Simulation Evaluation of Cooperative Intersection Traversing Method for Connected Vehicles

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Contents

INTRODUCTION

Connected Vehicles (CVs)

- Connected to network
- Communicate and share information
  with other vehicles (V2V) or roadside infrastructures (V2I)

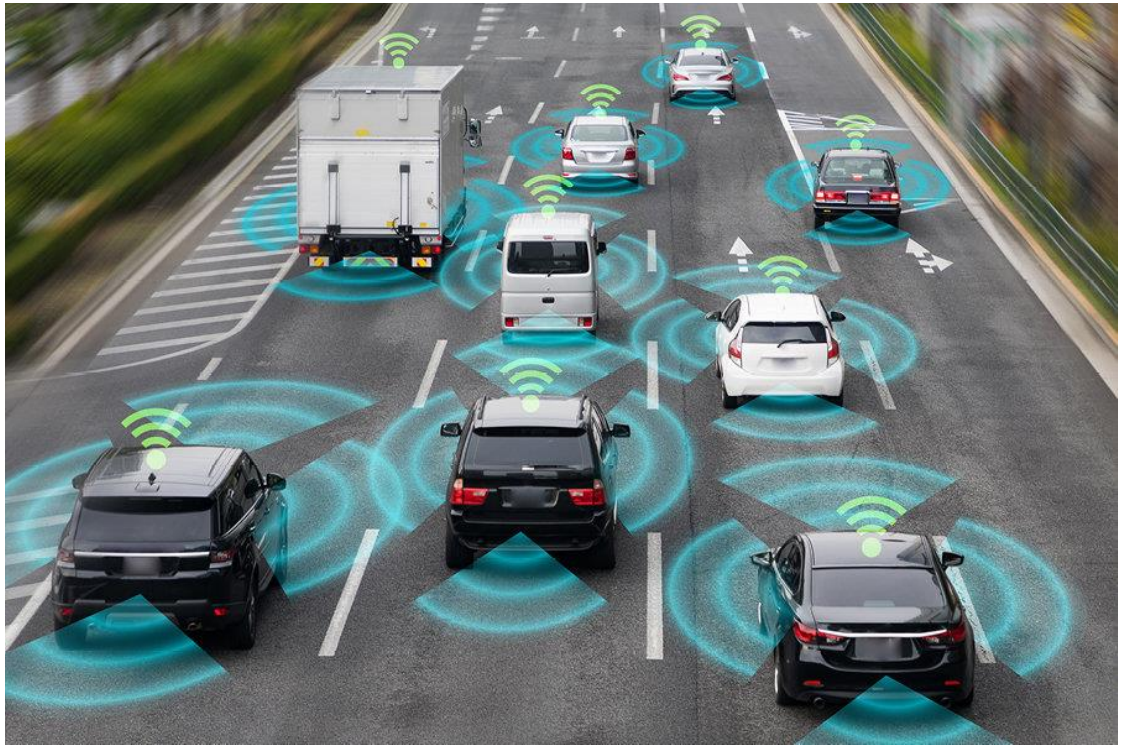
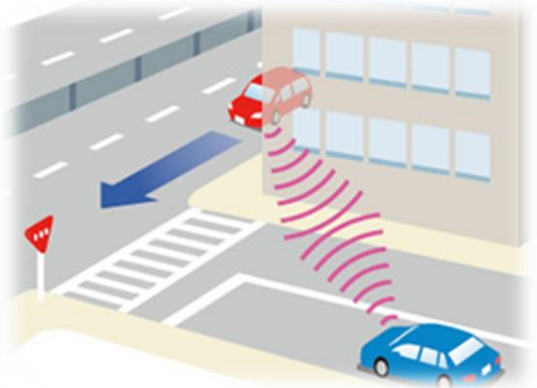


Image Source: PHYS.org

Autonomous Driving with Connected Vehicles

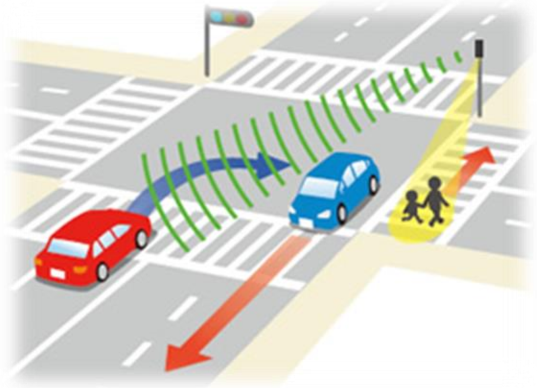
- Safe Driving Support

Images Source : ITS Connect Promotion Consortium



Detect other vehicles near an intersection

Give way to an emergency vehicle



Detect pedestrians in blind spots

- Connected Vehicles & Autonomous Driving Technology
⇒Cooperative, Safe and Efficient Traffic

Problem

However…

Connected vehicles and Non-Connected vehicles will be mixed and share the same roads

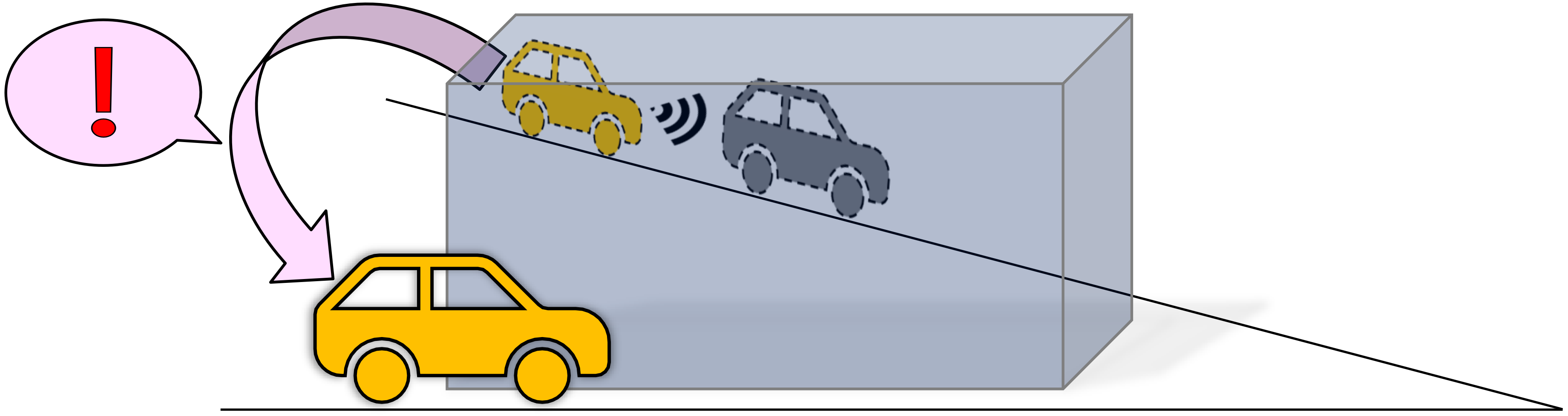
CVs can know other CVs' information (position, speed, and etc.)
cannot know Non-CVs' information

⇩

Need method to share and use information of Non-CVs

Purpose

- Target an intersection with mixed CVs and Non-CVs
- Propose a method for CVs to share information
  about the presence of Non-CVs near the intersection via V2V
- Consider safety and evaluate traffic flow efficiency



RELATED WORK

Related Work - 1

- Collective Perception
  - CVs with radar sensors and Non-CVs share the same road
  - CVs share the position information of surrounding vehicles detected by its sensor
  - →CVs can perceive the position of many vehicles around 300 m
    (at 70 % penetration rate, over 90 % of all vehicles was perceived)

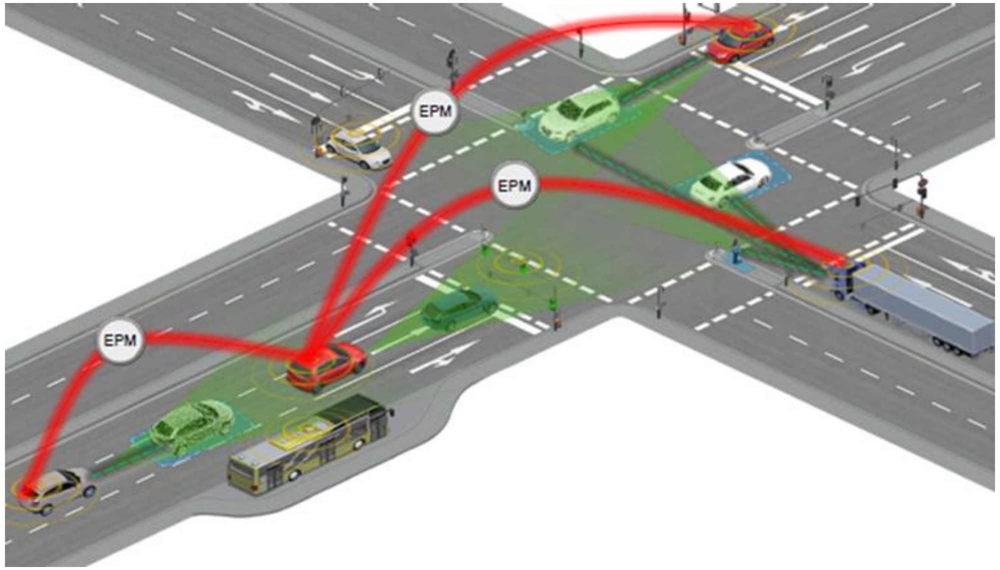
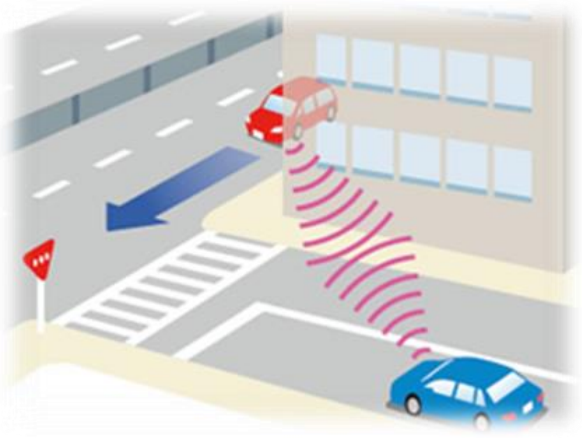


Image Sourece : Towards Autmatic Driving – Collective Perception

Hendrik-Jorn Gunther, Raphael Riebl, Lars Wolf, Christian Facchi,
"Collective Perception and Decentralized Congestion Control in Vehicular Ad-hoc Networks", Vehicular Networking Conference(VNC), 2016

Related Work - 2

- Safety and Efficiency of Connected Vehicles Traversing an Intersection
  - CVs get the position and speed of other CVs via V2V communication
  - determine whether it is safe to enter an intersection without stopping to check for oncoming vehicles



