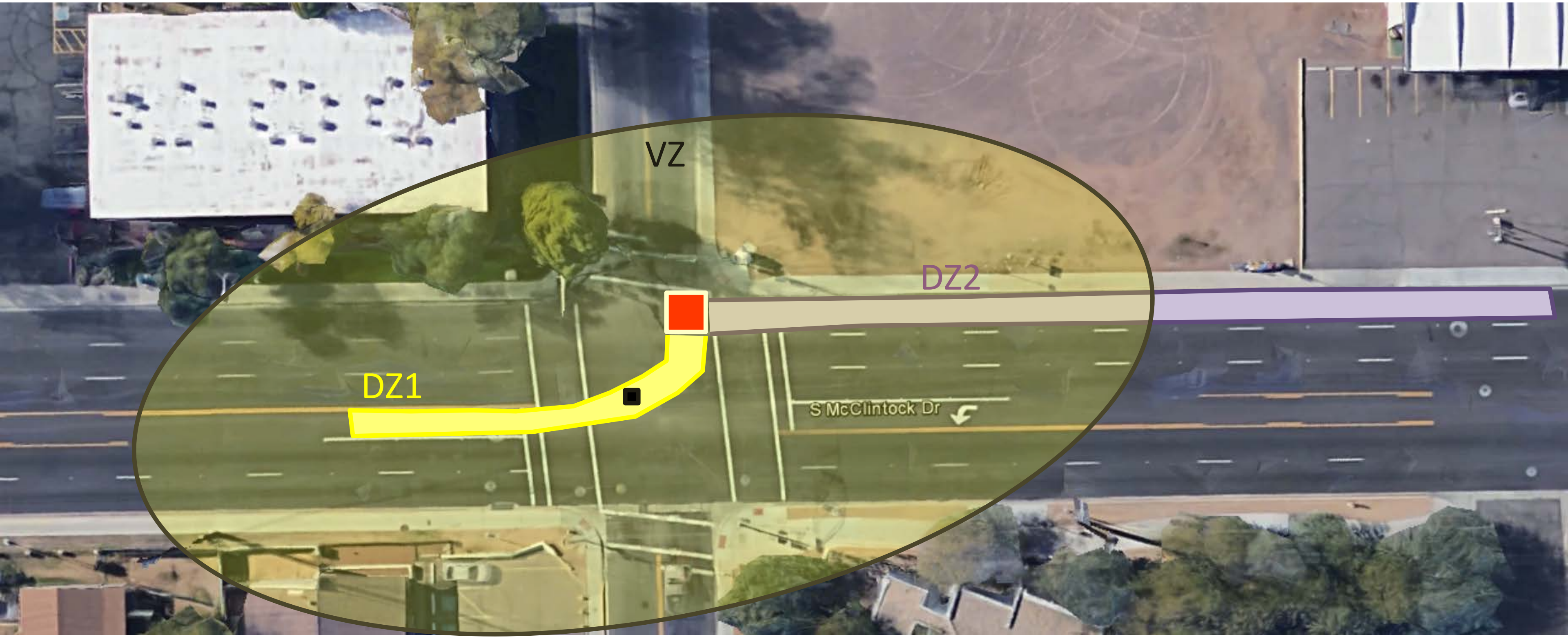
Uber Crash Case

Decision zones DZ1 and DZ2 are parts of guideways of vehicles V1, V2 upstream of CZ3.



