Making Intersections Safer with I2V Communication

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Summary

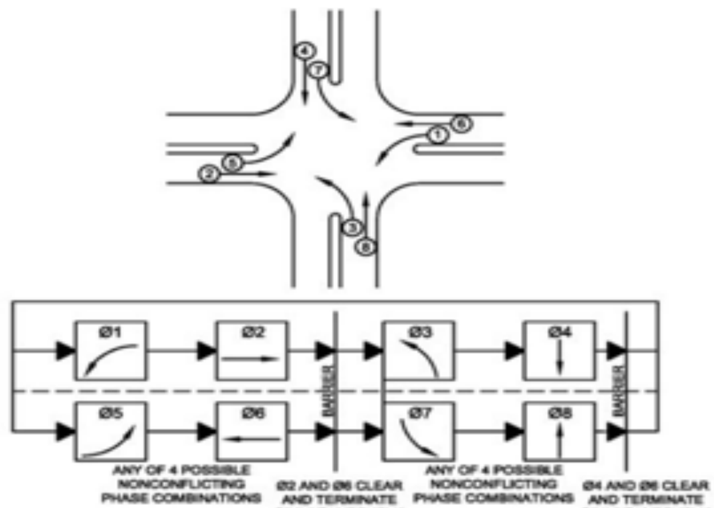
- Focus on intersection safety
- City planning approach: Vision Zero (VZ)
- Automated Vehicle (AV) solution: ready for prime time?
- AV operation: perception, planning, control
- Reconstructing an AV accident
- Accidents caused by incomplete information
- Constructing intersection intelligence
- Citywide intersection safety report
- Conclusion

Why focus on intersections?

Intersections are dangerous:

- 2.5M intersection accidents annually: 40 % of all crashes, 50 % of serious collisions, 20 % of fatal collisions. Bay Area fatalities jumped 43% in 2010-16, 62% were cyclists or pedestrians.
- Red light runners cause 165K accidents and 700-800 fatalities.
- 58 of 66 (88%) AV accidents in California (10/14-4/18) occurred in intersections.

Why? Because intersections have complex geometry, operational rules, signage.



Two policy prescriptions: Vision Zero and Automated Vehicles.

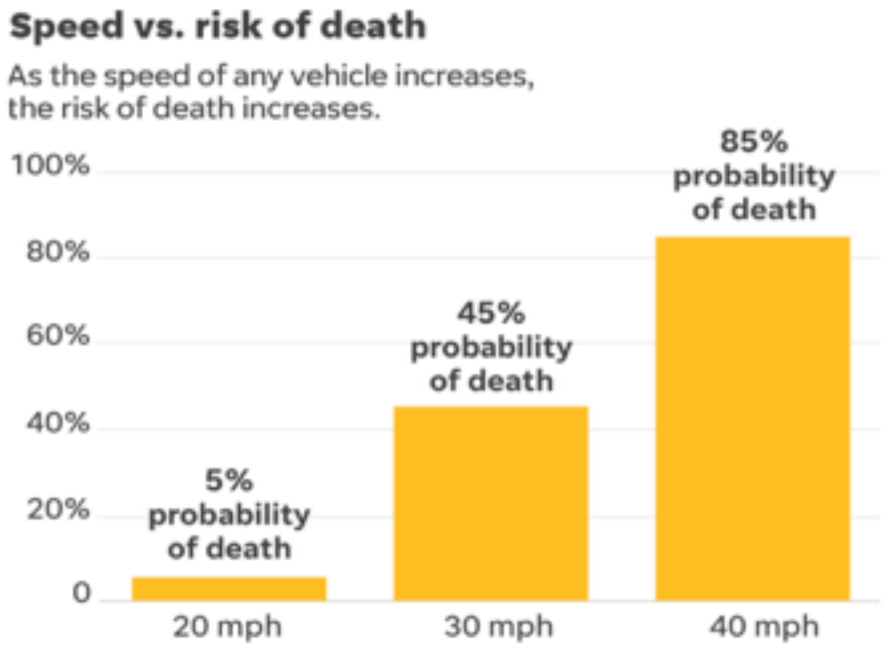
Vision Zero plans

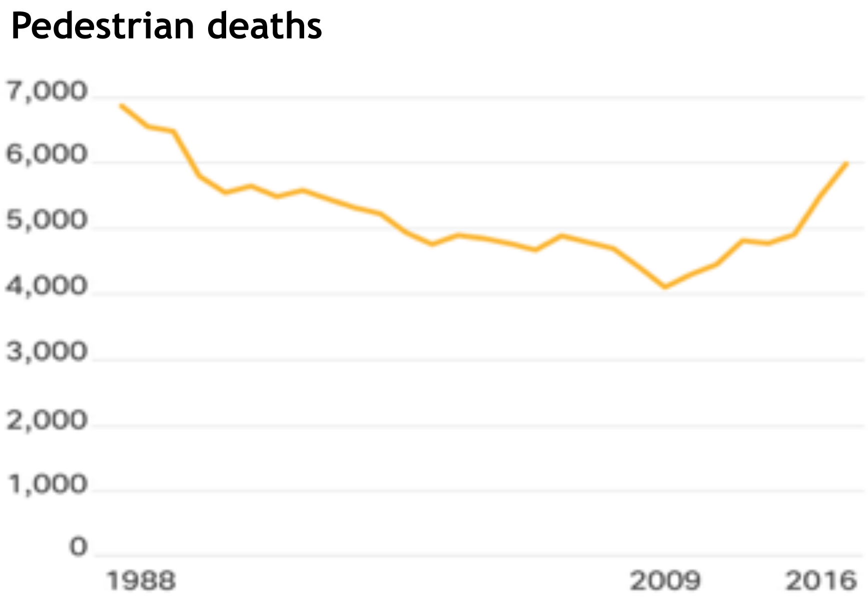
VZ cities seek to reduce serious accidents by infrastructure modifications:

- road diet: lane removal and enforced speed reduction;
- sidewalk extensions (bulb outs) to shorten pedestrian crossings;
- protected bike lanes to buffer cyclists from moving cars;
- protected intersection.

CA VZ cities include Berkeley, Los Angeles, San Mateo, San Jose, Santa Barbara, San Francisco, San Diego and Sacramento.

Lower speed limit is effective





Source: Detroit Free Press/USA TODAY NETWORK, July1, 2018

The promise of Automated Vehicles (AVs)

“Every year, 1.2 million lives are lost (worldwide) to traffic crashes … 94% involve human error* … our technology could save thousands of lives now lost to traffic crashes every year” – Waymo Safety Report (2017)

“Each year close to 1.25 million people die in car crashes. More than 2 million people are injured. Human error … in 94 percent* of these crashes” – GM Cruise Safety Report (2018)

Our vehicle “will achieve a verifiable, transparent,1,000 times safety improvement” - A. Shashua, CEO Mobileye, Intel

*The 94% is misleading. The NHTSA report, based on 2005-2007 data, states “in none of these cases was the assignment intended to blame the driver for causing the crash.”

Introduction to Connected and Automated Vehicles

Connected vehicle means radio connection to Internet (cloud), intersection controller (V2I), other vehicles (V2V), pedestrians (V2I), V2X vehicle to all.

Connection may be one-way or two-way; radio may be DSRC, cellular, bluetooth; GPS essential, but not accurate enough for some purposes.

Automated vehicles (AVs) use sensors and computers to automate driving tasks at Levels 0-5.

Level 3. Driver yields to vehicle full control of all safety-critical functions under certain conditions but returns control back to driver control when unsafe (today's AVs).

Level 4. Self-driving vehicle within specified domains (proposed AV tests).

Level 5. Self-driving vehicle whose performance equals that of human driver.

Today's AVs are not connected. Connected vehicles are not automated.

AV Skeptics

"door-to-door, without a safety driver, is not likely to happen for decades. … functional safety is impossible to enforce in complex environments … only a few use cases can be addressed in three to five years. You must get rid of the safety driver … otherwise there is no business."- Gilbert Gagnaire, CEO EasyMile

"It will take decades for self-driving cars to become common on roads, and even then they will not be able to drive in certain conditions—and that may never change."- Waymo CEO Krafcik, Nov 2018

She nearly hit a Waymo autonomous minivan because it stopped abruptly while making a right turn. "Go!" she shouted angrily, after getting stuck in the intersection midway through her left turn. Waymo vans might stop for at least three seconds at a stop sign.