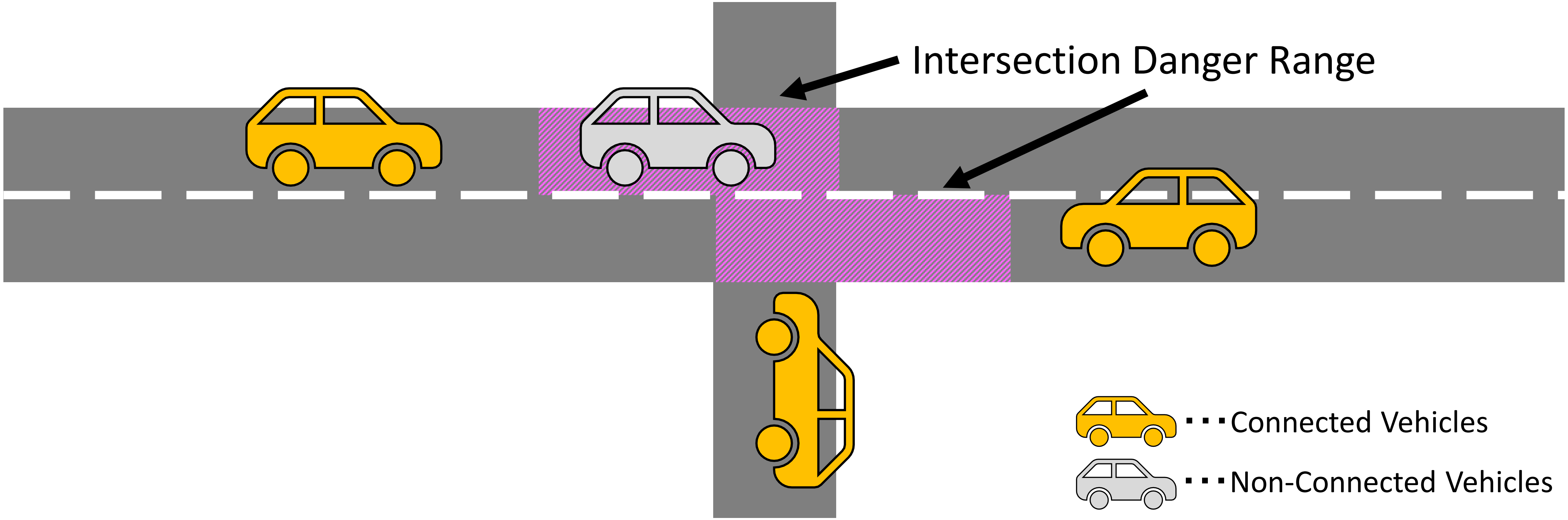
  - Travel time of vehicles was reduced compared with traffic right control and stop sign control

➡ We consider mixed situation with CVs and Non-CVs

K. Kimura, S. Azuma, and K. Sato, "Evaluation of Safety and Efficiency Simulation of Cooperative Automated Driving",
The Seventh International Conference on Advances in Vehicular Systems, Technologies and Applications (VEHICULAR 2018), pp. 66-71, Venice, Italy, 2018.

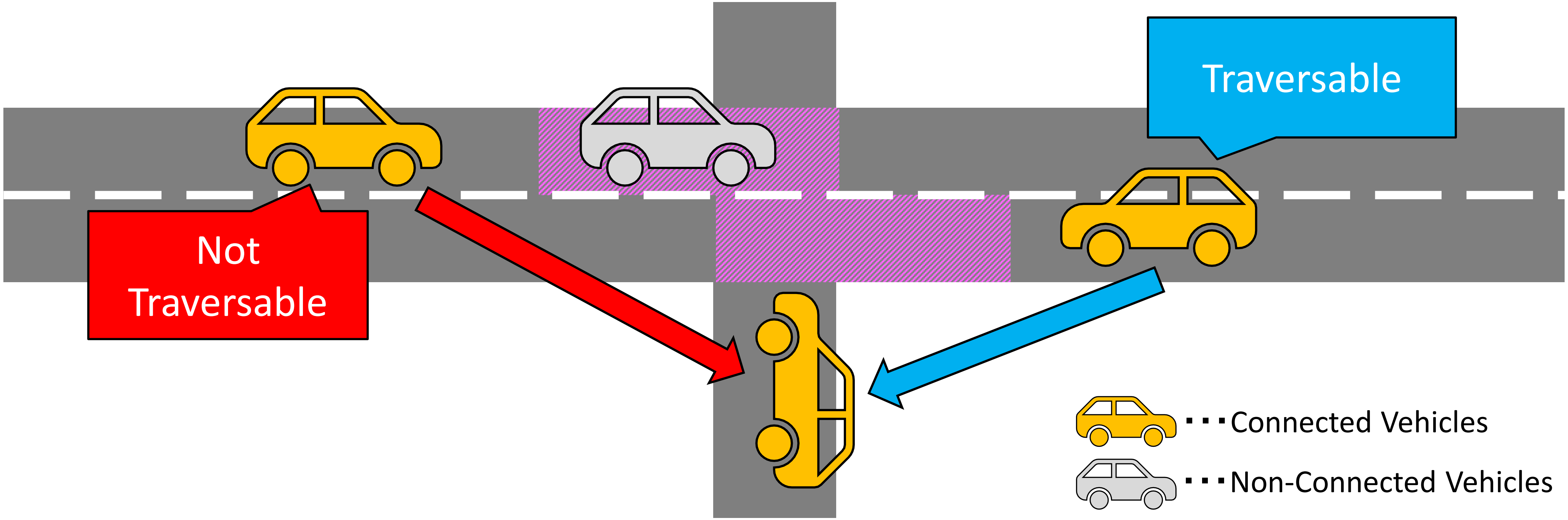
PROPOSED METHOD

Communication Procedure



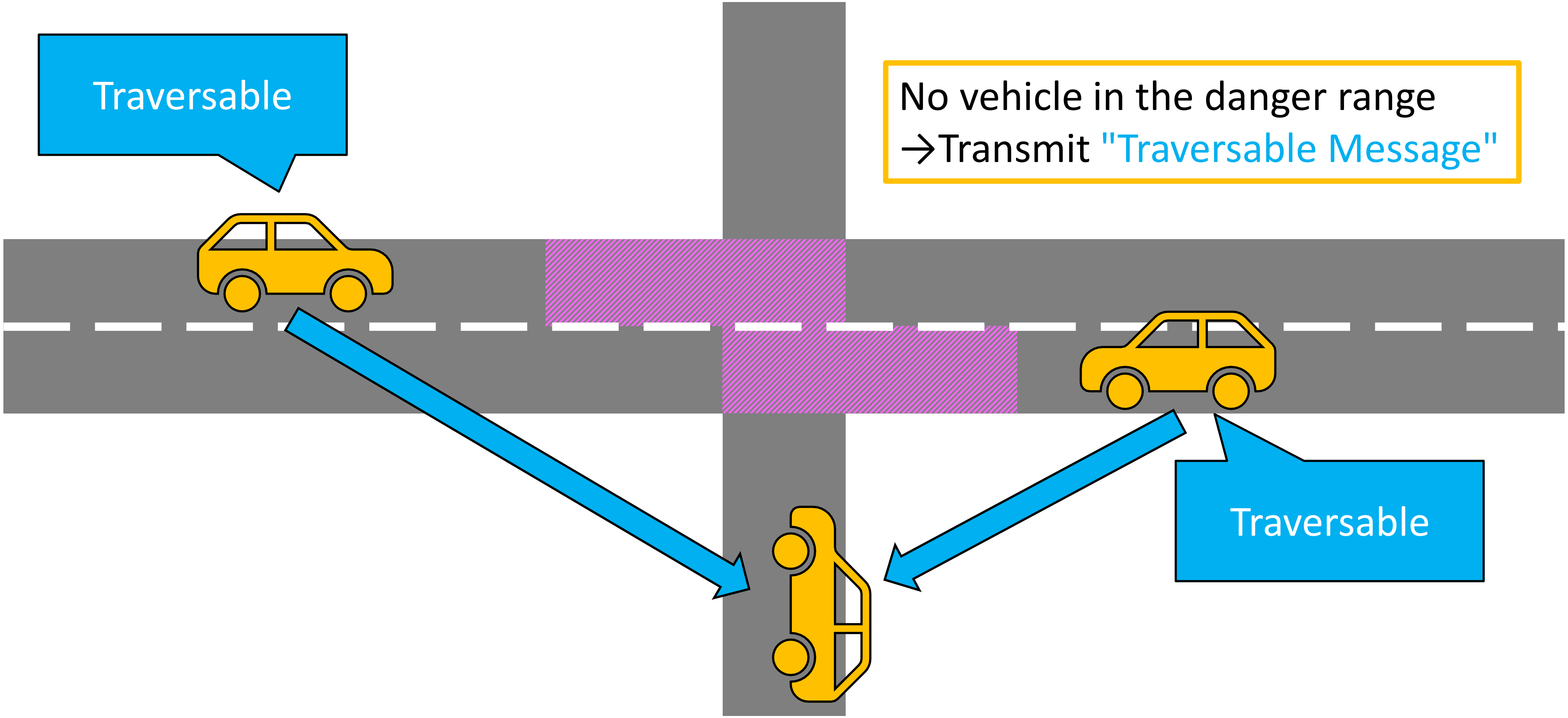
Can enter the intersection?
If vehicle(s) is in the danger range Unsafe (Not Traversable)
Otherwise Safe（Traversable）

