Vehicle-to-Vehicle Communication for Autonomous Vehicles: Safety and Maneuver Planning

Anum Ali[1], Libin Jiang[2], Shailesh Patil[3], Junyi Li[2], and Robert W. Heath Jr.[1]

[1]The University of Texas at Austin, Austin, TX.

[2]Qualcomm R&D, Bridgewater, NJ.

[3]Qualcomm R&D, San Diego, CA.

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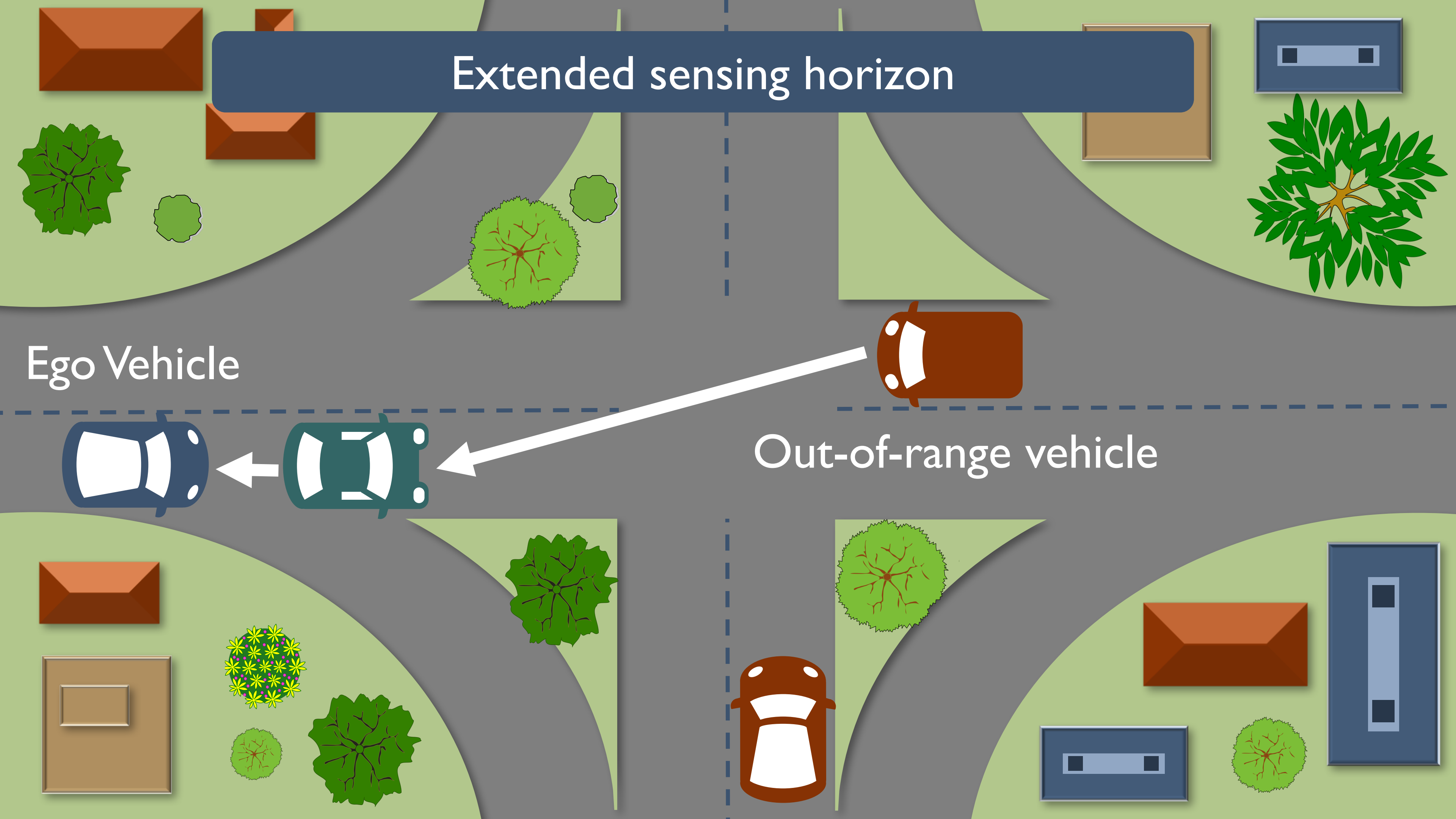
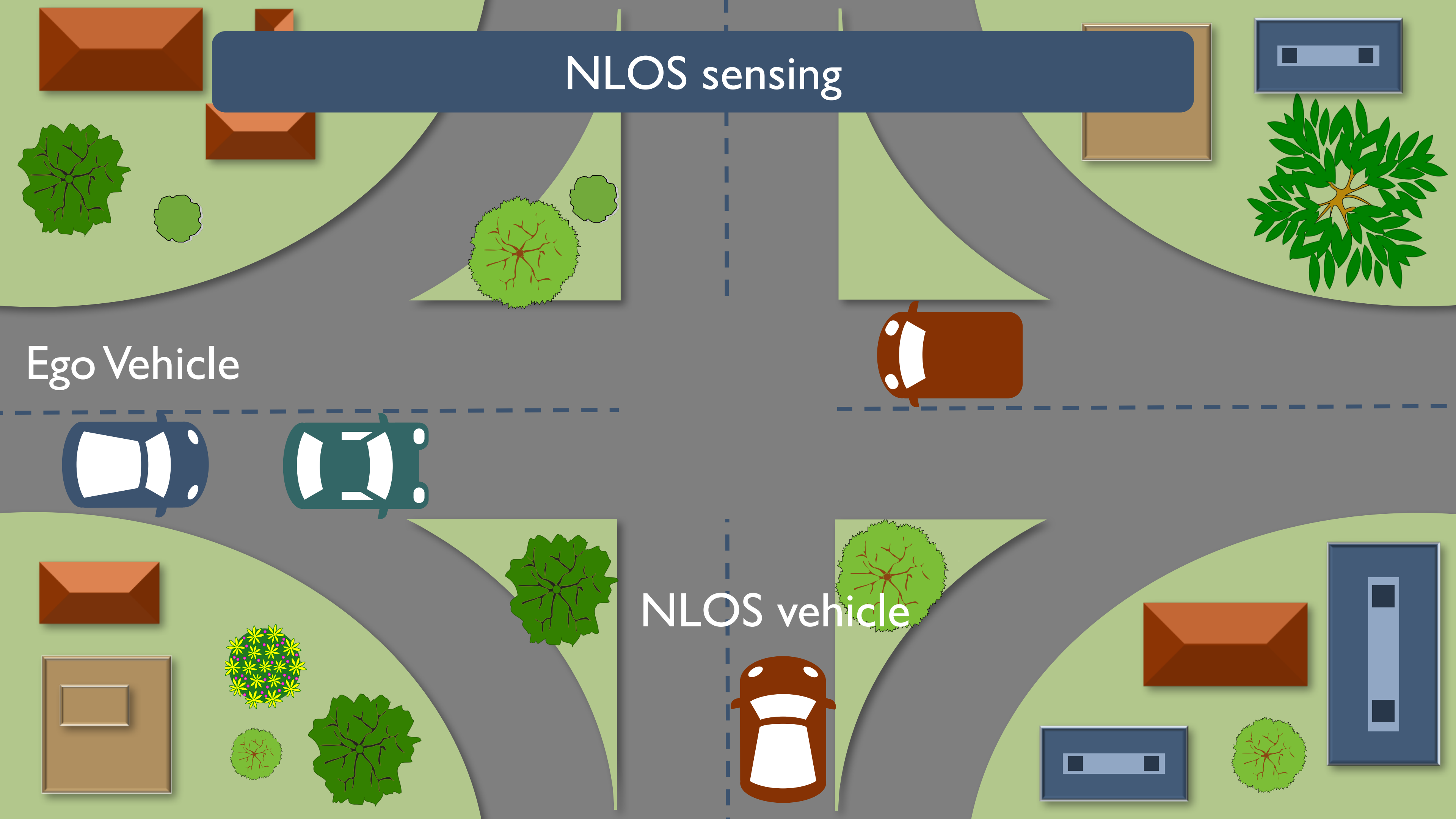
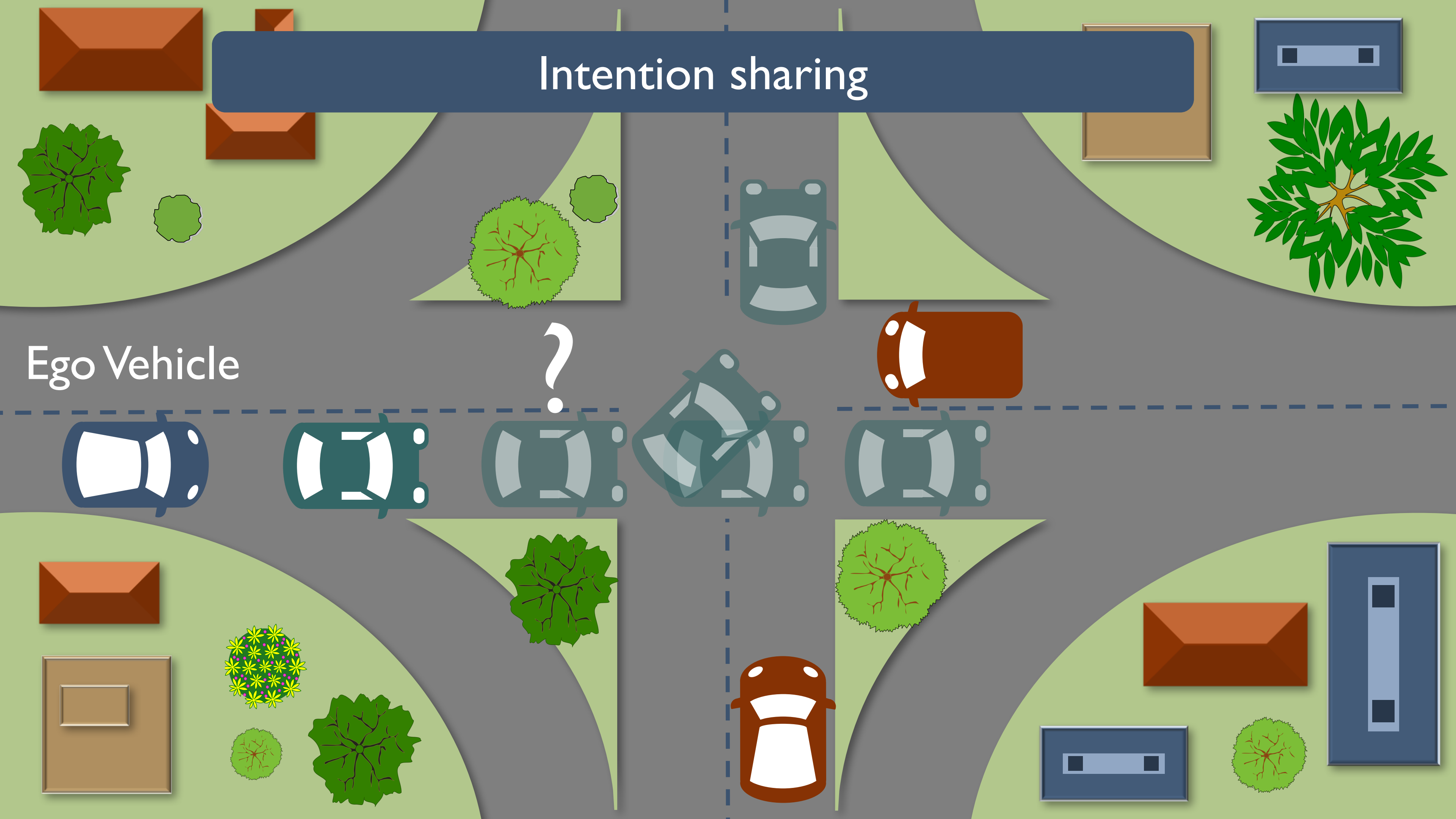
V2V can help autonomous driving!