AV Safety Record

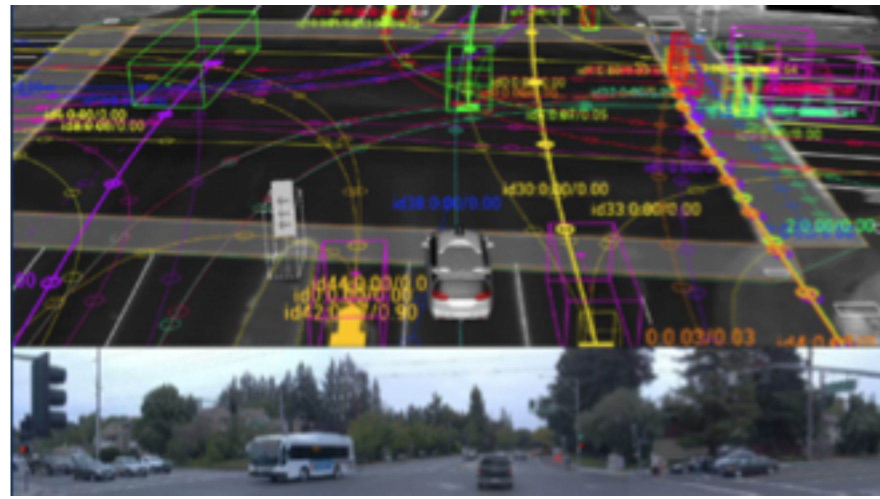
- AV rate is 40K miles per accident, mostly minor.
- Waymo rate is 5.5K miles per self-reported disengagement.*
- US rate is 500K miles per accident reported to police.
- Waymo accident (disengagement) rate is 13 (100) times worse than human drivers.

*Disengagement occurs when a failure of the autonomous technology is detected, or when the safe operation of the vehicle requires that the test driver take over immediate manual control.

AV Operation: Sense, Plan, Control

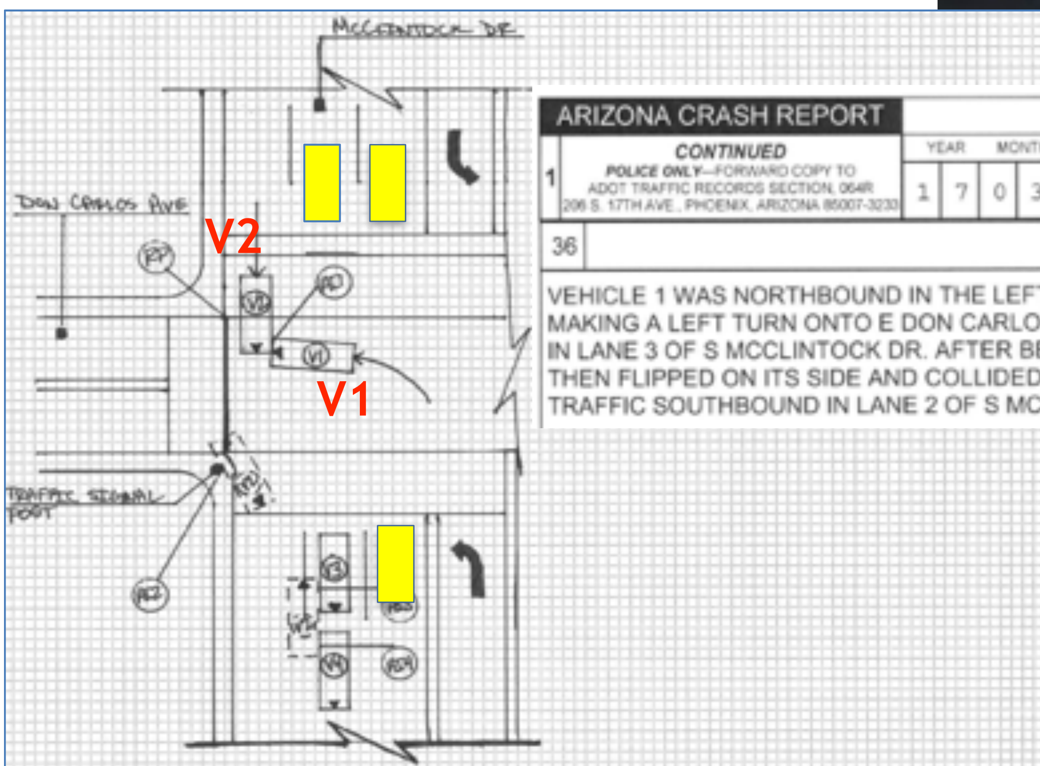
Automated vehicles

- use lidars, radars, and cameras to detect and classify objects, estimate position and speed, and predict trajectory of objects in field of view;
- plan path that avoids other objects;
- calculate commands for steering, throttle, brake to follow plan.



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

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



ARIZONA CRASH REPORT	REPORT ID						Agency Report Number
CONTINUED POLICE ONLY—FORWARD COPY TO ADOT TRAFFIC RECORDS SECTION, 064R 206 S. 17TH AVE., PHOENIX, ARIZONA 85007-3233	YEAR	MONTH	DAY	HOUR	NCIC NO.	OFFICER ID NO.	
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 errors:

(1) Uber did not predict light would turn yellow before entering intersection;
(2) Uber did not know traffic in opposing direction could turn left;
(3) Uber safety operator saw the Honda too late to react “as traffic in the first two lanes had created a blind spot”;
(4) Honda driver “about to cross the third lane 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:
  - Green light changing to yellow in 5s, 4s, …
  - Phase says left turn ahead permitted; and

- 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)

The spatial and temporal uncertainty can be removed by information from infrastructure. This information cannot be derived from AV on-board sensors.

Other Intersection Crash Scenarios

1: Signal confusion and limited line of sight

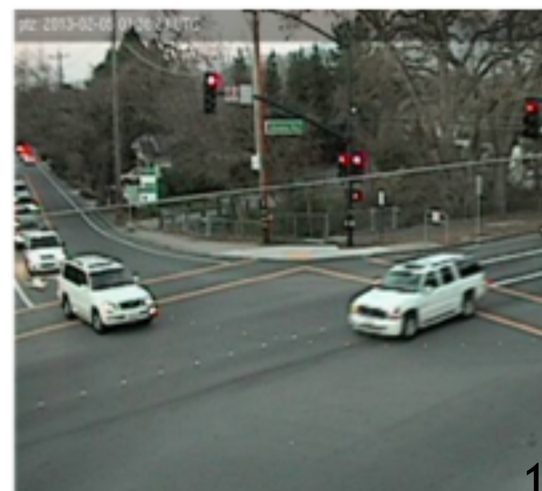
2: Delayed reaction to pedestrian crossing

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

Remove spatial and temporal uncertainty:

1. Inform vehicle of complete signal phase and predict time of next phase change (SPaT). (Can be used for fuel efficiency.)

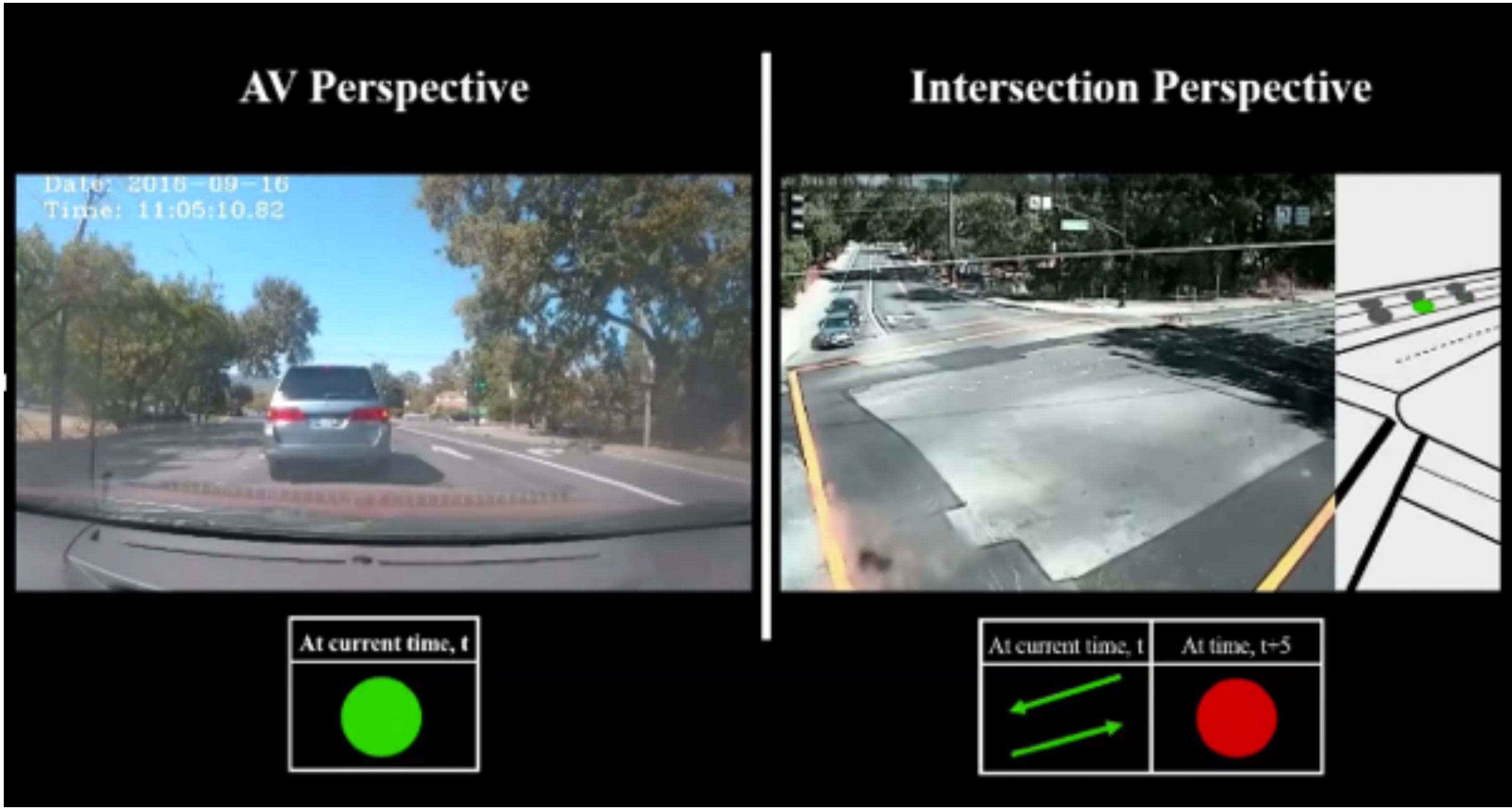
2. Inform vehicle of conflict zones and potential blind zones (static information).