Communication Procedure

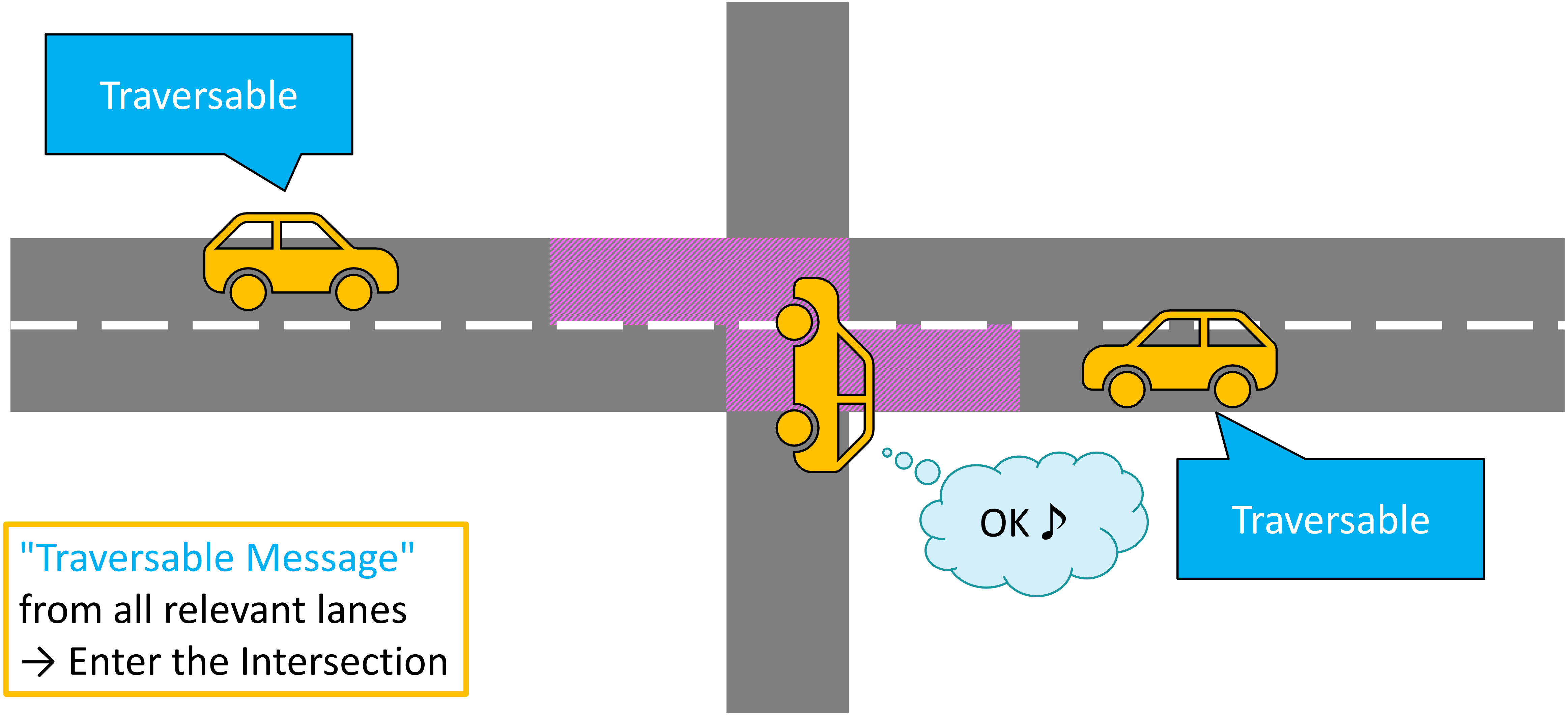


Broadcast constantly
to CVs on the non-priority road

Traversable Example

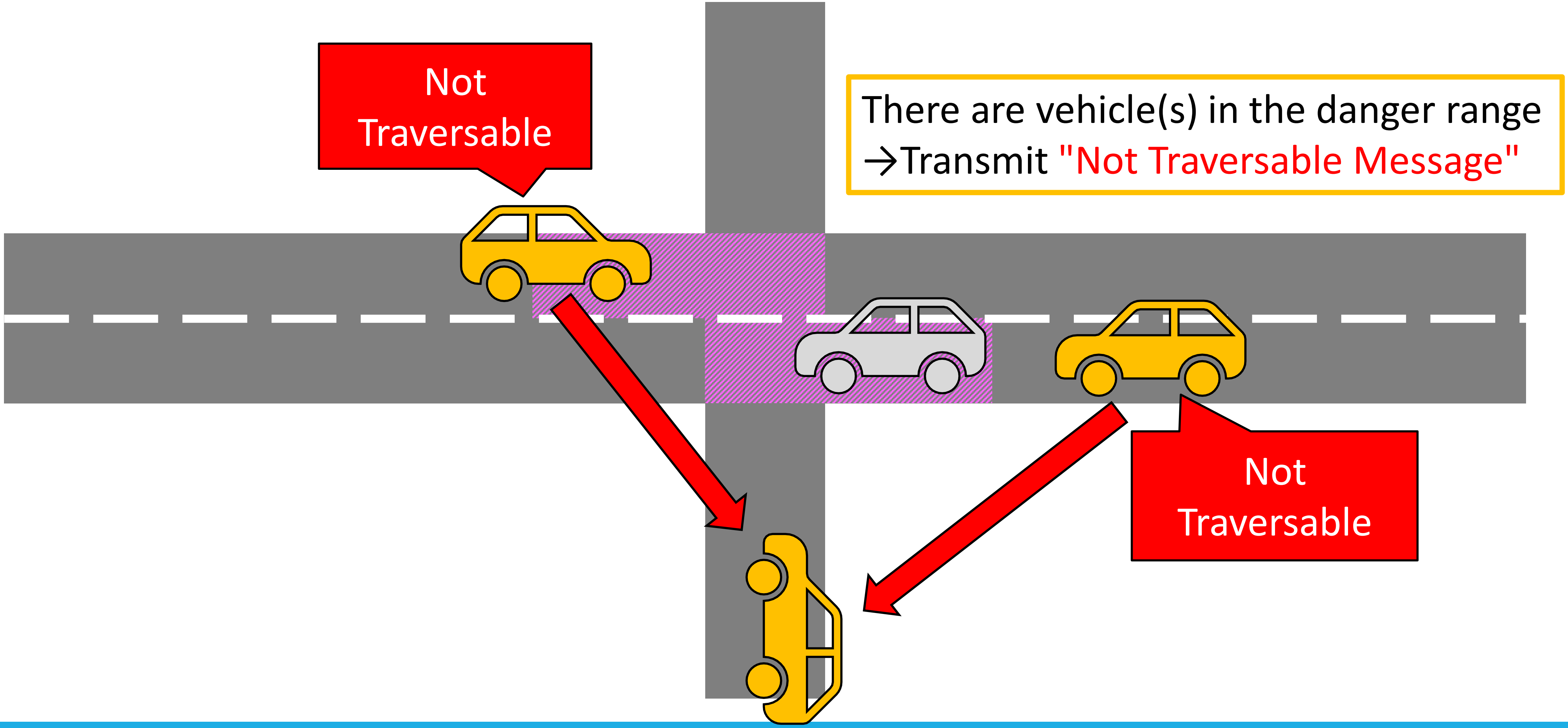


Traversable Example

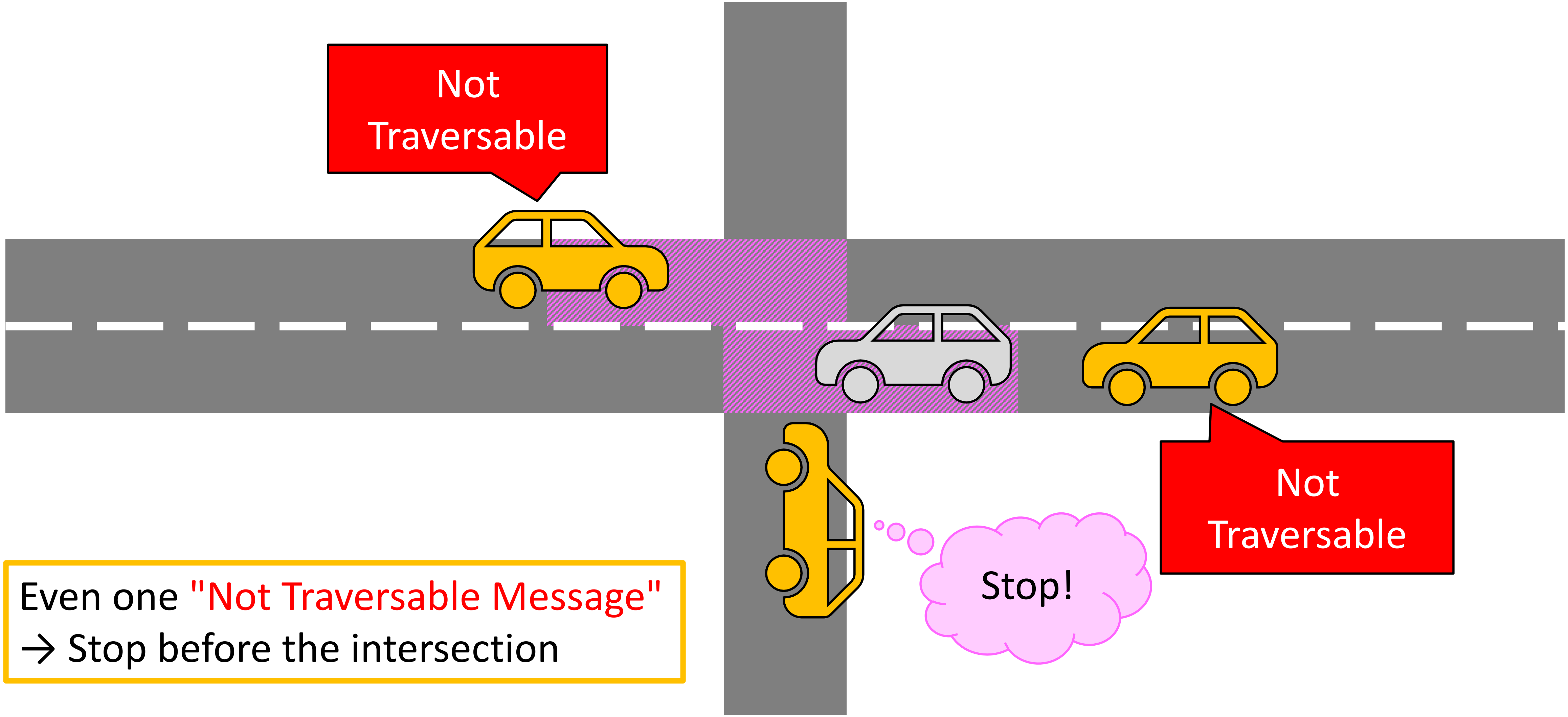


"Traversable Message"
from all relevant lanes
→ Enter the Intersection

Not Traversable Example - 1

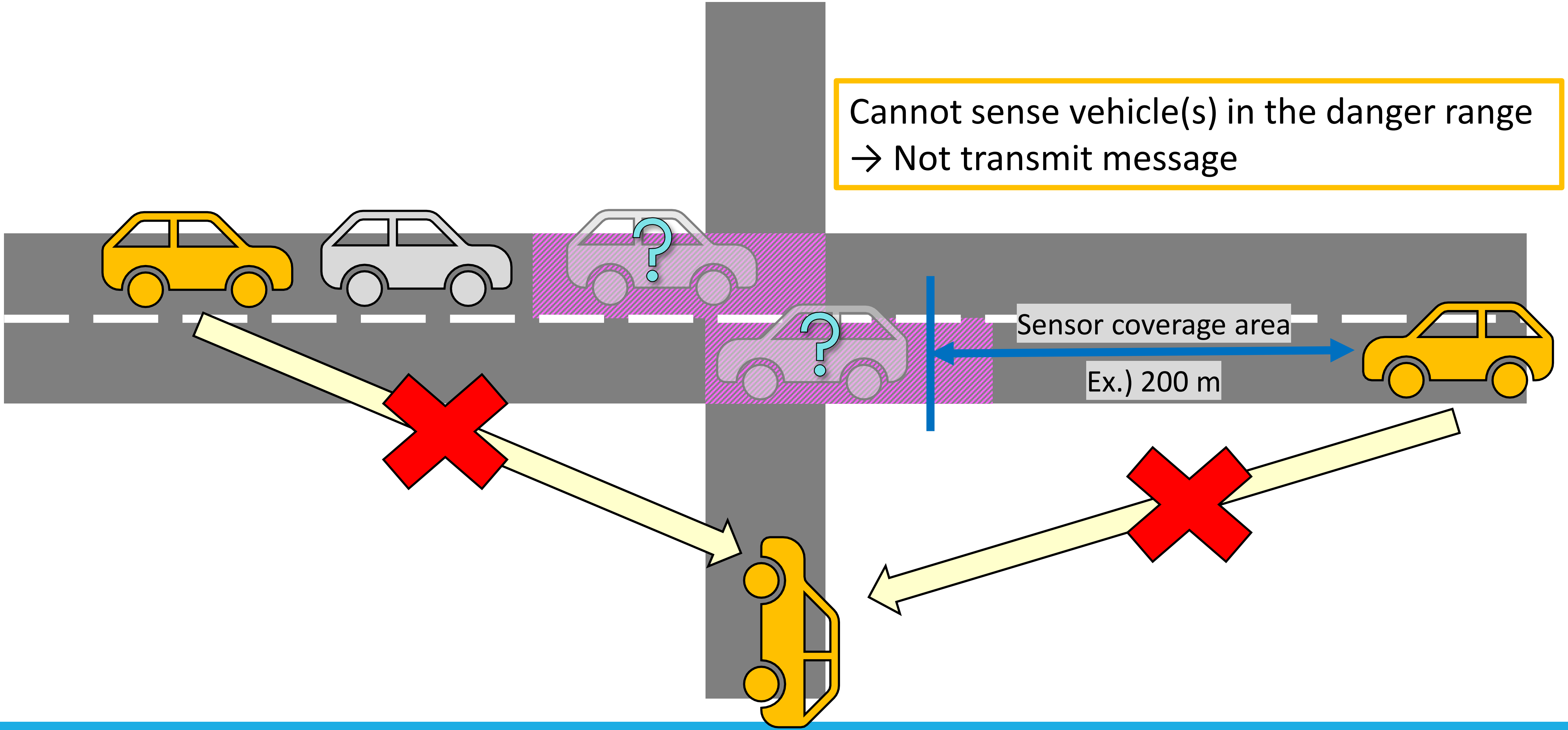


Not Traversable Example - 1

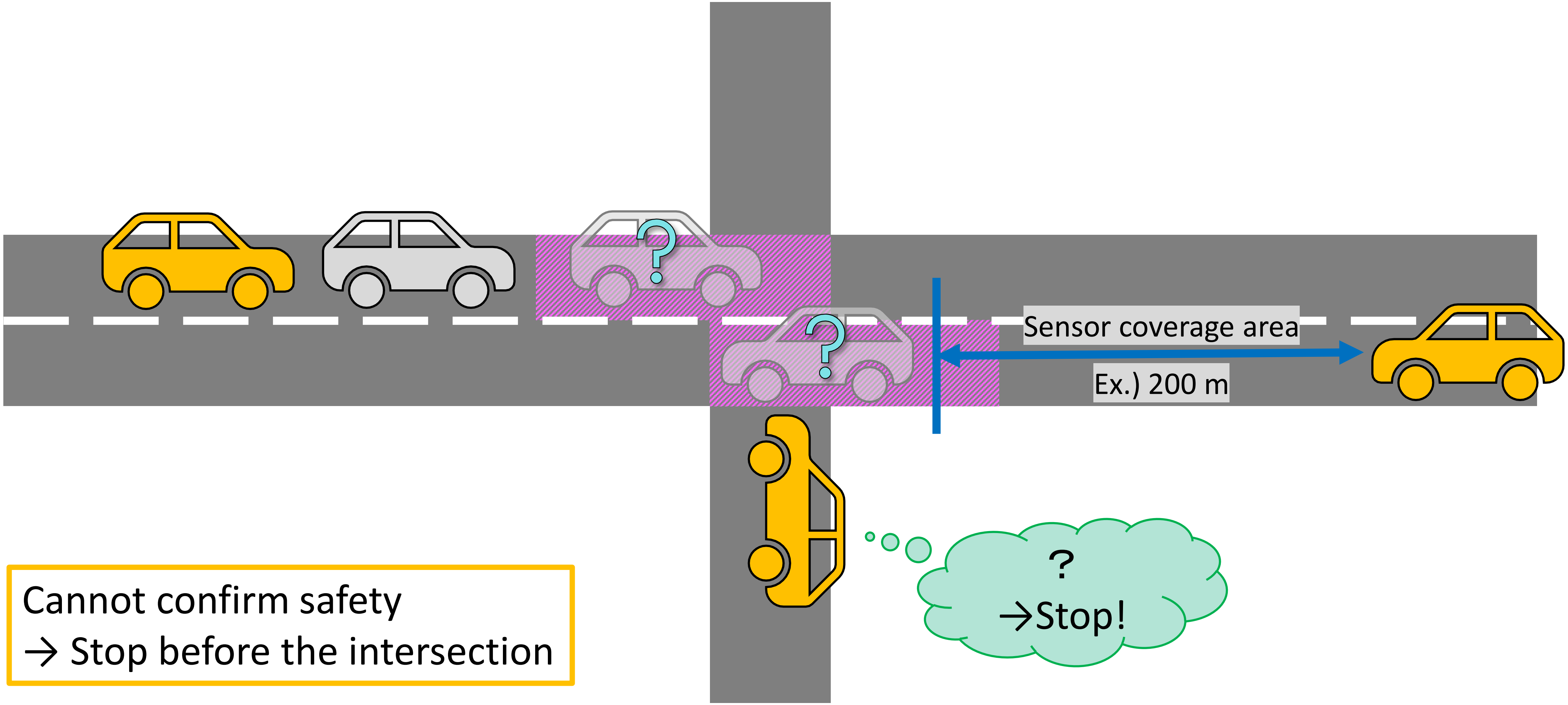


Even one "Not Traversable Message"
→ Stop before the intersection

Not Traversable Example - 2



Not Traversable Example - 2

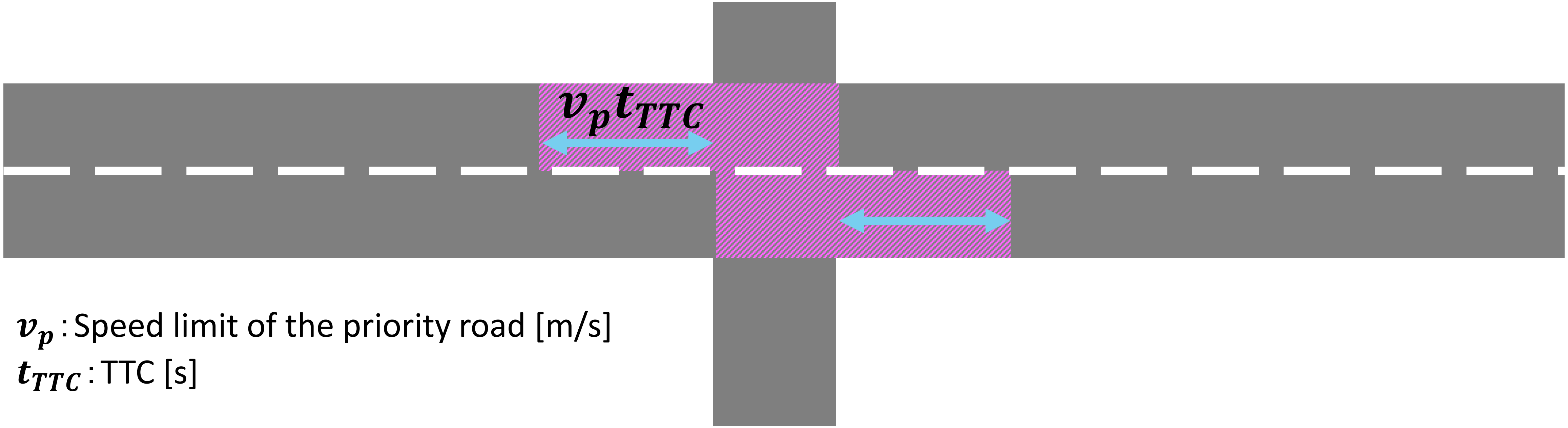


Cannot confirm safety
→ Stop before the intersection

Safety with Intersection Danger Range - 1