Extended sensing horizon
Ego Vehicle
Out-of-range vehicle


NLOS sensing
Ego Vehicle
NLOS vehicle

Intention sharing



Outline

Quantifying the benefits of V2V

Safety

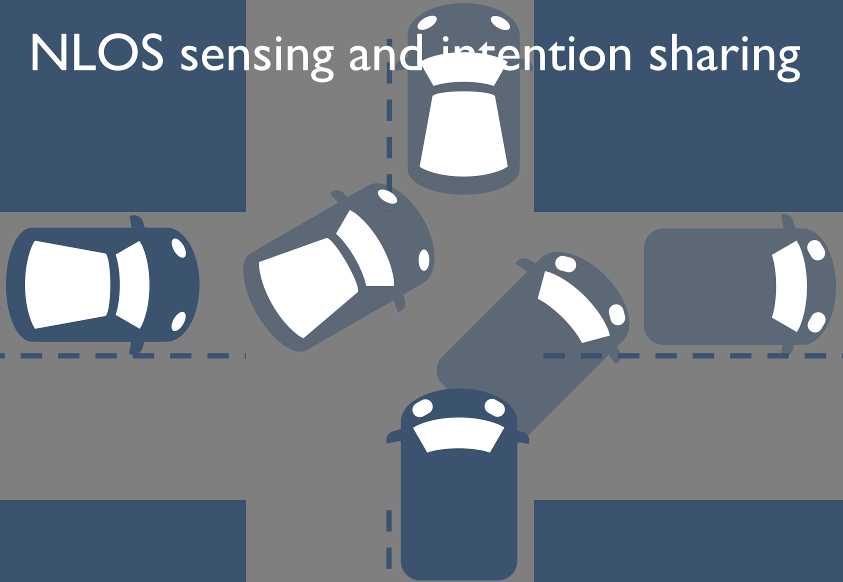
Accidents involving AVs

Accidents potentially avoided Using V2V

Maneuver planning

Lane change and turns

NLOS sensing and intention sharing



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Safety

Autonomous vs Conventional (State of the art)

Autonomous vehicles not necessarily safer

Conventional (2015) [1]

Miles driven: 3,095,373 million

Accidents: 6,296,000

Accidents per 100 million miles driven

203

Waymo (aka Google) (2016/17)

Miles driven: 988,412 [2][3]

Accidents: 10 [3]

Accidents per 100 million miles driven

1011

More than 4x higher accident rate for autonomous cars

[1] NHTSA safety report https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812384
[2] https://www.dmv.ca.gov/portal/wcm/connect/946b3502-c959-4e3b-b119-91319c27788f/GoogleAutoWaymo_disengage_report_2016.pdf?MOD=AJPERES
[3] https://www.dmv.ca.gov/portal/wcm/connect/42aff875-7ab1-4115-a72a-97f6f24b23cc/Waymofull.pdf?MOD=AJPERES&CVID=
[4] https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/autonomousveh_ol316

Example rear end collision

Waymo AV 09/07/2016

Safe distance

[1] https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/autonomousveh_ol316