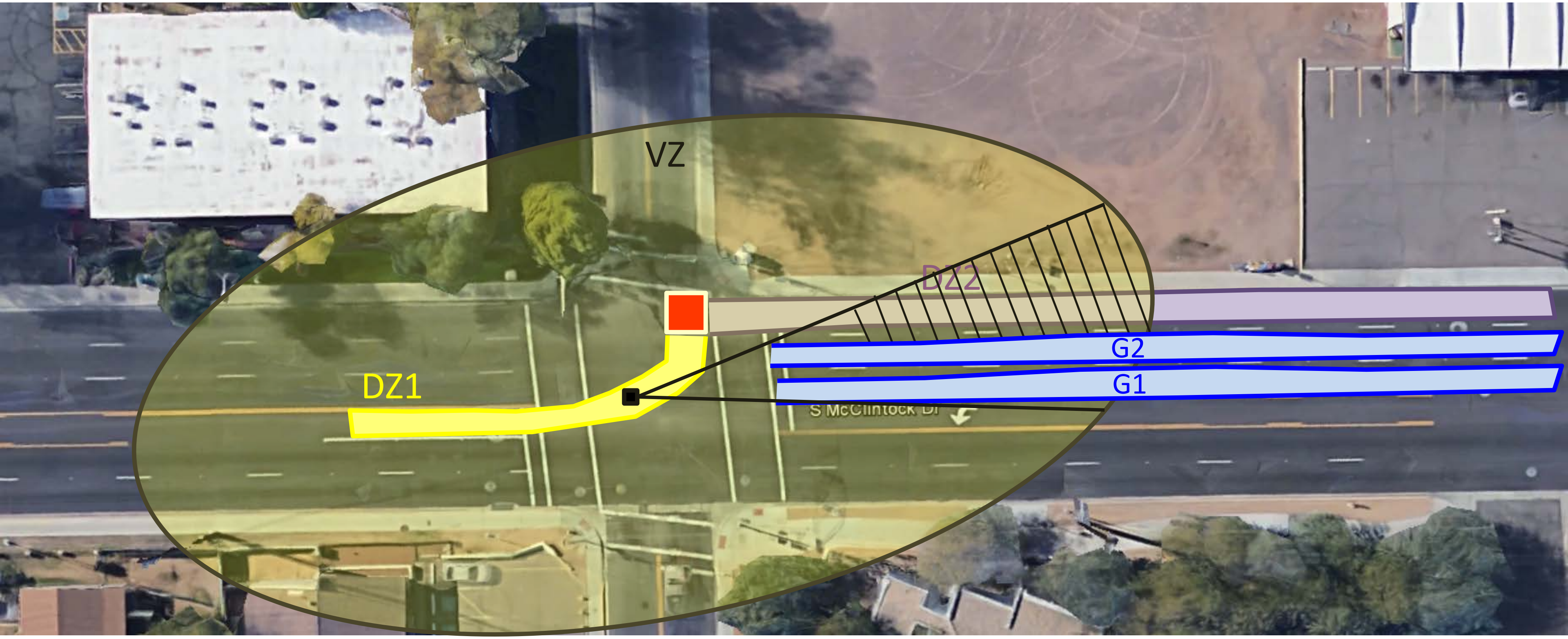
Uber Crash Case

From each point of decision zone DZ1 check visibility of DZ2 from vision zone VZ.



Uber Crash Case

Consider vision zone VZ. It intersects two active guideways G1 and G2, so occlusion will occur if G1, G2 are occupied.