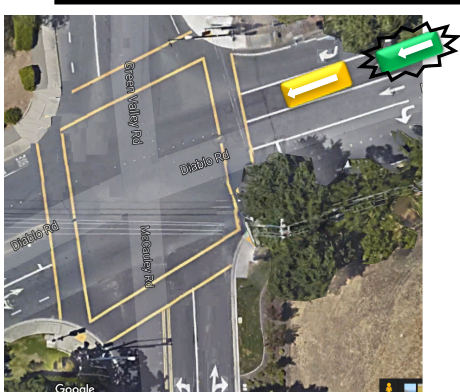
3. Inform vehicle of presence of other vehicles, bicyclists or pedestrians in those blind zones (real-time information).

4. Warn vehicles of red-light violators (real-time information).

5. Cost $10K-$30K per intersection.

Signal Phase and Timing (SPaT)

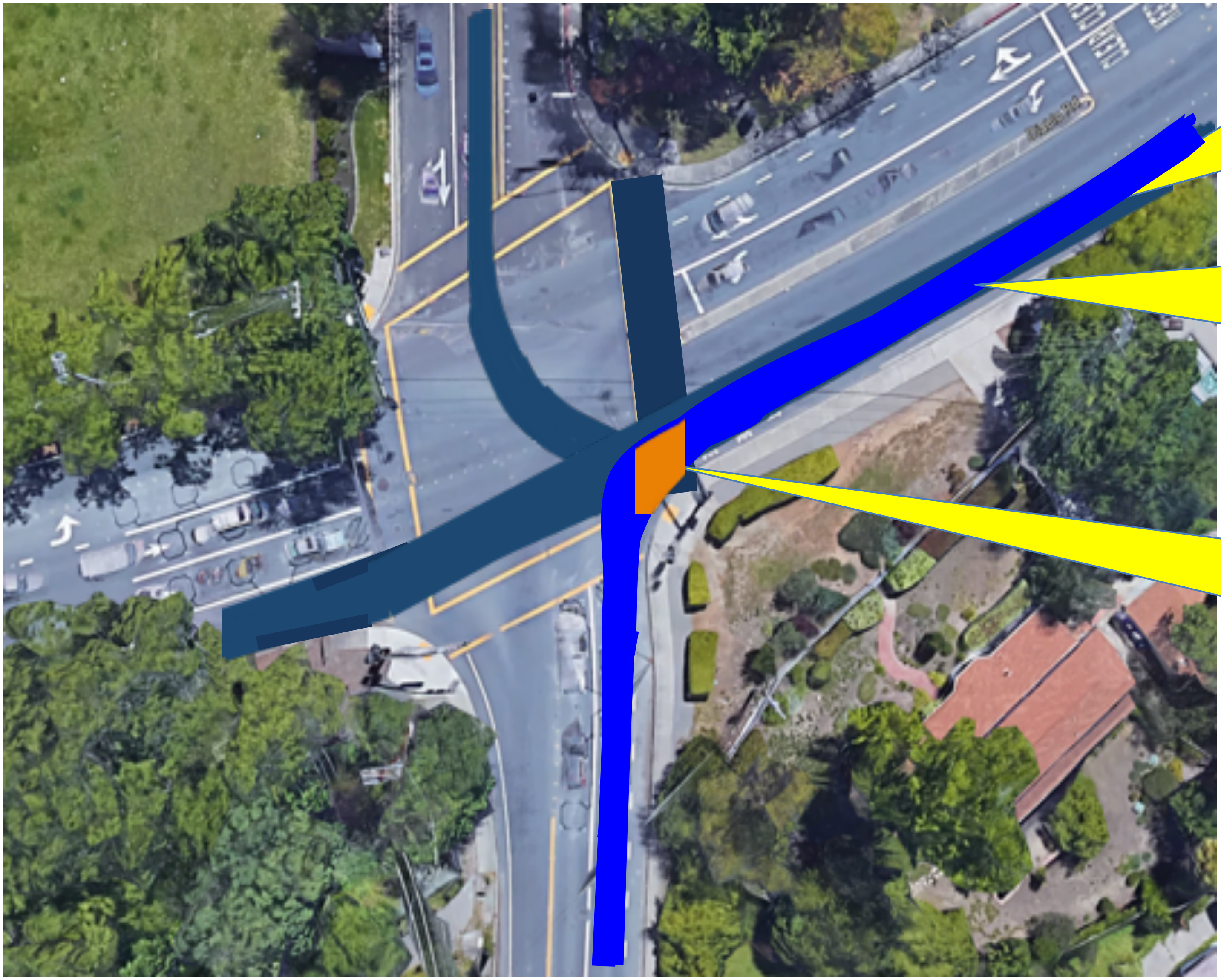




phase is ‘green’ as seen from rear vehicle at time t

intelligent intersection tells rear vehicle at time t that phase will be ‘red’ at t+5

Blind Zone Calculation: Conceptual Approach

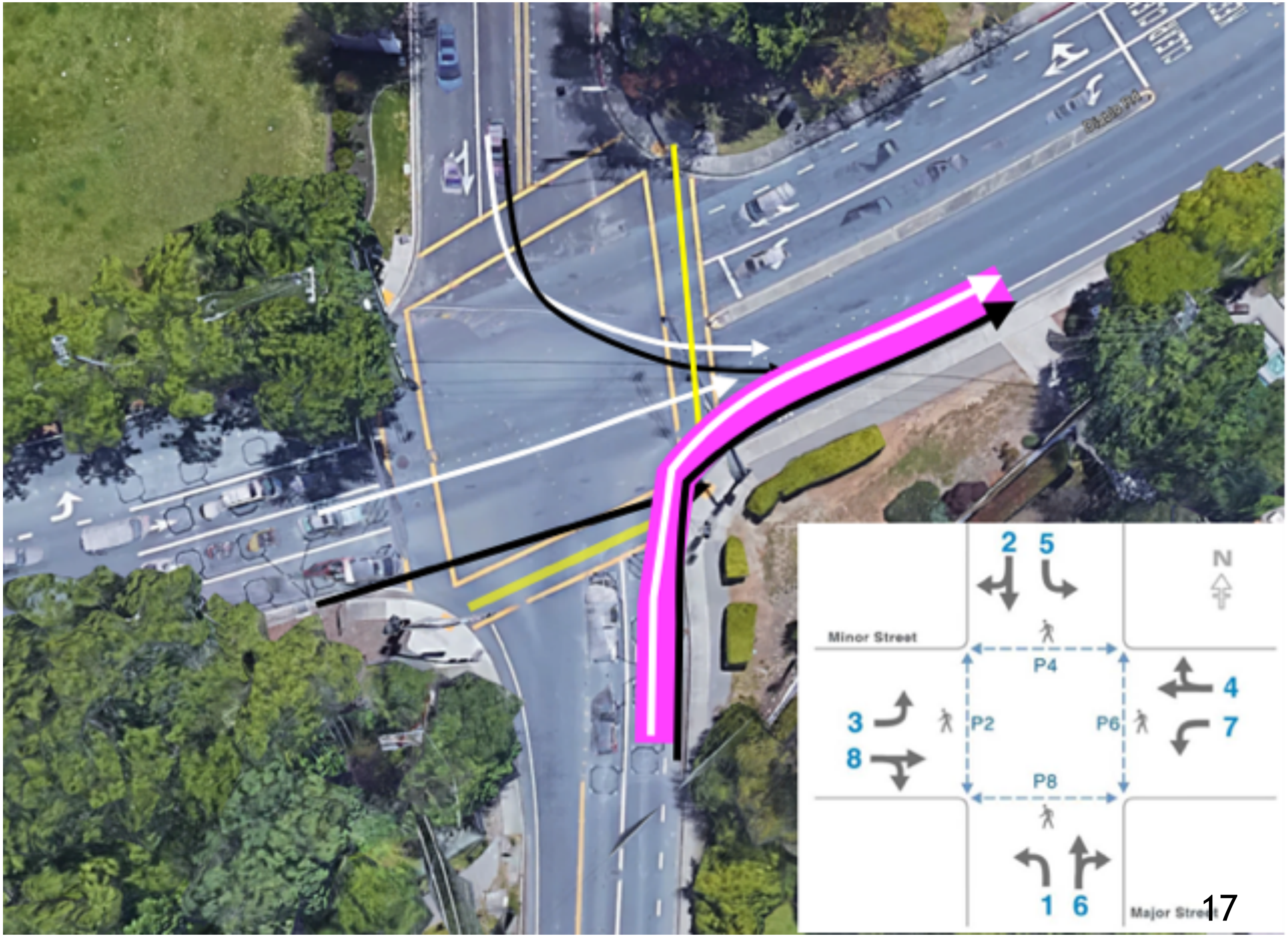


Trajectory is the route of one vehicle.