Example rear end collision

Waymo AV 09/07/2016

At stop sign, Waymo advances forward at 5 km/h to gain view

[1] https://www.dmv.ca.gov/portaldmv/detail/vr/autonomous/autonomousveh_ol316

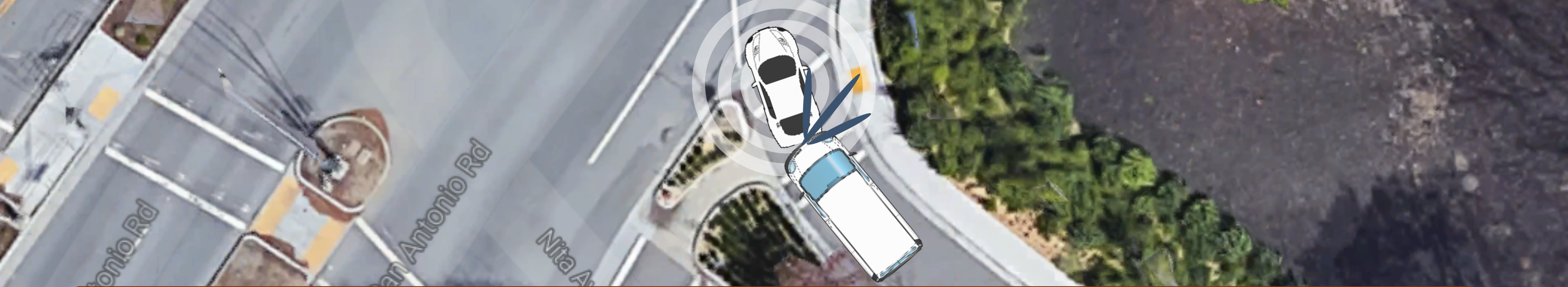
Example rear end collision

Waymo AV 09/07/2016

Passenger van moves forward at 11km/h and causes accident

[1] https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/autonomousveh_ol316

Example rear end collision



Forward Collision Warning deactivated for speeds below 32 km/h [2]

Intention sharing using V2V can help

Waymo AV 09/07/2016

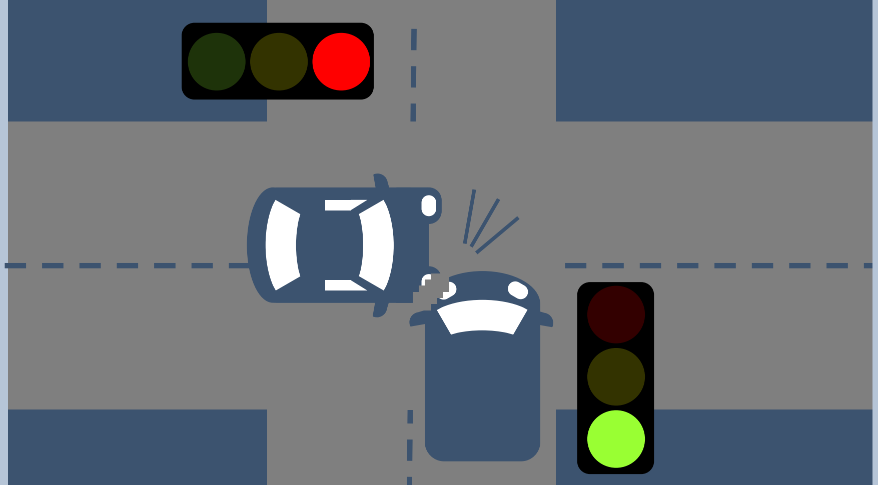
Passenger van moves forward at 11km/h and causes accident

[1] J. B. Cicchino, "Effectiveness of forward collision warning systems with and without autonomous emergency braking in reducing police-reportedcrash rates," Jan. 2016, insurance Institute for Highway Safety.

Red light running accidents

771 deaths and 137,000 injuries in 2015

Waymo vehicle got hit after it's light was green for more than 6s



At 35 km/h, an AV will has a stopping distance of 18.3 m with LOS sensing

The road design permits on 6.6 m view [1]

With V2V range of 107 m [2], an AV can make safe stop for up-to 90 km/h

[1] "Policy on geometric design of highways and streets." American Association of State Highway and Transportation Officials, Washington, DC 1.990 (2001): 158.
[2] Accelerating C-V2X commercialization. [Online]. Available: https://www.qualcomm.com/media/documents/files/the- path- to- 5g- cellular- vehicle- to- everything- c- v2x.pdf

Accident Classification

Accidents reported to DMV in 2016/2017

Accident Type	Lane Change	Rear-end	Intersection	Unclassified	Total
Reported	6	12	1	1	20
Relevant	6	8	1	1	16
V2V can help	6	8	1	1	16