What Vehicles Must See

Left-turn movement must see Uber and pedestrian presence

■ Stop bar detector ■ Approach detector

4-th lane (Uber) through movement must see left turn presence

■ Approach detector ■ Stop bar detector ■ Exit detector

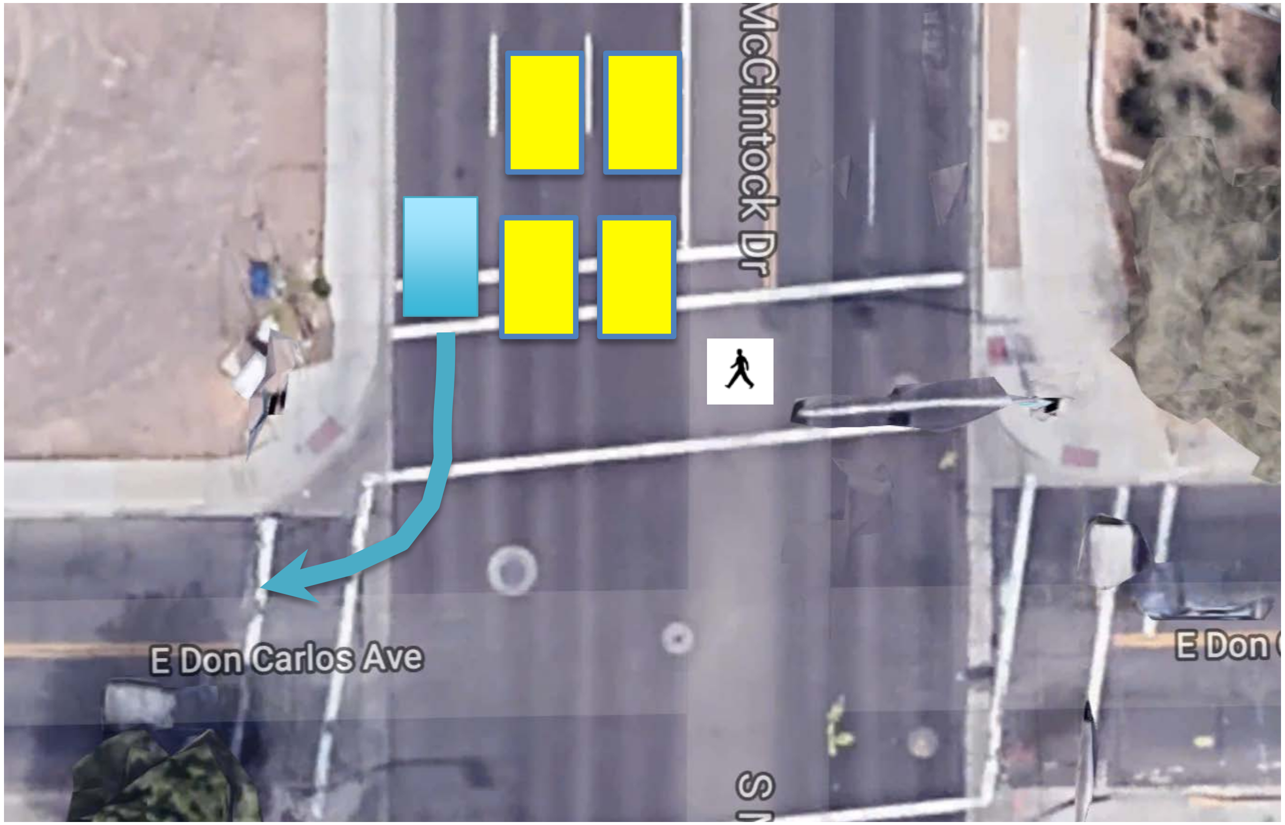
Avoiding Uber Crash with I2V

Avoiding Uber Crash with I2V

Red Light Violation

In both cases, violator entered intersection 7 sec into red and could be detected by red-light camera setup.

How likely is a RTOR near collision?



During peak period, in each cycle, probability of RTOR near collision is
$P(\mathrm{RTOR}) \times P(\mathrm{blocking}) \times P(\mathrm{ped}) = 1 \times 1 \times P(\mathrm{Ped})$

We can make rough estimates of other common intersection near collisions to rank intelligent intersection upgrades.

Conclusions

VZ infrastructure modifications reduce vehicle mobility and may not increase safety of cyclists and pedestrians.

AVs do not know intersection phase, cannot predict phase change, do not see obscured agents. AVs may not eliminate crashes due to driver spatial and temporal uncertainty.

An intelligent intersection removes temporal and spatial uncertainty by

- SPaT message giving full phase and phase change prediction;
- map of conflict zones and potential blind zones;
- blind zone occupancy detection;
- red-light violation detection.