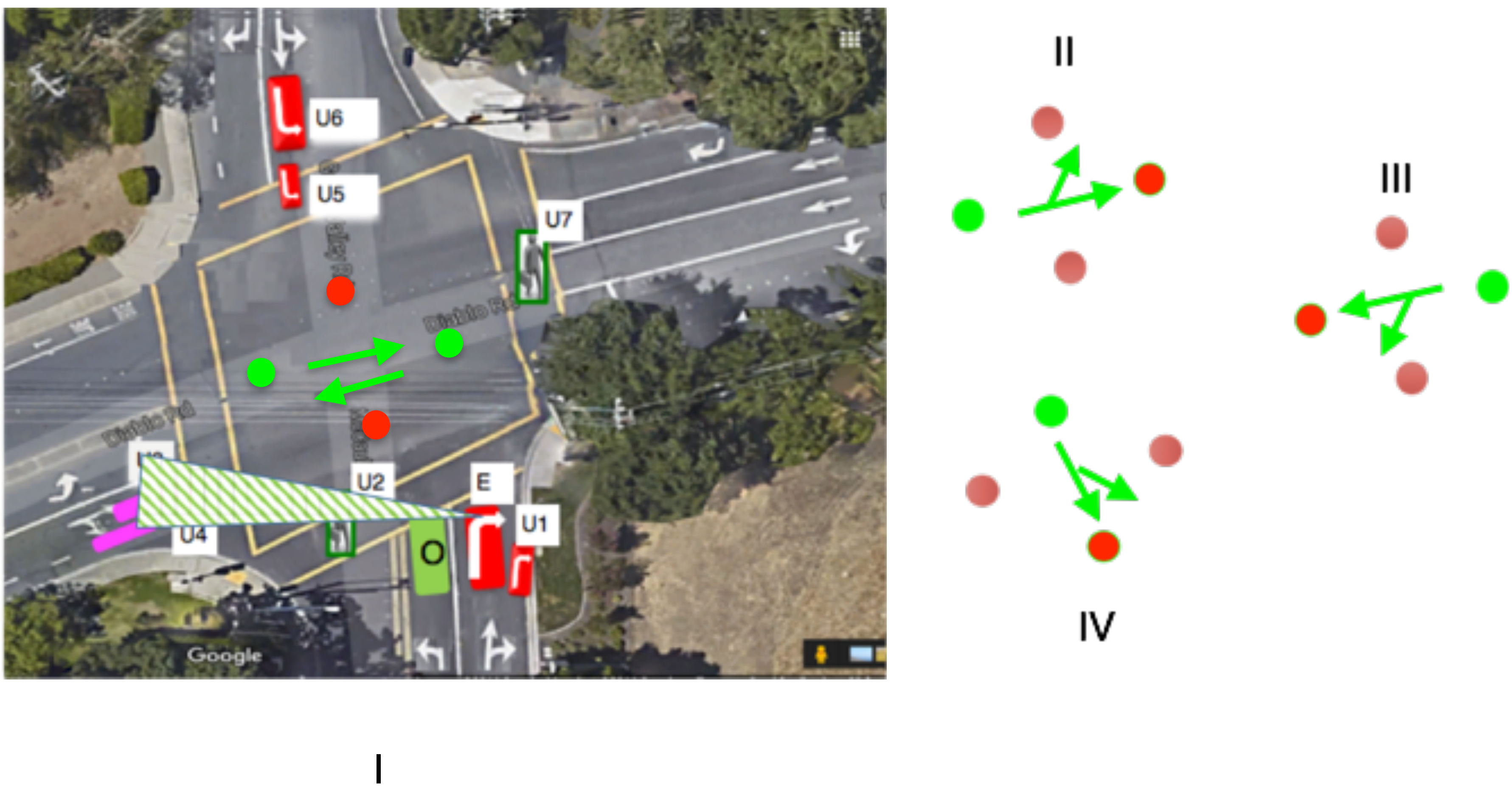
Guideway is bundle of vehicle trajectories for a given movement, eg. right-turn.