- Intersection Danger Range
  - the range in which a vehicle on a non-priority road may collide with a vehicle on the priority road upon entering the intersection

- The length is calculated using speed limit of the priority road and Time-To-Collision (TTC)



v_p : Speed limit of the priority road [m/s]

t_{TTC} : TTC [s]

Safety with Intersection Danger Range - 2

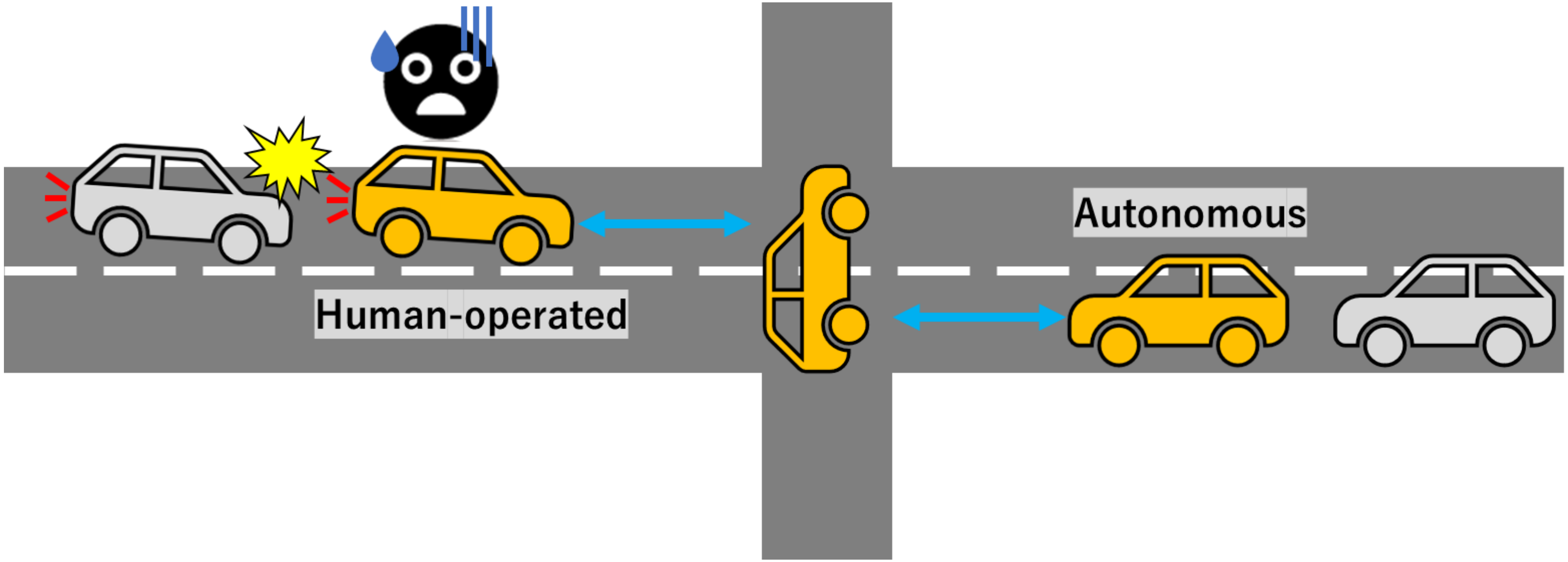
- Assumed Connected Vehicles
  - Autonomous Vehicles (AVs)
  - Human-operated Vehicles (HVs)
    - Information is notified to drivers through onboard equipment and drivers make decisions and perform operations

The length of the intersection danger range (= TTC) differs between AVs and HVs !