V2V possibly helpful for 100% of the relevant accidents

V2V possibly helpful for 80% of the total accidents involving autonomous cars

Maneuver planning

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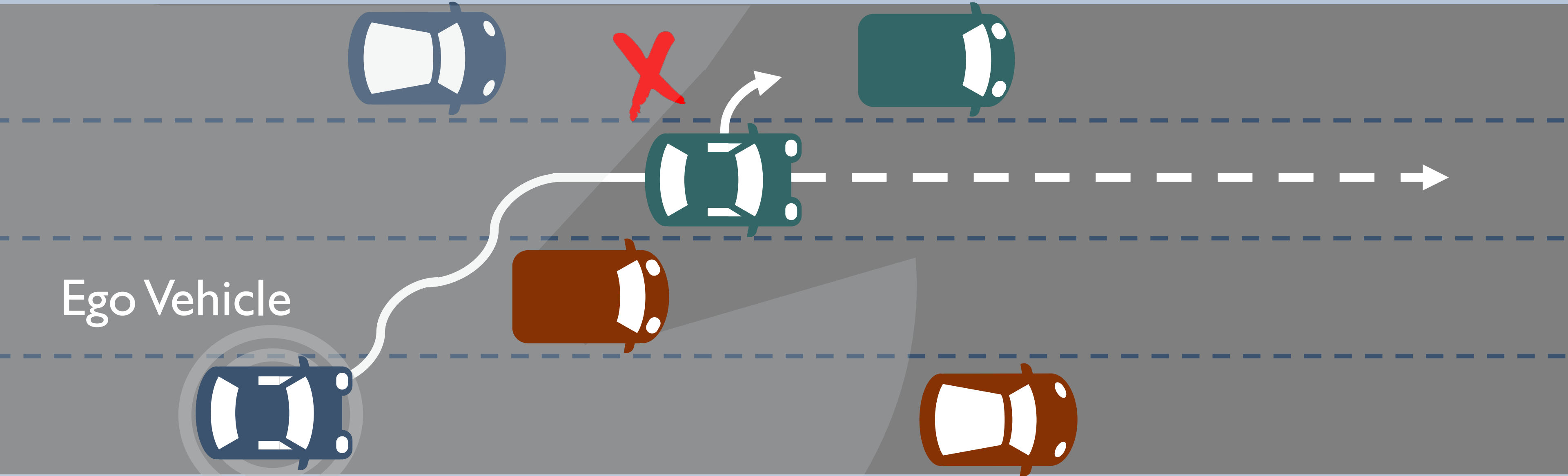
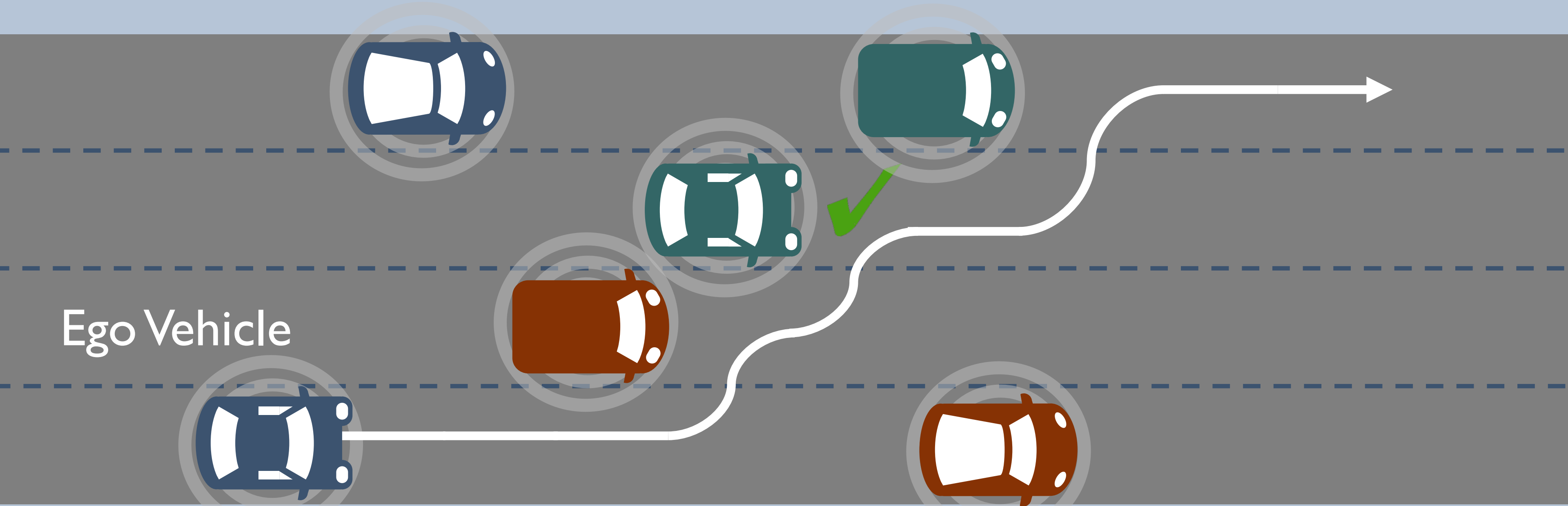
Maneuver planning

LOS sensing based maneuver planning not necessarily optimal



Maneuver planning

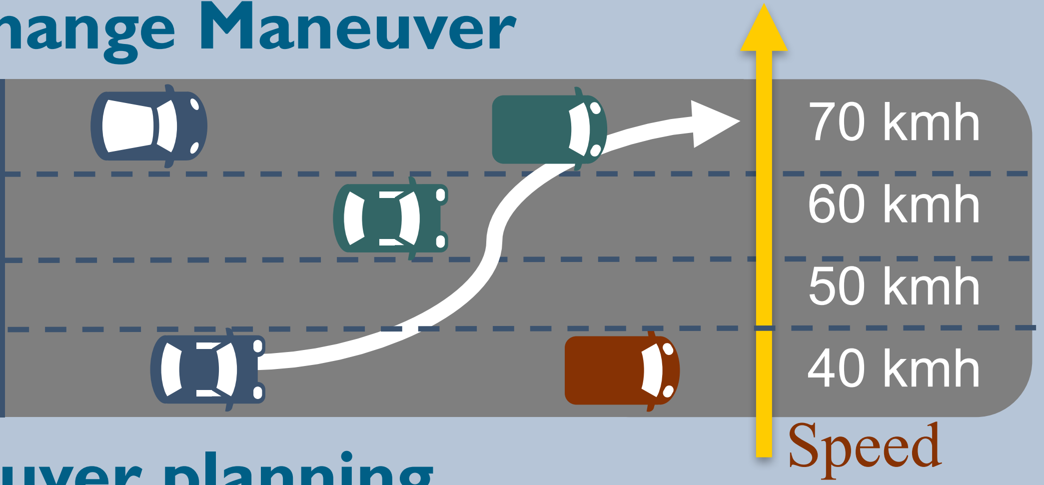
Better path planning with V2V: NLOS sensing and trajectory sharing