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

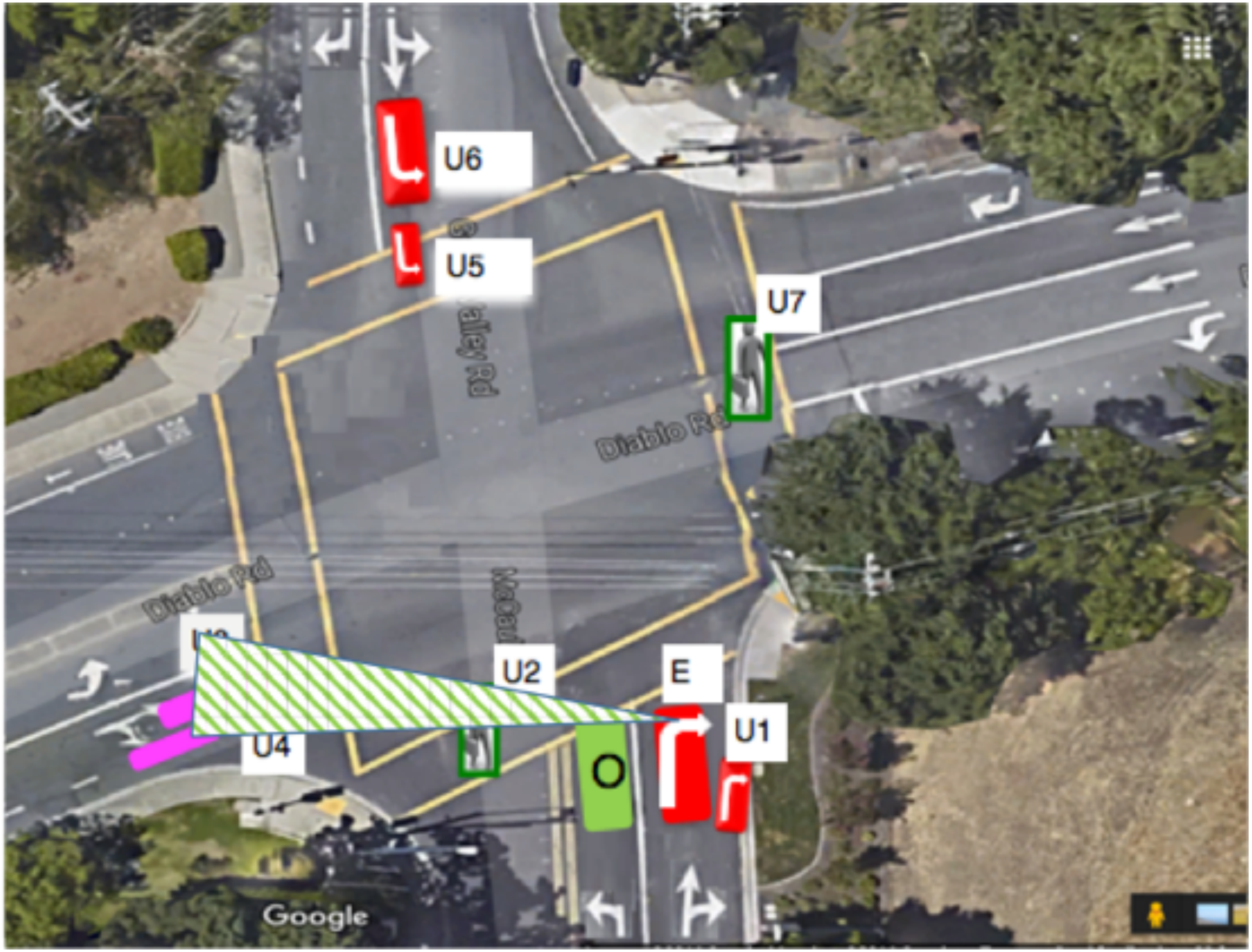
Right turn has 7 conflicting movements



Resolve conflicts with SPaT + visually

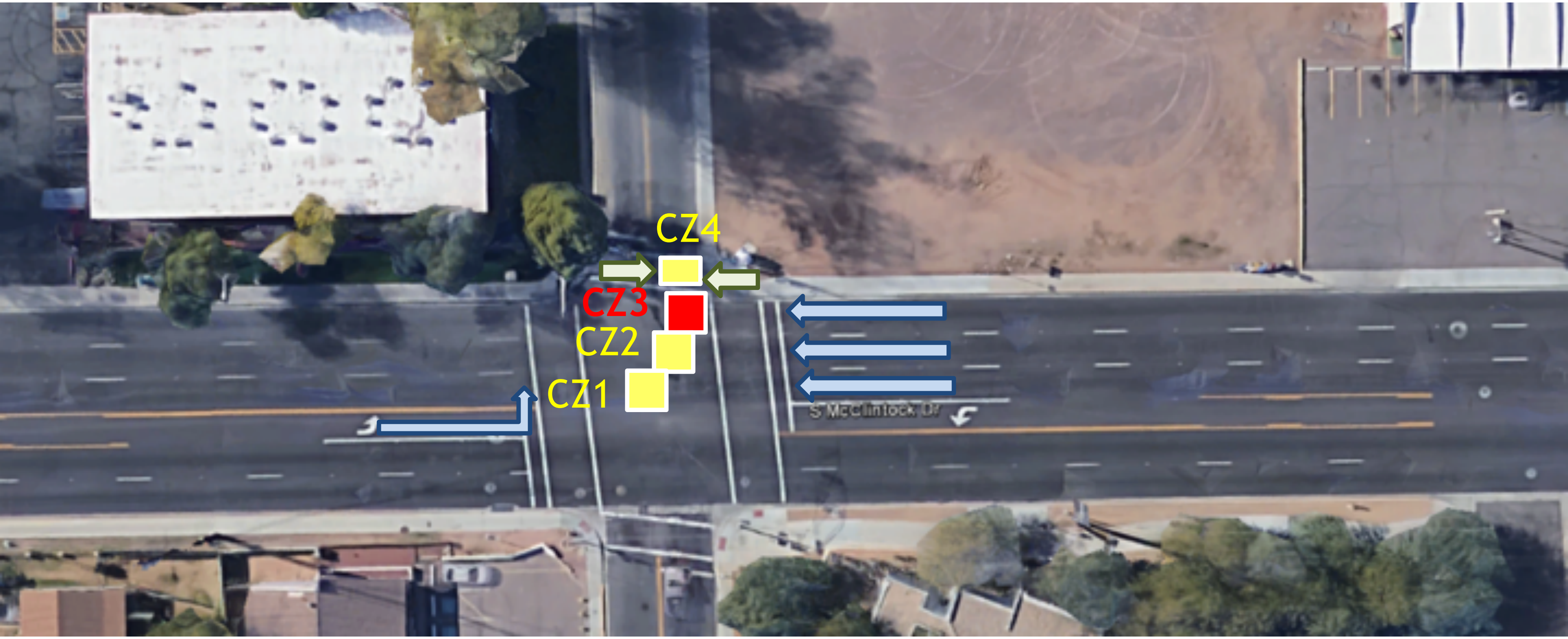


Remaining conflicts have blind zones

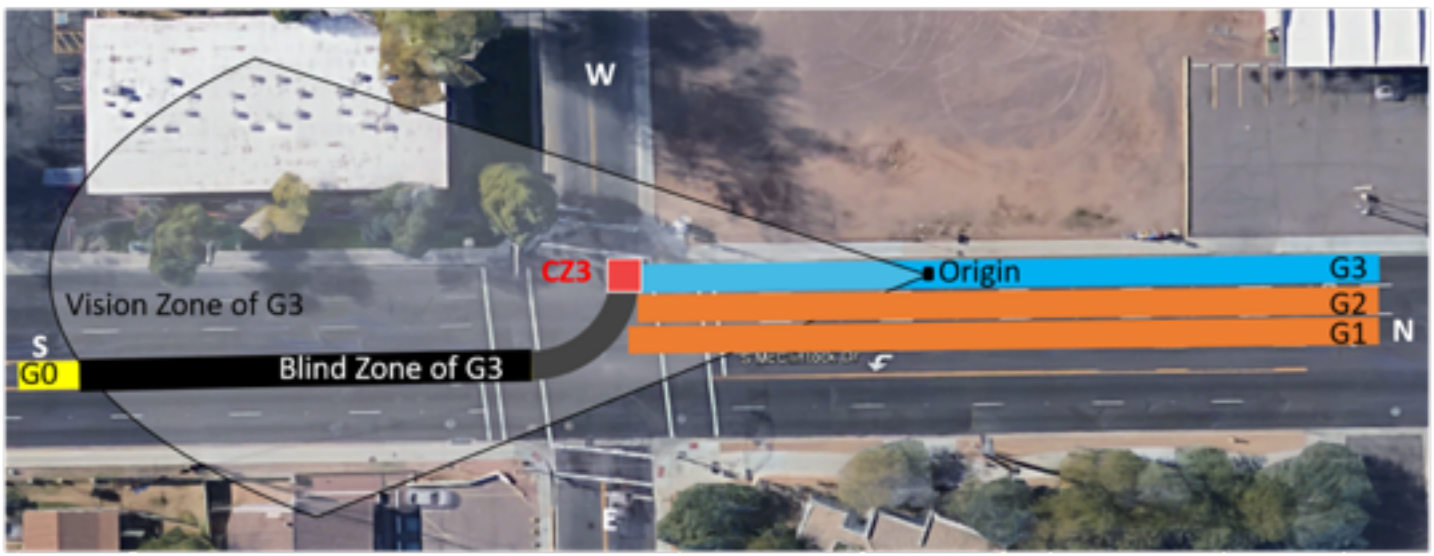


Uber Crash Conflict Zones

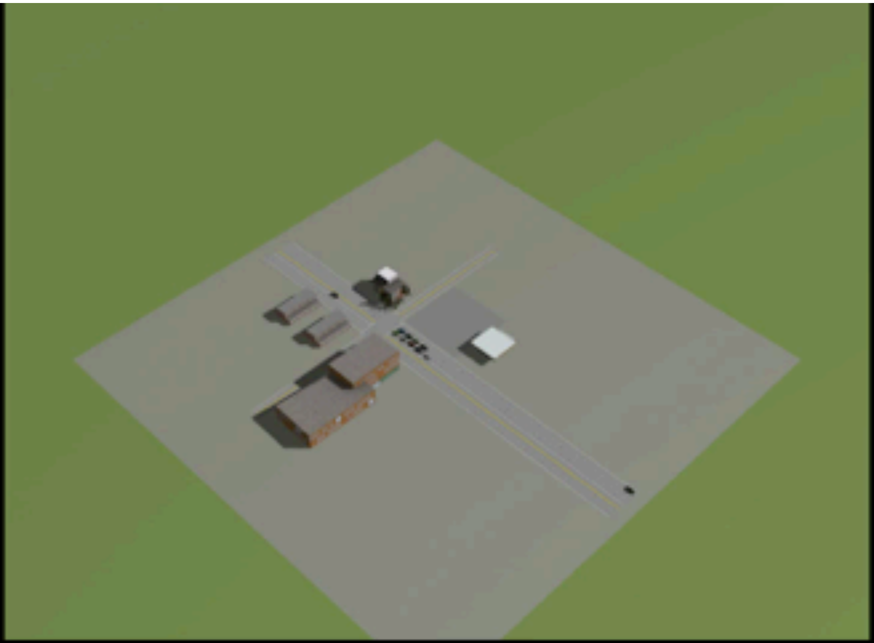
Blind zone corresponds to conflict zone. Focus on CZ3 where Uber crash occurred.



Uber Crash Blind Zones



Avoiding Uber Crash with I2V



Left-turning car acts as before

Uber gets a timely warning

Red Light Violation

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

Citywide Intersection Safety Report

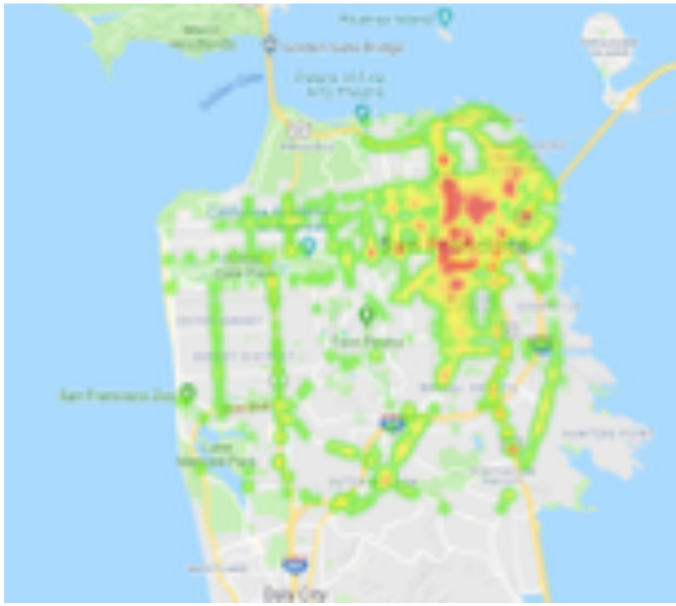
1. Intersection geometry
2. Map guideways, conflict zones, blind zones
3. Collect crash data
4. Obtain traffic data
5. Calculate crash probability
6. Rank intersection safety