- AVs need only small TTC if there are no collisions
- HVs need more time margin to prevent surprising drivers

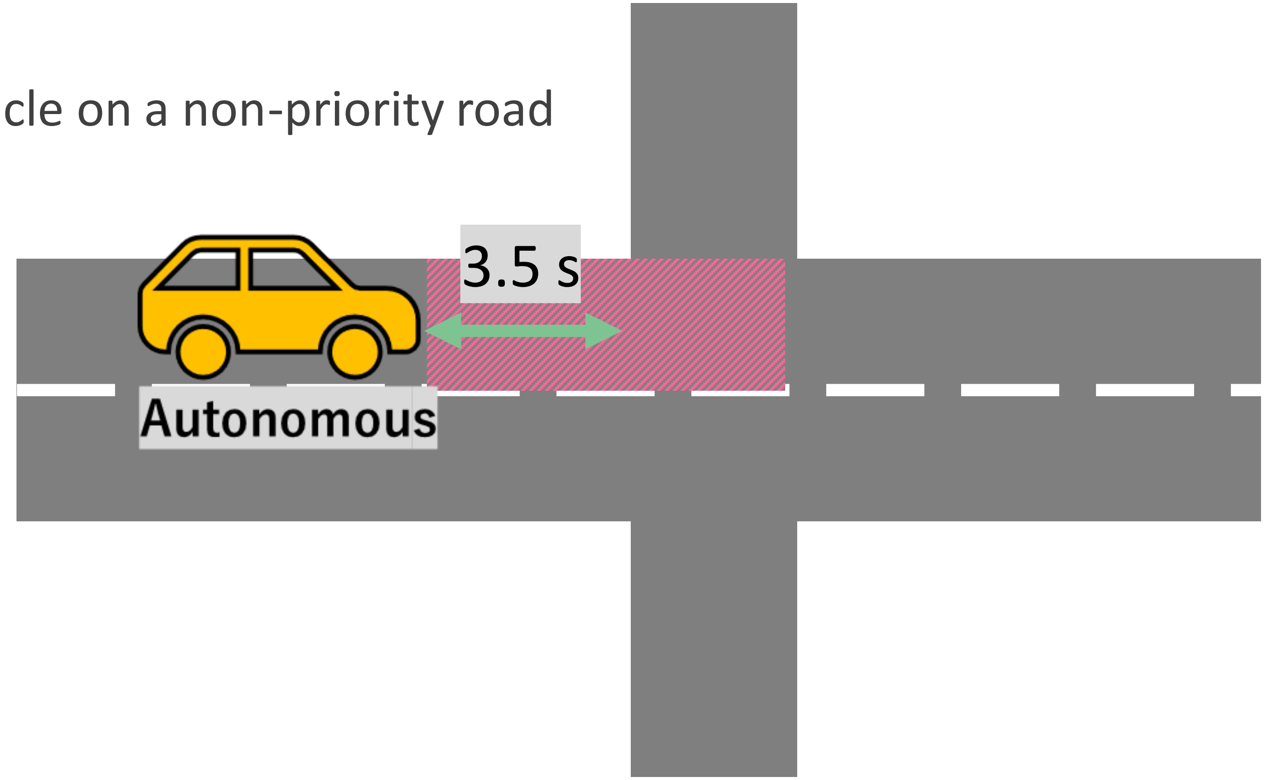
Safety with Intersection Danger Range - 3

- Drivers on HVs
  surprised by vehicles entering the intersection from the non-priority road
  →Lead sudden brake, traffic jams and collisions



Safety with Intersection Danger Range - 4

- The minimum TTC
  for connected vehicles on the priority road to transmit traversable messages
  - Autonomous Vehicles
    - the maximum time required for a vehicle on a non-priority road to traverse an intersection: 3.5 s
  - Human-operated Vehicles
    - Above 3.5 s ＋
      Time margin to prevent drivers from being surprised: 1.5 s
      ＝5.0 s



Safety with Intersection Danger Range - 4

- The minimum TTC
  for connected vehicles on the priority road to transmit traversable messages
  - Autonomous Vehicles
    - the maximum time required for a vehicle on a non-priority road to traverse an intersection: 3.5 s
  - Human-operated Vehicles
    - Above 3.5 s ＋
      Time margin to prevent drivers from being surprised: 1.5 s
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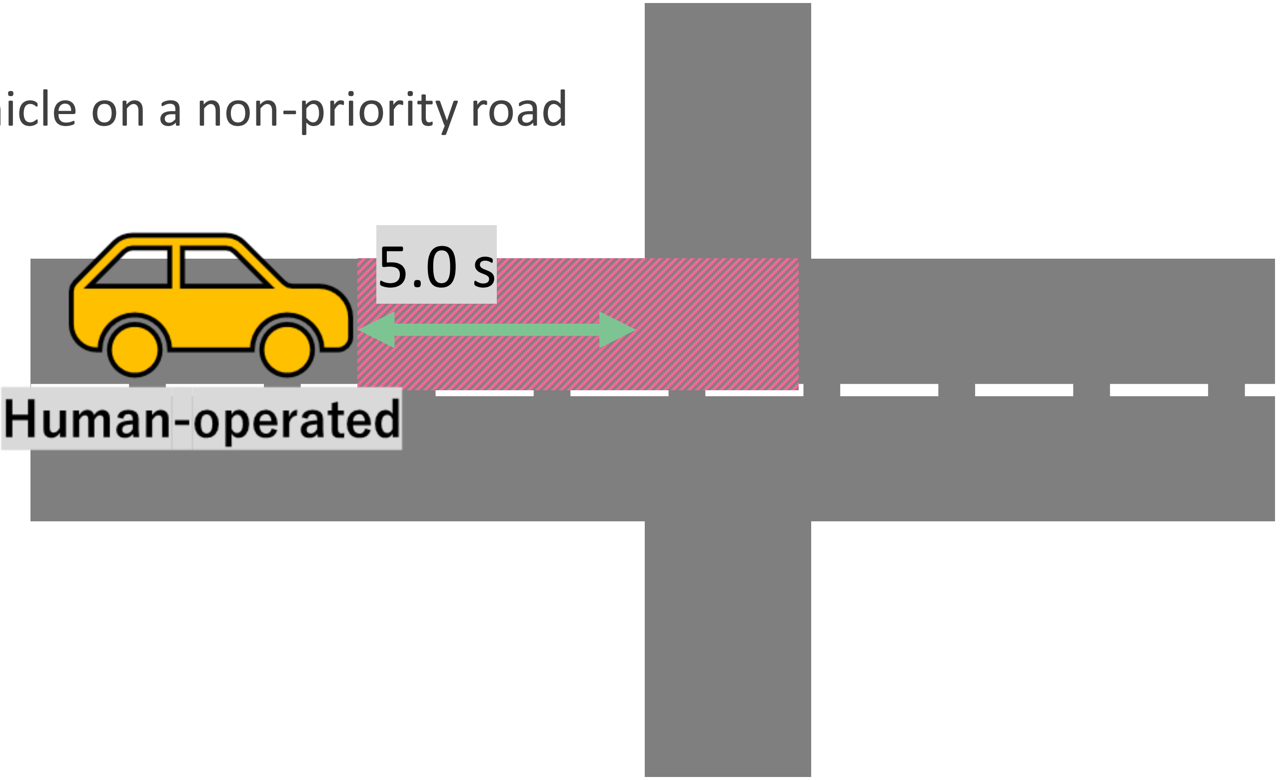


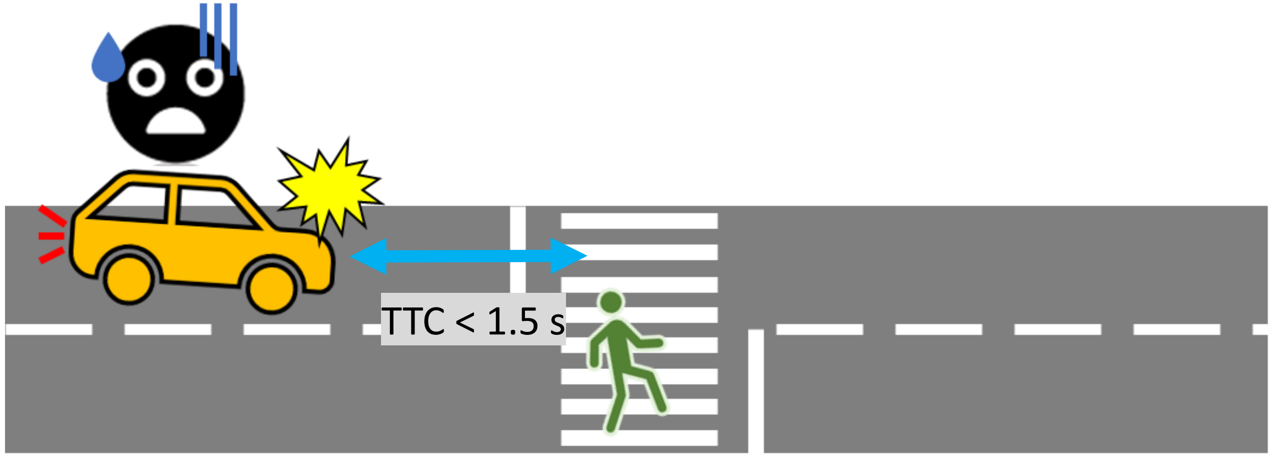
Safety with Intersection Danger Range - 5

- Time margin to prevent drivers from being surprised

【Reference Study】
Analyzed the relationship between the TTC for a pedestrian and the driver's surprise when a pedestrian suddenly started crossing the road

<u>Less surprise TTC ≧ 1.5 s</u>

※Although the target was a pedestrian, the situation is similar to that of vehicles entering from intersecting roads



A. Nakamura, S. Tominaga, and M. Okano, "Car-to-pedestrian Hiyari-Hatto Incident Analysis by Using Drive-recorder", The 2010 Technical Papers of Academic Lecture, Faculty of Science and Engineering, Nihon University, pp. 343-344, 2010.