Lane change Maneuver

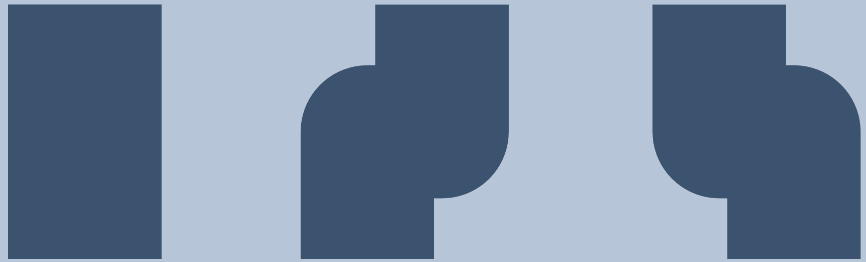
Objective: Reach left-most lane

Subsequent travel at maximum allowable speed



Maneuver planning

Three maneuvers

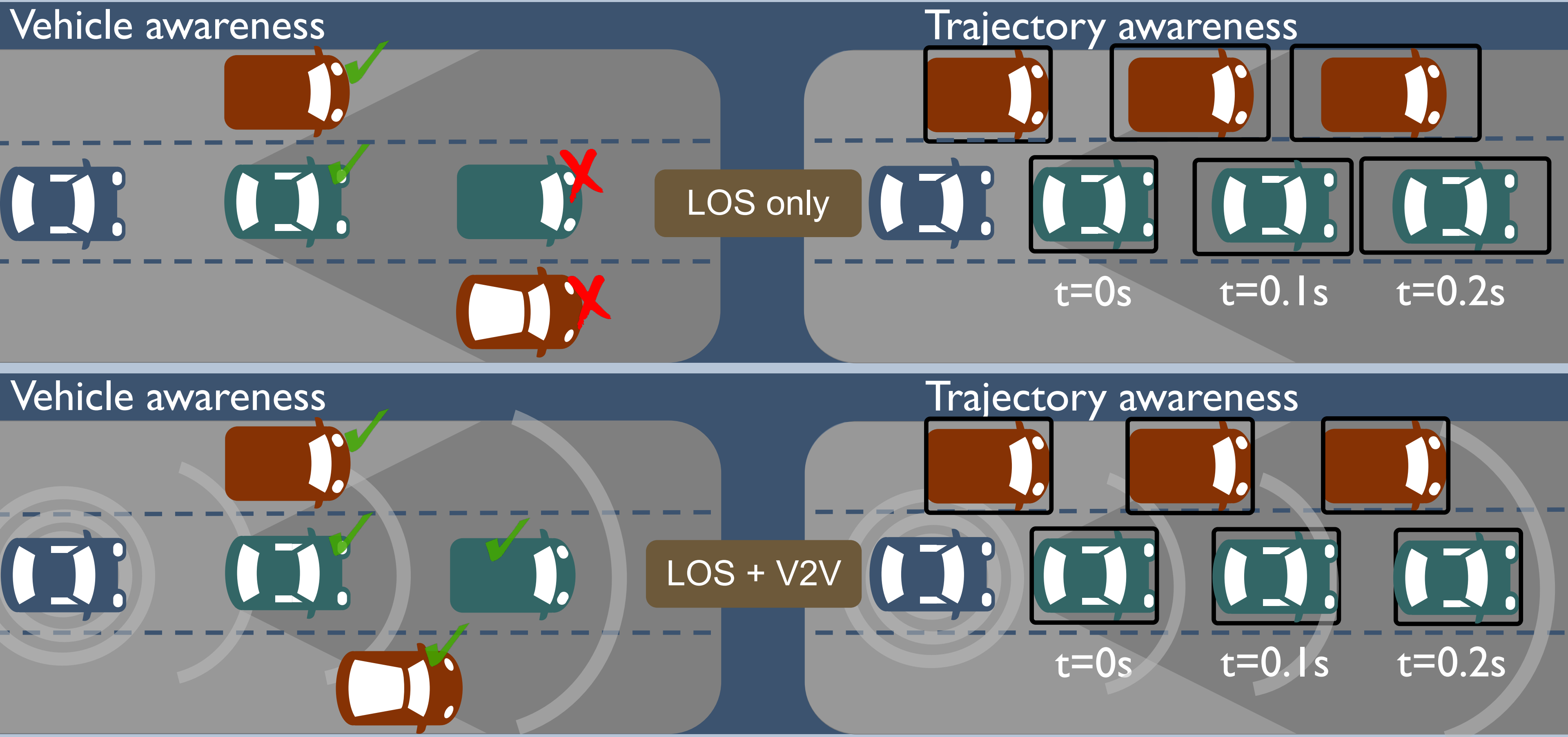


Stay in lane | change to right | change to left

- Maintain speed, accelerate, or decelerate
- Lane change will take ~5 seconds [1]
- Search for the shortest path using A* [2]
- Forward simulation to check feasibility