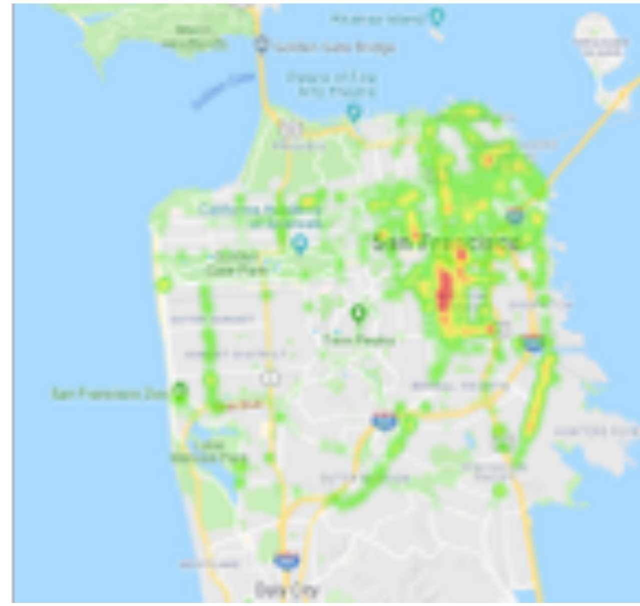
SF Intersection Geometry

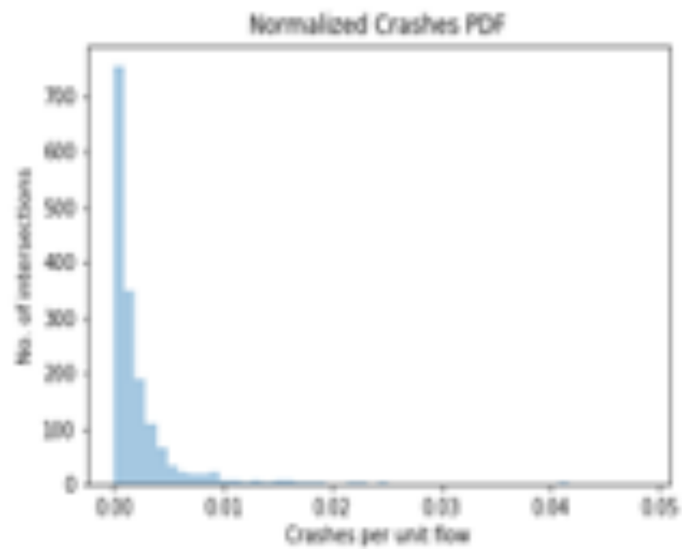
Intersection	Longitude	Latitude	diameter	stop_sign	number_of_	min_number	number_of	number_of	max_number_	signal_pre	number_of	max_curvat
(u'10th Avenue', u'California Street')	-122.468855	37.7846249	20.37355143	no	0	1	0	4	2	yes	4	0.018812
(u'10th Avenue', u'Fulton Street')	-122.468049	37.7733056	20.5547132	no	0	1	0	3	2	yes	3	0.039512
(u'10th Avenue', u'Geary Boulevard')	-122.4685808	37.78083395	118.7295807	no	0	1	0	4	3	yes	4	0.05304
(u'10th Street', u'Division Street')	-122.4083342	37.7692104	151.9250724	no	0	1	0	2	3	yes	6	0.444827
(u'10th Street', u'Folsom Street')	-122.4128343	37.7728201	25.23214928	no	0	3	0	1	4	yes	2	0.008676
(u'10th Street', u'Harrison Street')	-122.4112871	37.7715867	149.6601241	no	0	1	0	2	5	yes	3	0.660892
(u'10th Street', u'Howard Street')	-122.414368	37.774043	21.57115552	no	0	3	0	2	4	yes	2	0.003869
(u'10th Street', u'Jessie Street')	-122.4164871	37.77573185	141.8888439	no	0	1	0	3	1	yes	2	0.058199
(u'10th Street', u'Minna Street')	-122.4153843	37.7748526	14.99345442	no	0	1	0	2	4	yes	1	0.030136
(u'10th Street', u'Mission Street')	-122.4159234	37.7752776	22.43428673	no	0	1	0	3	2	yes	3	0.001983
(u'10th Street', u'Natoma Street')	-122.4149212	37.7744848	18.32640302	no	0	1	0	1	4	yes	2	0.001983
(u'10th Street', u'Potrero Avenue')	-122.4079497	37.7687935	162.481976	no	0	1	0	2	3	yes	5	0.689801
(u'10th Street', u'Sheridan Street')	-122.411897	37.772073	18.07241784	no	0	1	0	1	4	yes	2	0.001923
(u'11th Avenue', u'Geary Boulevard')	-122.4696512	37.7807854	127.719003	no	0	1	0	4	4	yes	4	0.067846
(u'11th Street', u'Folsom Street')	-122.4140462	37.7718632	21.58075347	None	0	1	0	3	3	yes	3	0.567346
(u'11th Street', u'Harrison Street')	-122.4124934	37.7706339	34.47198715	None	0	1	0	3	3	yes	4	1.041613
(u'11th Street', u'Howard Street')	-122.4155785	37.7730974	19.2566645	no	0	1	0	3	3	yes	4	0.117208
(u'11th Street', u'Kissling Street')	-122.4149972	37.7726292	150.8524527	no	0	1	0	4	1	yes	4	0.564517
(u'11th Street', u'Minna Street')	-122.4165917	37.7739012	133.1373378	no	0	1	0	3	2	yes	3	0.038009
(u'11th Street', u'Mission Street')	-122.4171256	37.7743254	17.48211691	no	0	1	0	4	2	yes	4	0.188022
(u'11th Street', u'Natoma Street')	-122.4161272	37.7735327	13.28249214	no	0	1	0	3	1	yes	3	0.00387
(u'12th Avenue', u'California Street')	-122.4709958	37.7845276	20.23356745	no	0	1	0	4	2	yes	4	0
(u'12th Avenue', u'Geary Boulevard')	-122.4707233	37.7807367	122.7539469	no	0	1	0	4	4	yes	4	0.036235
(u'12th Street', u'Folsom Street')	-122.4150033	37.7708952	20.32950355	no	0	1	0	3	3	yes	4	0.387184
(u'12th Street', u'Harrison Street')	-122.4130818	37.7700605	57.59885031	no	0	1	0	3	2	yes	4	1.213995
(u'12th Street', u'Howard Street')	-122.4169251	37.77173	79.87726972	no	0	1	0	4	2	yes	4	2.383987
(u'12th Street', u'Isis Street')	-122.4143409	37.7706075	14.73506271	no	0	1	0	3	1	yes	3	0.127879
(u'12th Street', u'Kissling Street')	-122.4161895	37.7714105	14.66389103	no	0	1	0	3	1	yes	3	0.102006
(u'12th Street', u'Market Street', u'Page Street')	-122.420451	37.7743311	101.8090256	no	3	1	0	3	4	yes	4	0.461615
(u'12th Street', u'Mission Street', u'Otis Street', u'South V	-122.4187023	37.7730813	120.8159872	no	0	1	0	5	5	yes	5	1.448347
(u'12th Street', u'Stevenson Street')	-122.4196758	37.7738924	174.4247553	no	4	1	0	3	1	yes	3	0.553426
(u'13th Street', u'Bernice Street')	-122.4141025	37.769623	129.9989877	no	0	1	0	2	1	yes	3	0.926218