EVALUATION

Prerequisites

Connected Vehicles in simulation experiment

- Can communicate with other CVs within a radius of 250 m ※1
- Communication frequency is 100 ms ※1
- Equipped with radar sensor that can detect a vehicle 200 m in front and behind ※2

※1　in accordance with
MIC "ITS communication requirements", ETSI "Cooperative Awareness Message", and SAE "Basic Safety Message"

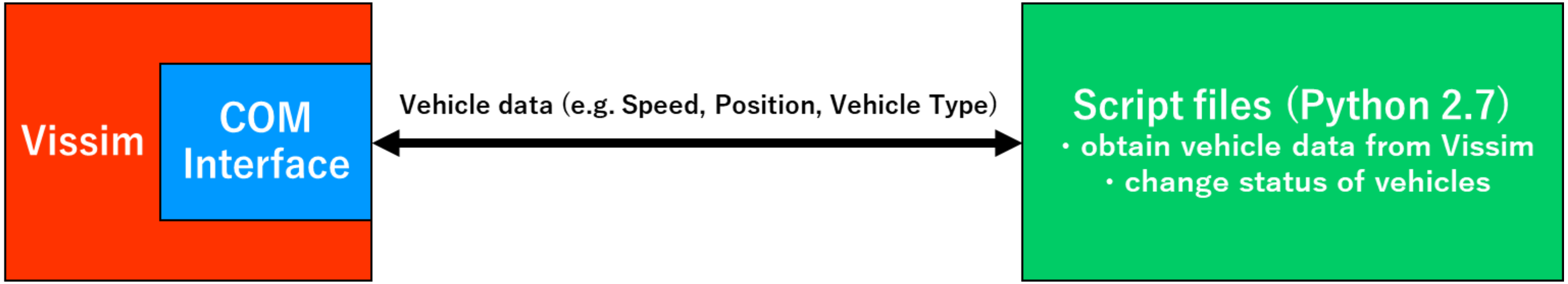
※2　Matching the performance of in-vehicle millimeter wave radar sensor in practical use

Simulation Environment - 1

- Simulator

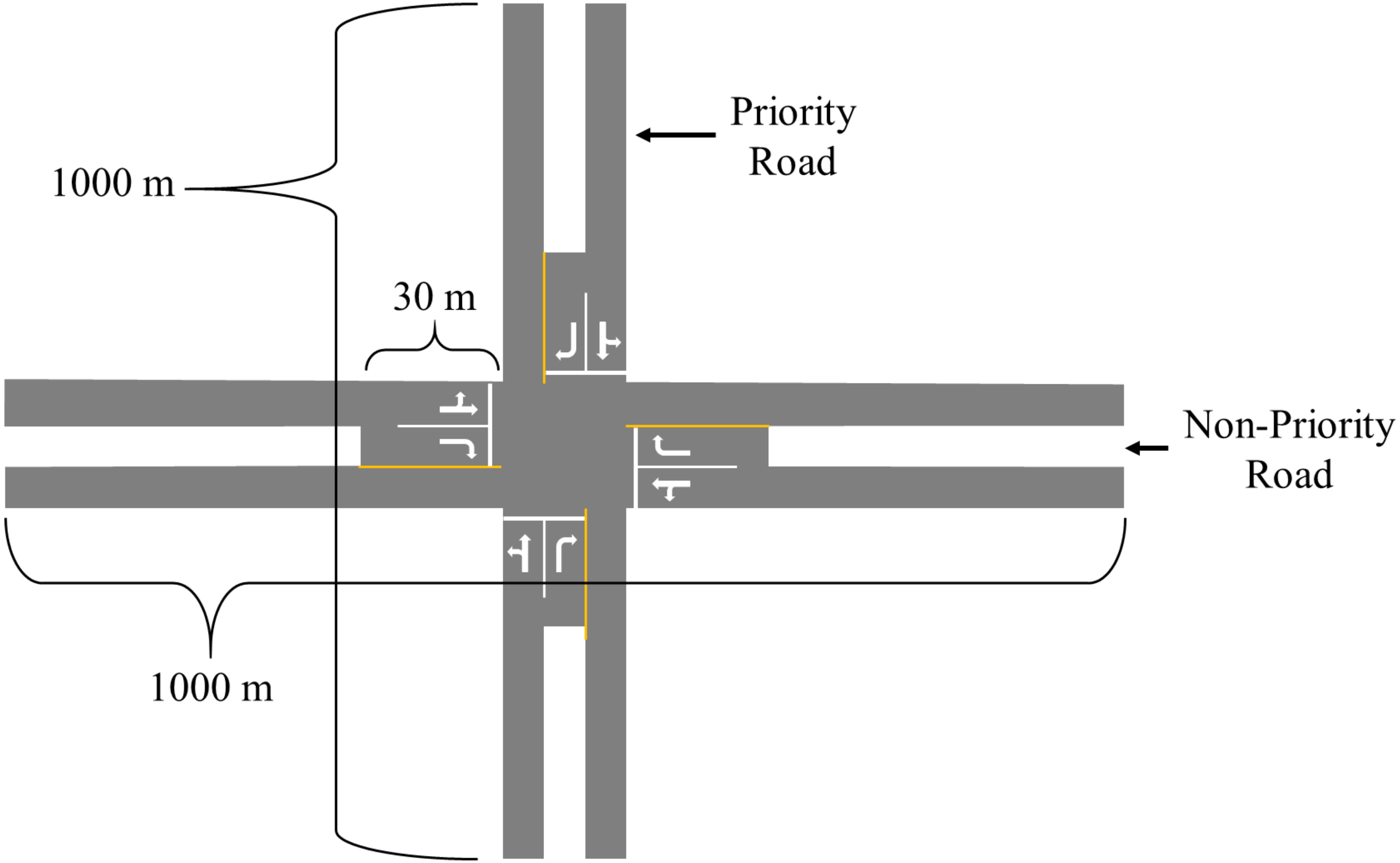
PTV Vissim 9

- A microscopic multi-modal traffic flow simulator developed by Planung Transport Verkehr AG, Germany
- Supports the Component Object Model (COM) interface
  - Programmed the operation of CVs with script files



Simulation Environment - 2

- Layout of the intersection used for evaluation simulation



Evaluation Indexes

Travel Time Delay 

① Time taken for a vehicle to traverse measurement section (actual travel time)

② Time taken to traverse the same section without stopping
when entering the intersection (ideal travel time)

Evaluate the difference between the actual time and the ideal time (① ー ②)

Maximum Queue Length

- the maximum length of the traffic queue at the intersection

Simulation Settings

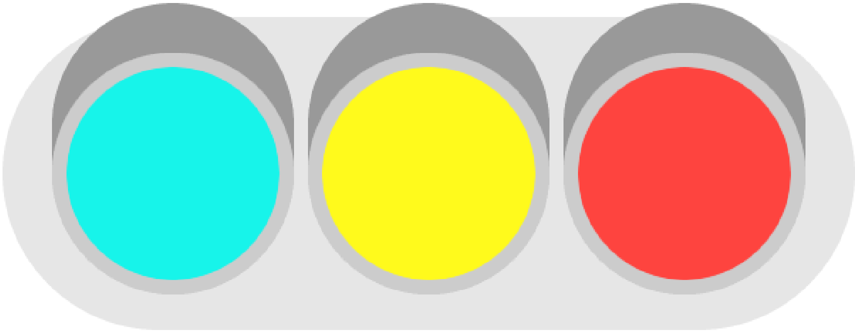
Parameter	Setting
Speed limit	Priority Road: 50 km/h
	Non-Priority Road: 40 km/h
Ratio of vehicles（Priority : Non-Priority）	3 : 1
Lane width	3.5 m
Measurement time × number	30 minutes × 10
Minimum TTC to transmit traversable message	Autonomous: 3.5 s
	Human-operated: 5.0 s (3.5 s + 1.5 s time margin)

Comparison with Conventional Methods

- Two Conventional Models

Stop model

The conventional intersection with stop signs



Traffic light model

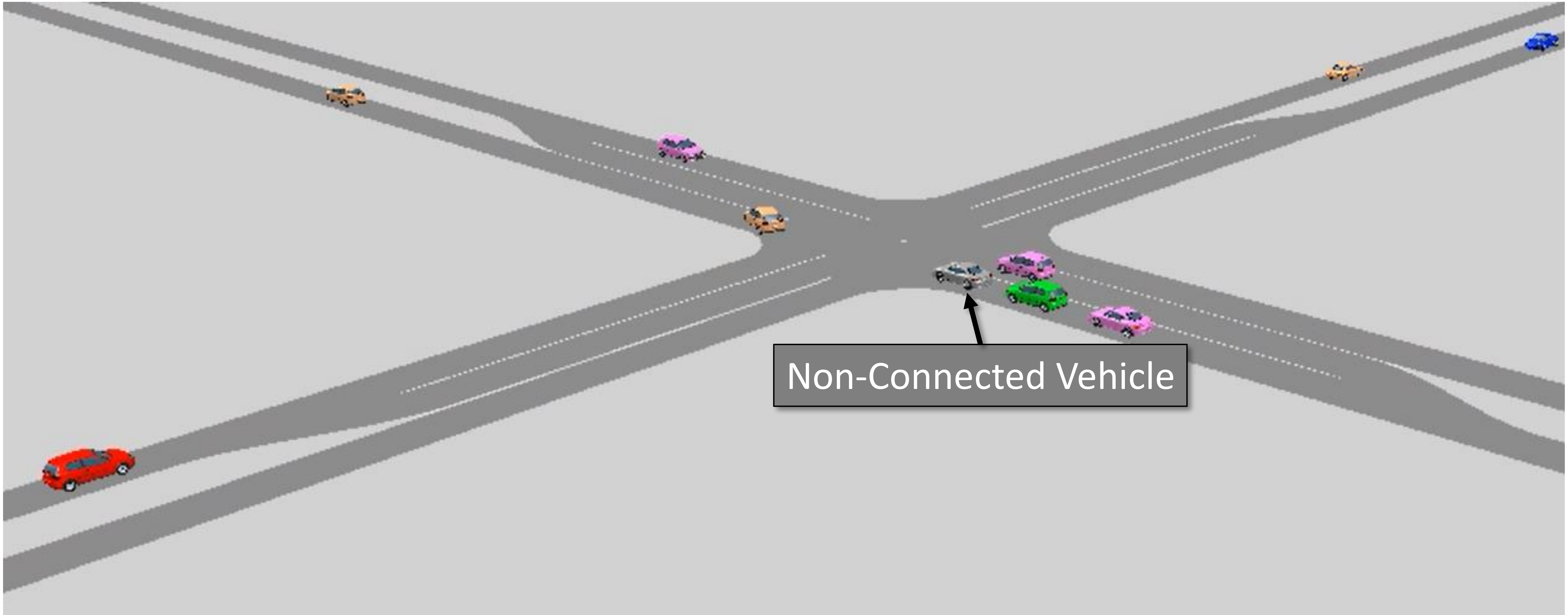
The conventional intersection with traffic lights