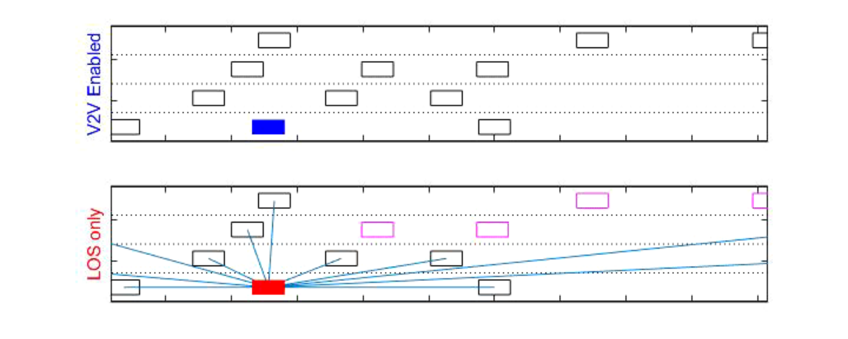
[1] Toledo, Tomer, and David Zohar. "Modeling duration of lane changes." Transportation Research Record: Journal of the Transportation Research Board 1999 (2007): 71-78.
[2] https://en.wikipedia.org/wiki/A*_search_algorithm

Sensing and communication assumptions



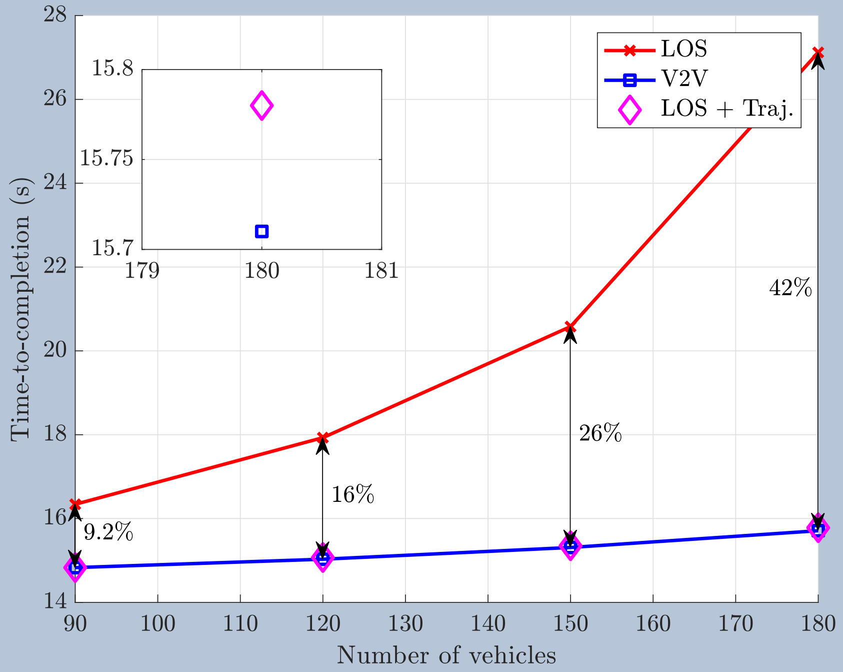
Results

Example Run



Red: LOS only Ego Vehicle
Blue: V2V enabled Ego Vehicle
Black: Currently detected vehicles
Magenta: Current undetected vehicles
Line segments: vehicles detected via LOS sensing