Source: OSM, partial list of attributes

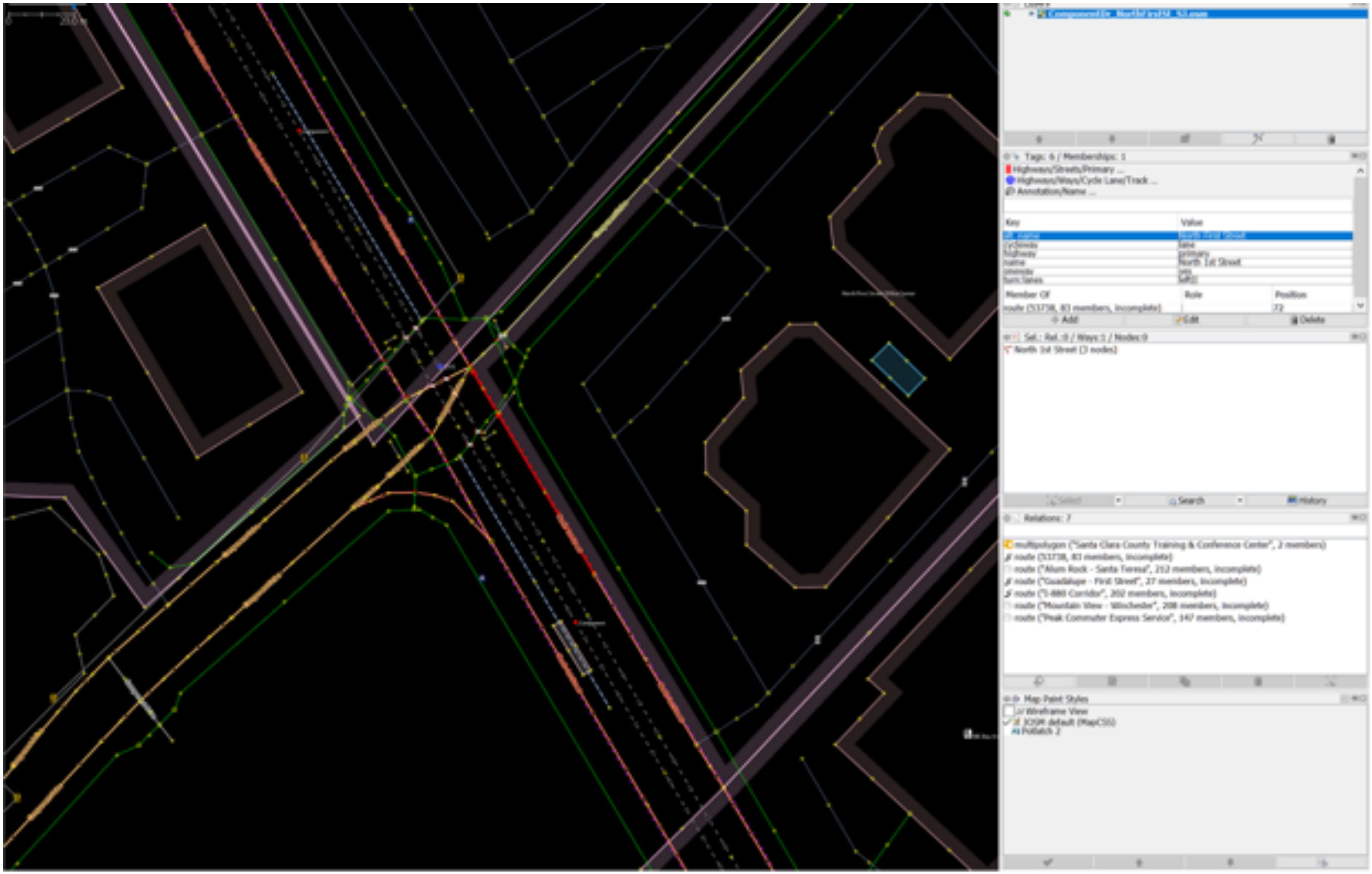
SF crashes, crashes/flow, histogram







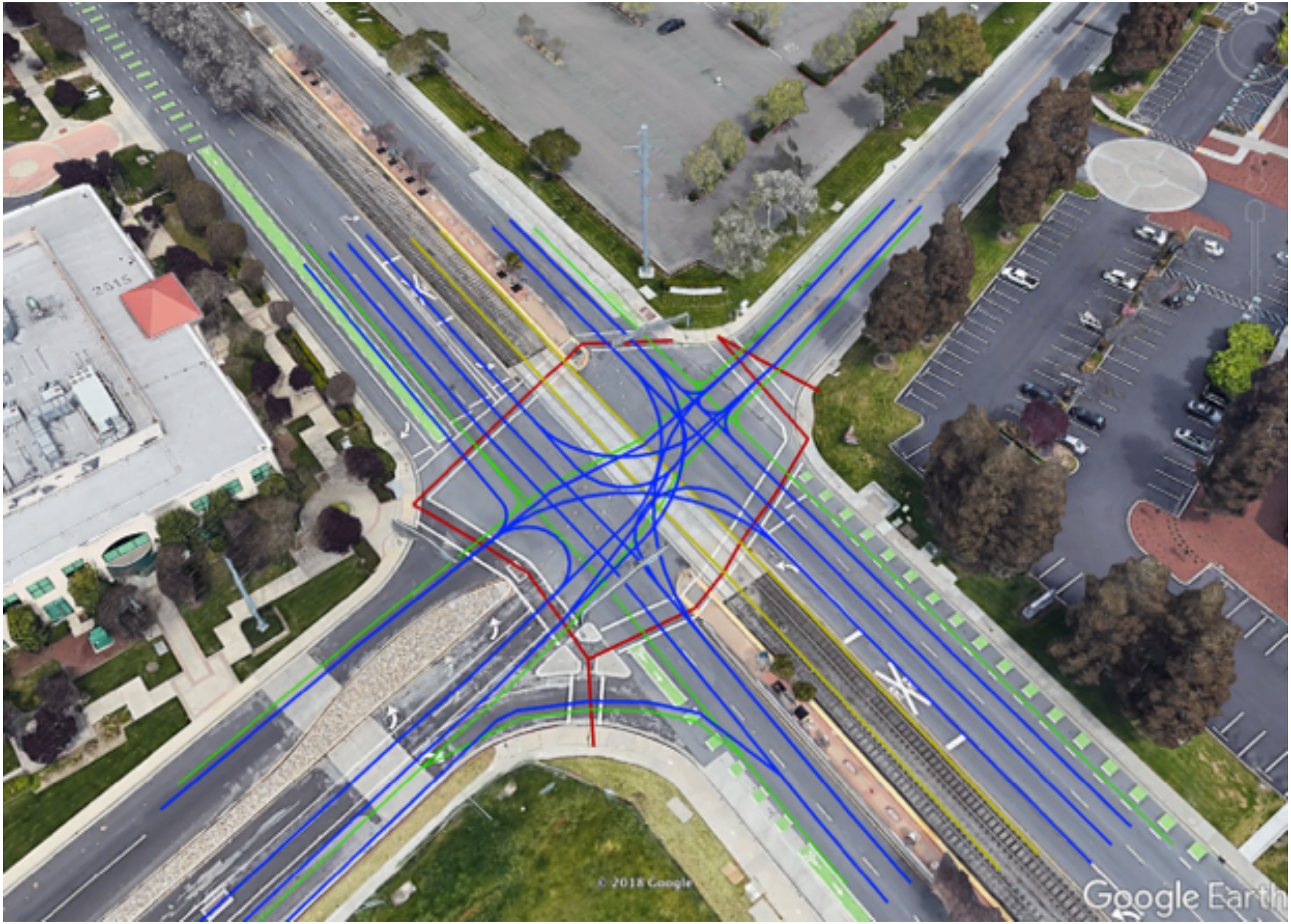
Constructing intersection catalog



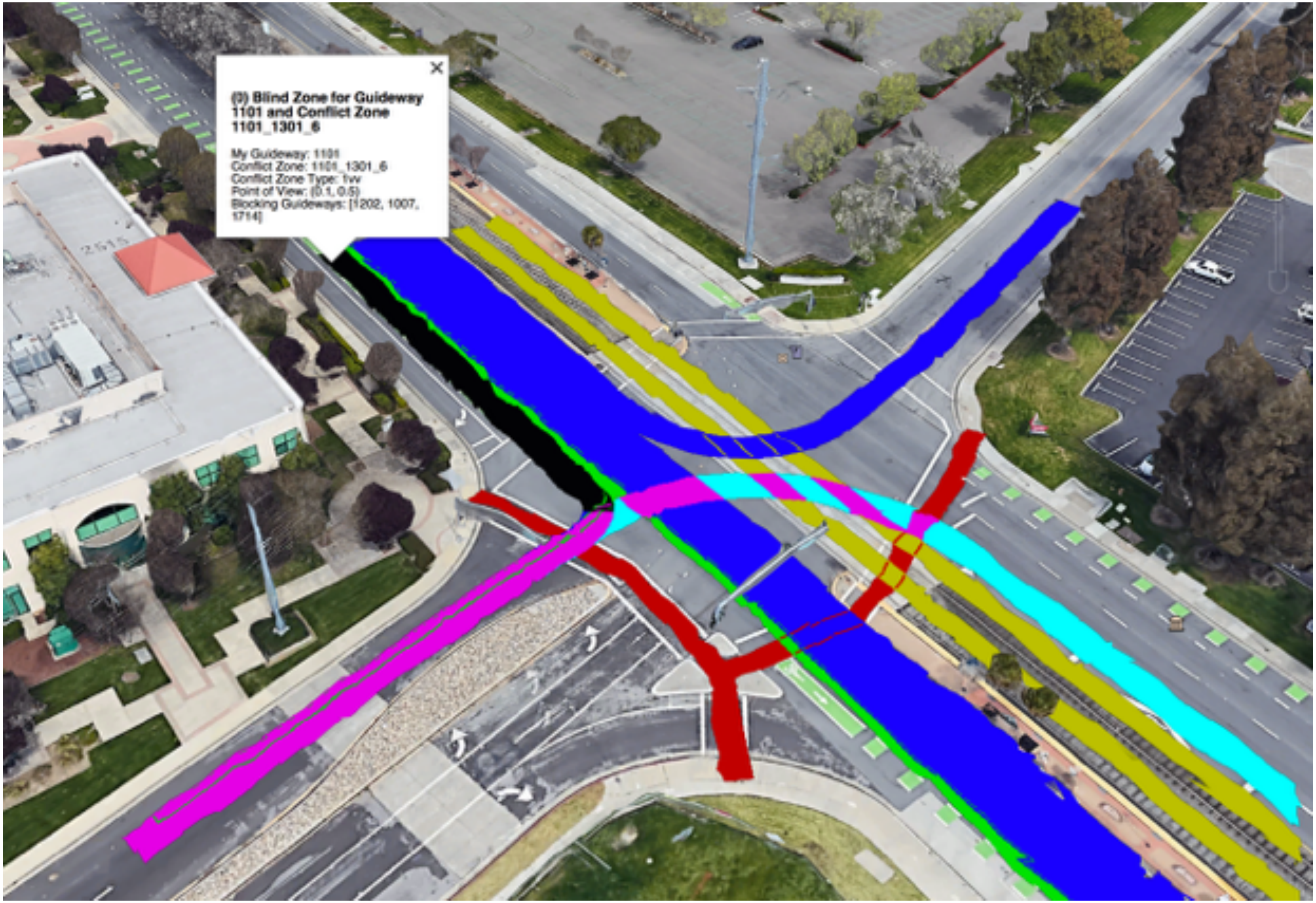
Start with OSM of intersection at N. 1st St & Component Dr, San Jose, CA