Simulation Parameter

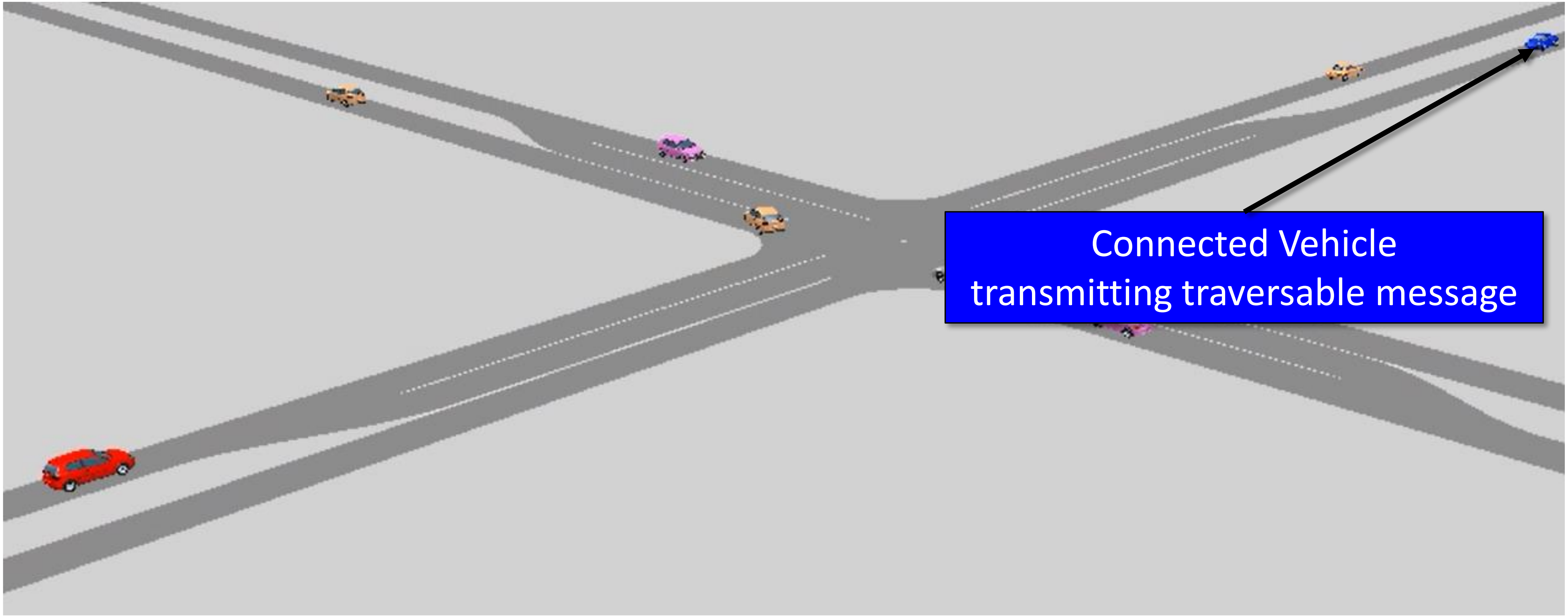
- Traffic volume
  - The number of vehicles per lane per hour

- Penetration rate of Connected Vehicles

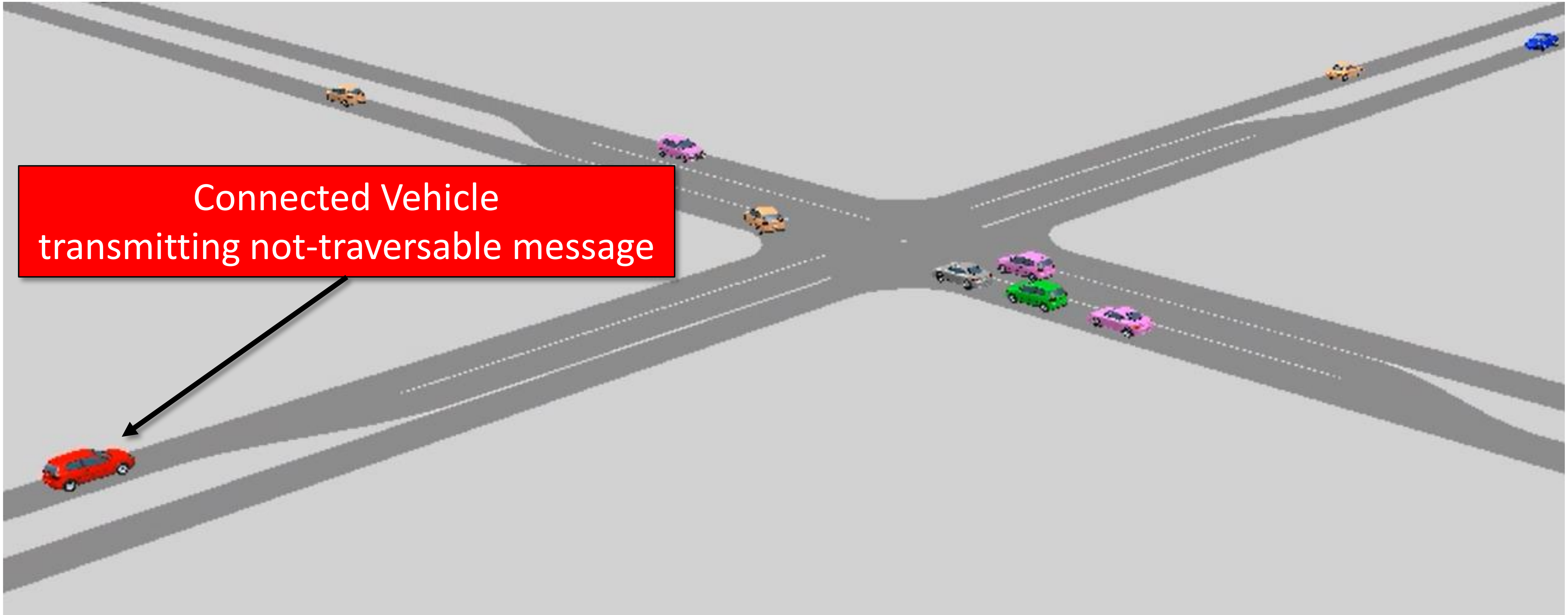
Simulation Running – Color Classification