Averaged time



Trajectory information helps more than NLOS sensing

Turn Maneuver

Objective: Make right or left turn

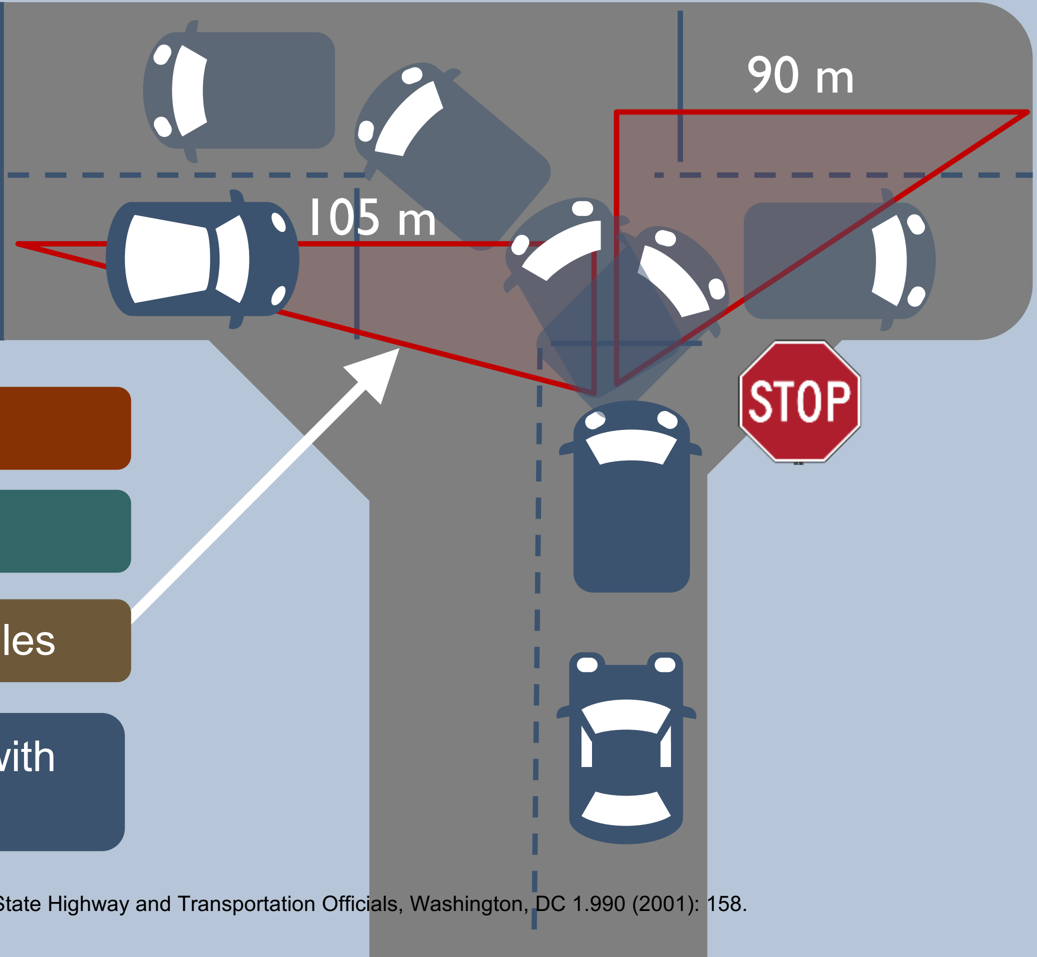
Saves time in urban driving

Right turn takes 6.5 sec [1]

Left turn takes 7.5 sec [1]

LOS sensing based on sight triangles

Vehicles arrive at the intersection with exponential rate



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Results

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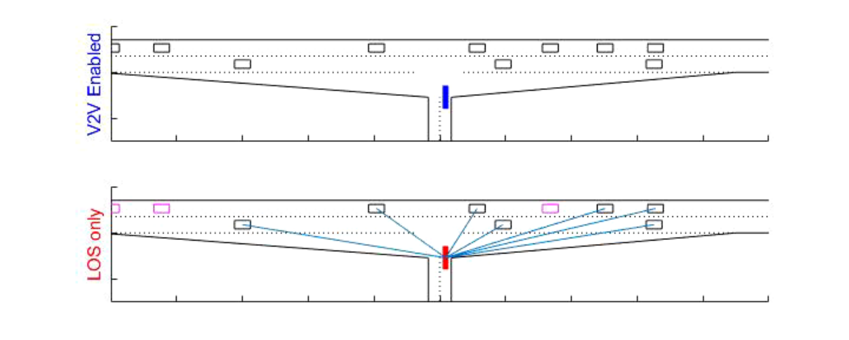

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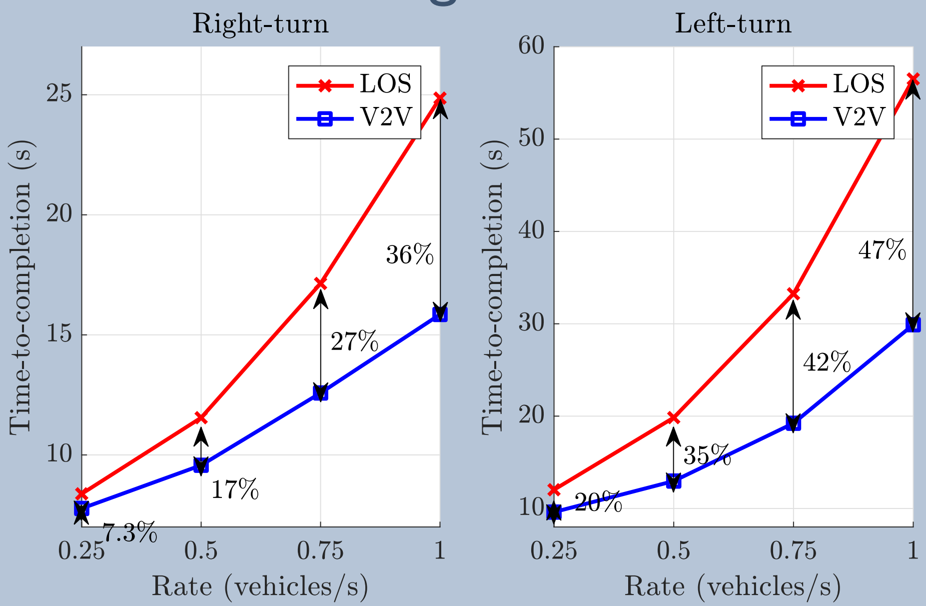

Percent savings higher in left-turn manuever

Conclusion

Conclusions

V2V can help in reducing the accidents involving AVs

V2V can reduce the time to left-most lane by up to 42%

V2V can help reduce the time of left and right turn by 47% and 36% respectively

Sharing current speed/velocity is not sufficient – trajectory sharing is needed

Thank you!

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Backup slides

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Time-to-completion with error

Sensors provide noisy measurements

V2V enabled

Upto 60% savings in lane change maneuver with V2V