Google earth view of intersection

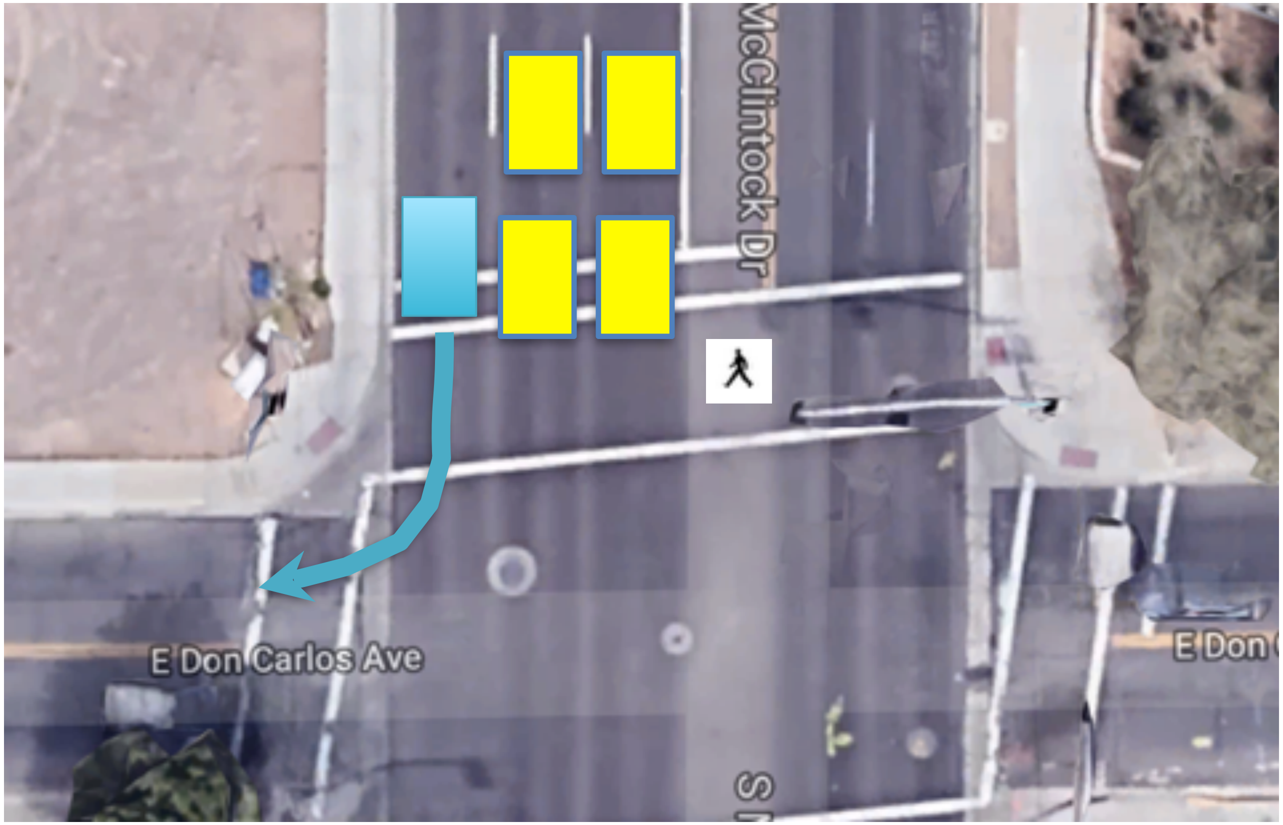
Compute guideway centerlines



Compute guideways, conflict zones, blind zones



Calculate intersection crash probability



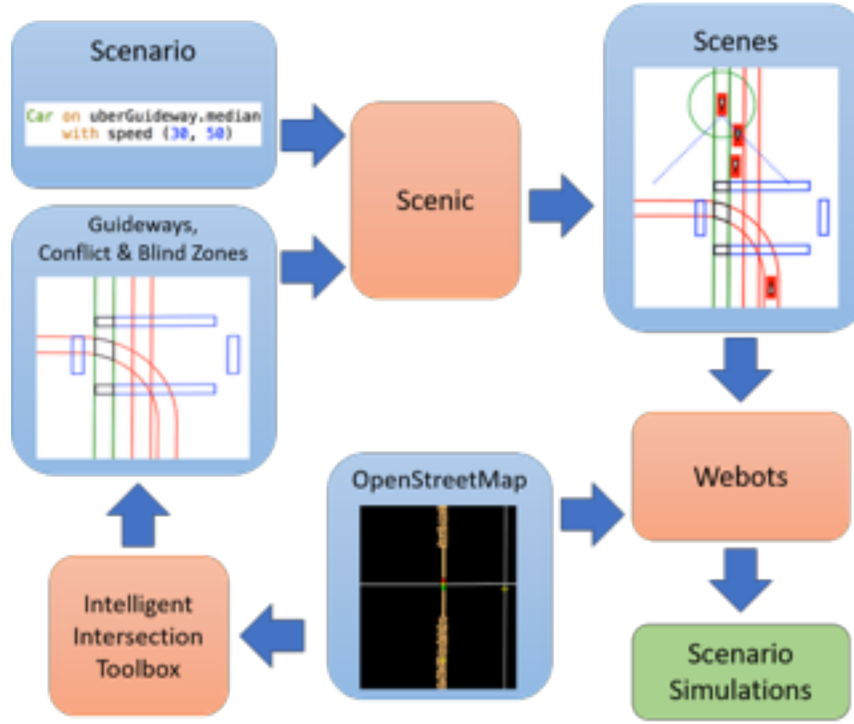
In each peak-hour cycle, probability of RTOR accident is
$$P(\text{RTOR}) \times P(\text{blocked view}) \times P(\text{ped crossing})$$

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

Generating hazardous scenarios

3 types of hazards:

1. Two agents on guideways to conflict zone cannot see each other (e.g. Uber crash) or misinterpret each others intentions
2. An agent abruptly changes its expected route (e.g. lane change) or violates the rule of the road (e.g. red light running)
3. Longitudinal conflict within one guideway (e.g. due to abrupt braking of the agent in front)



Crash narrative of AV safety driver

A Waymo Autonomous Vehicle ("Waymo AV") was traveling in autonomous mode on northbound View Street at California Street in Mountain View, approaching a four-way intersection with a traffic calming island. After coming to a complete stop at a two-way stop sign, the Waymo AV determined it was safe to proceed through the intersection and began to do so, when it detected a bicyclist approaching from the right. The Waymo AV then stopped for the bicyclist, whose front tire made contact with the passenger side of the stationary Waymo AV at approximately 3 MPH. The bicyclist remained upright and rode away without exchanging information. No injuries or damage were reported or observed.

Scene of crash

TIMS description of crash

- Intersection: View Street and California Street
- AV on View Street (going North), stopped
- Bicyclist on California Street (going West), proceeding straight
- Type of collision – “Other” (even though actually broadside) as vehicle/bicycle
- No injury

- (AV maybe occluded by tree on the right)

Transportation Injury Mapping System: TIMS

Where Can We Go from Here

1. City-scale intersection characterization
2. Use TIMS database (https://tims.berkeley.edu) to identify intersection accidents and place agents into their guideways
3. Obtain possible narratives for TIMS description
4. Prediction of agent movements at an intersection
5. Design of a planning control for intersection crossing
6. Modeling of multi-agent dynamics at intersections for the purposes of testing an ego-vehicle control
7. Greatly increase effectiveness of Vision Zero efforts