Simulation Running – Color Classification

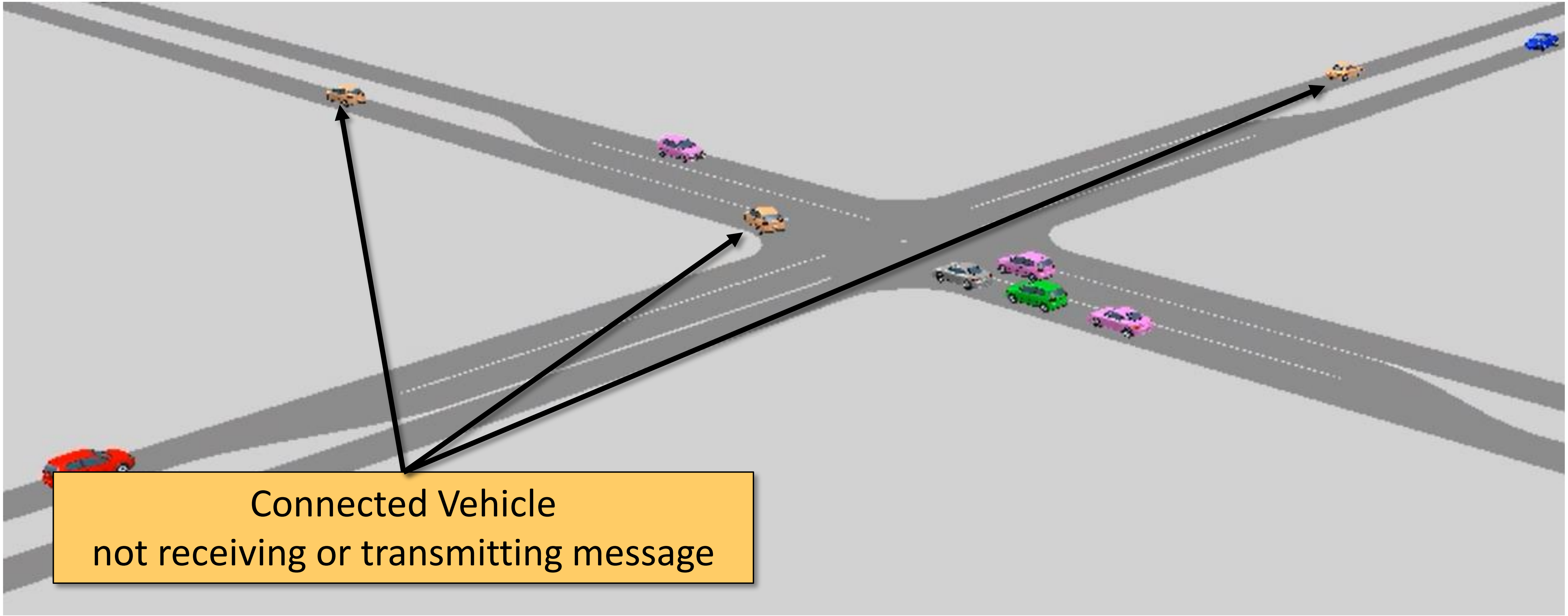


Simulation Running – Color Classification

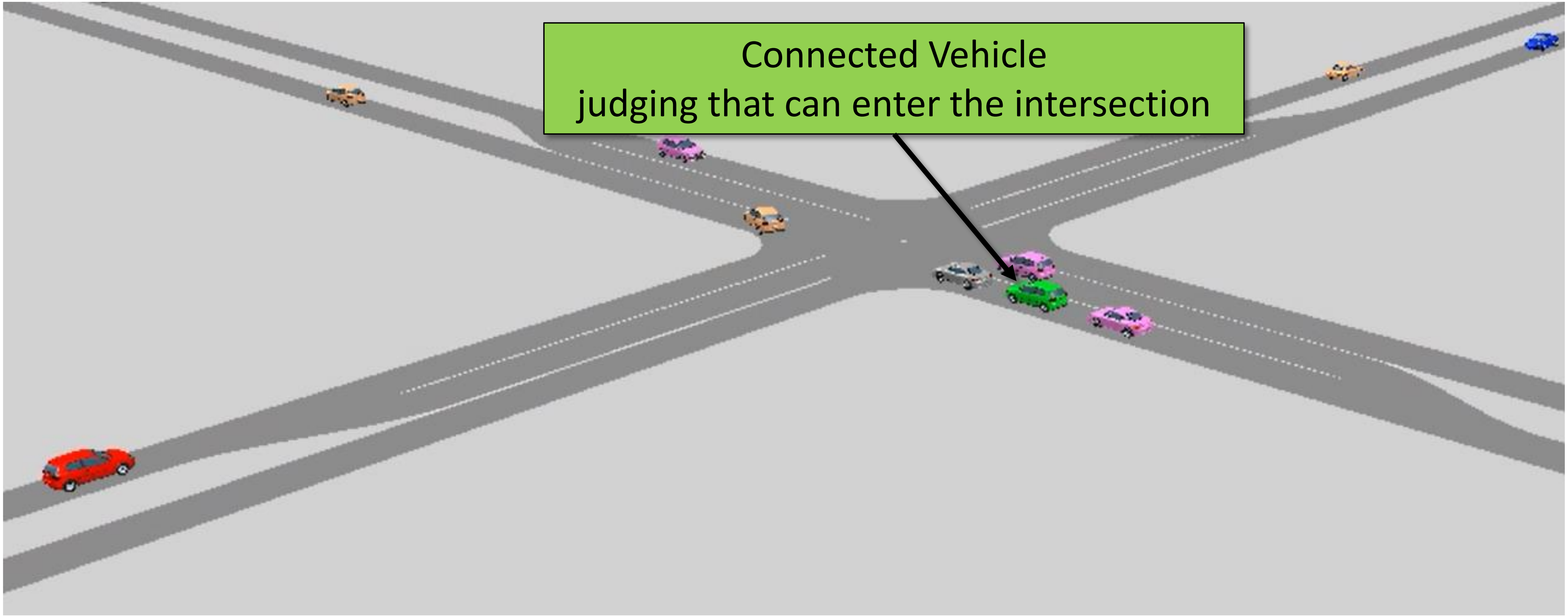


Connected Vehicle
transmitting not-traversable message

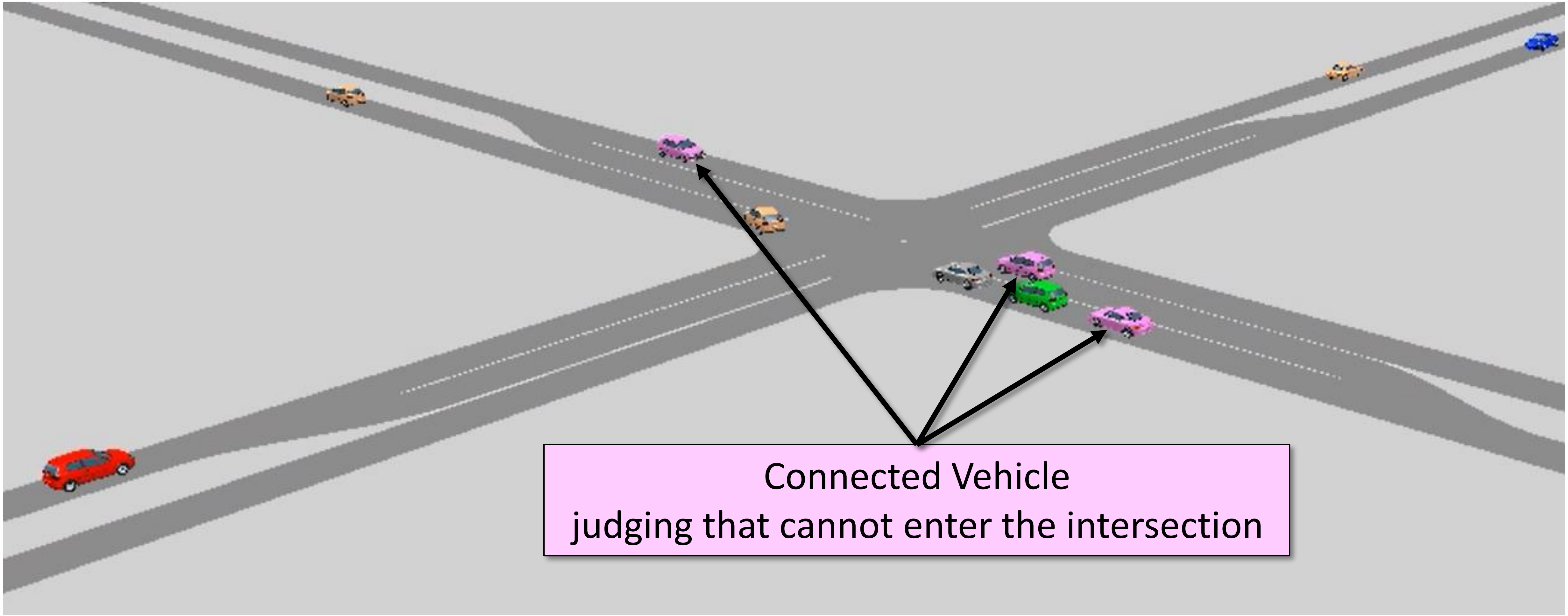
Simulation Running – Color Classification



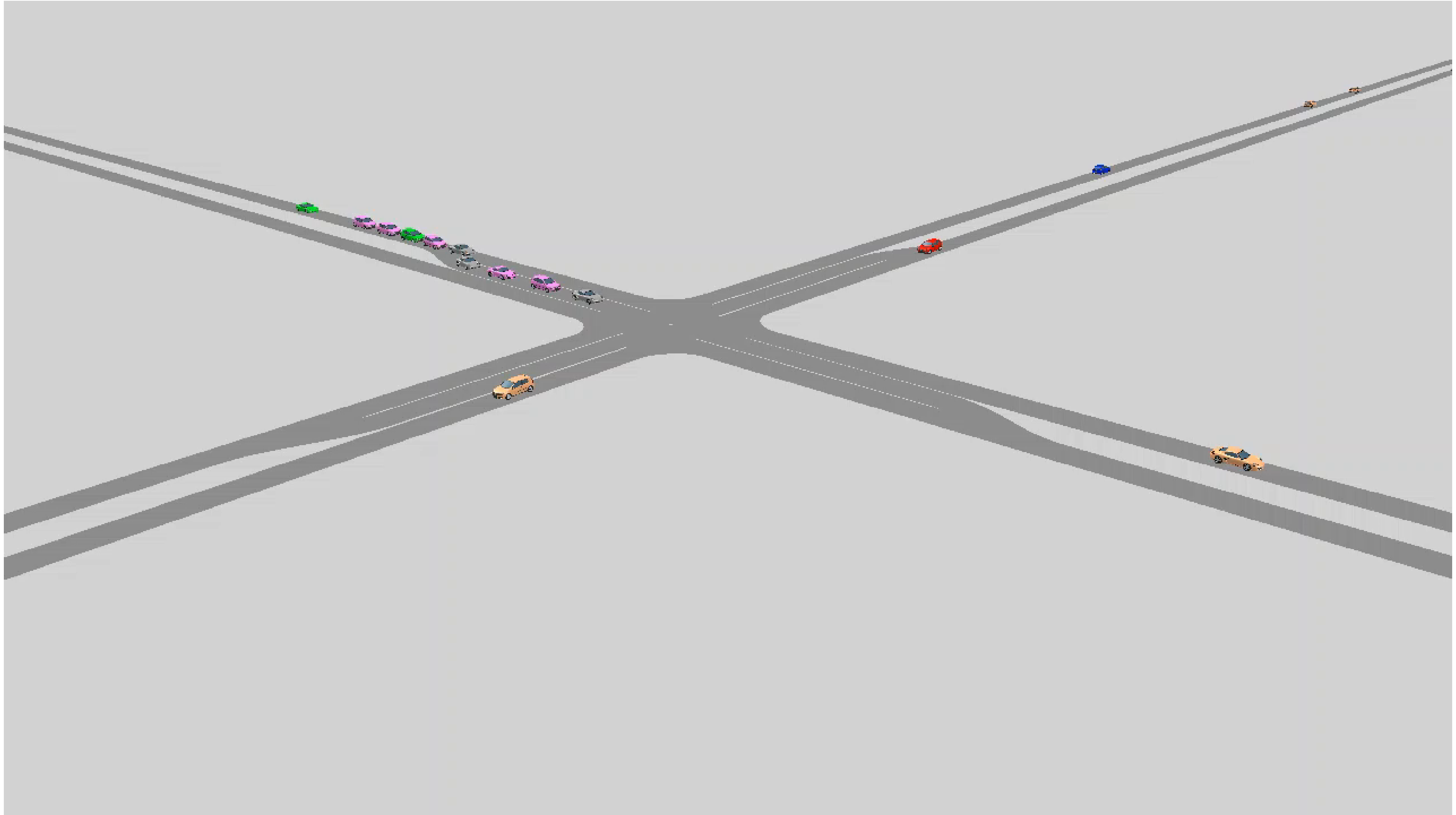
Simulation Running – Color Classification



Simulation Running – Color Classification



Simulation Running - Movie



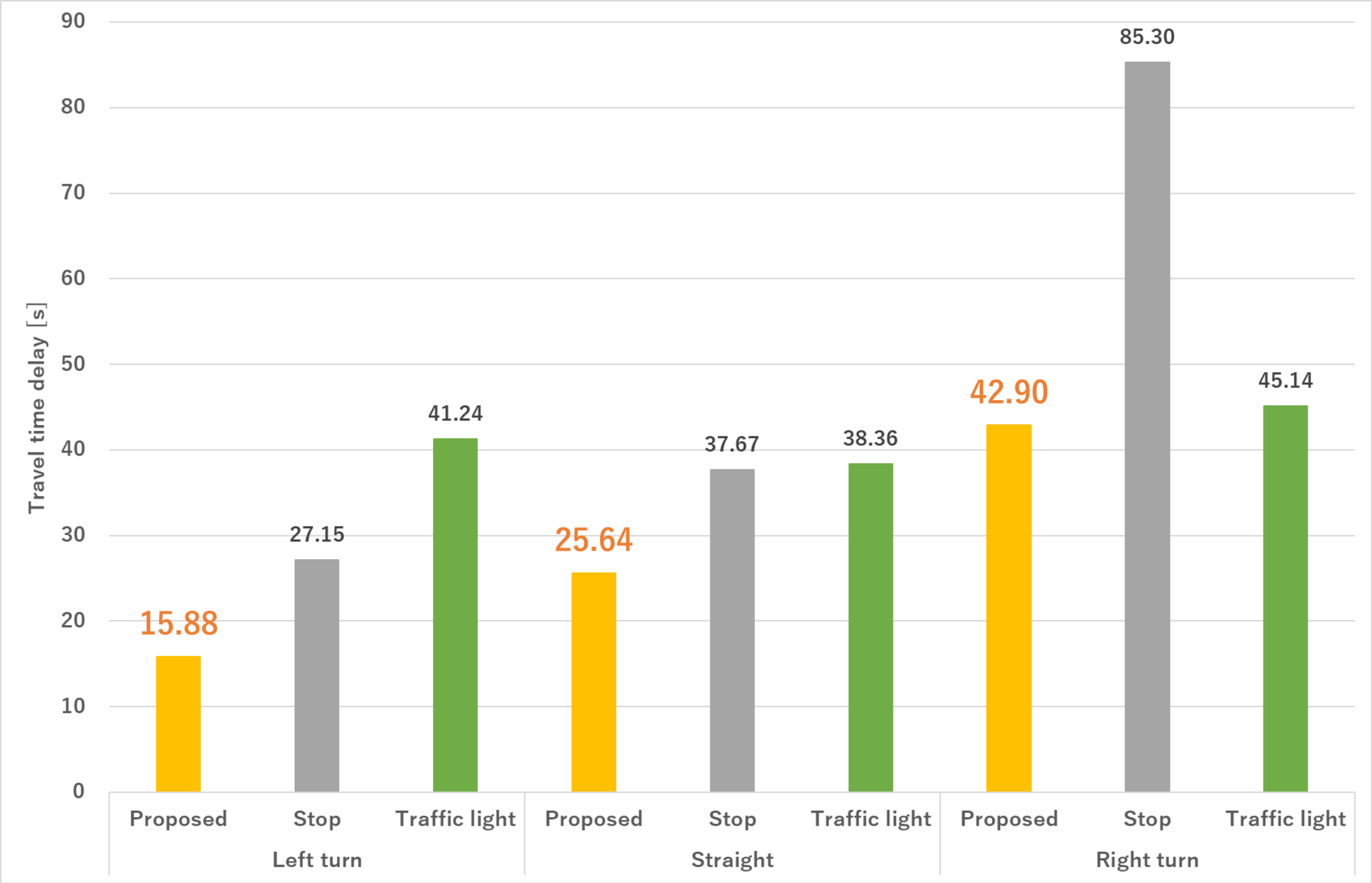
※3X speed

RESULTS

Comparison of Travel Time Delay

- Traffic volume: 500 vehicles/h
- Penetration rate: 70 %

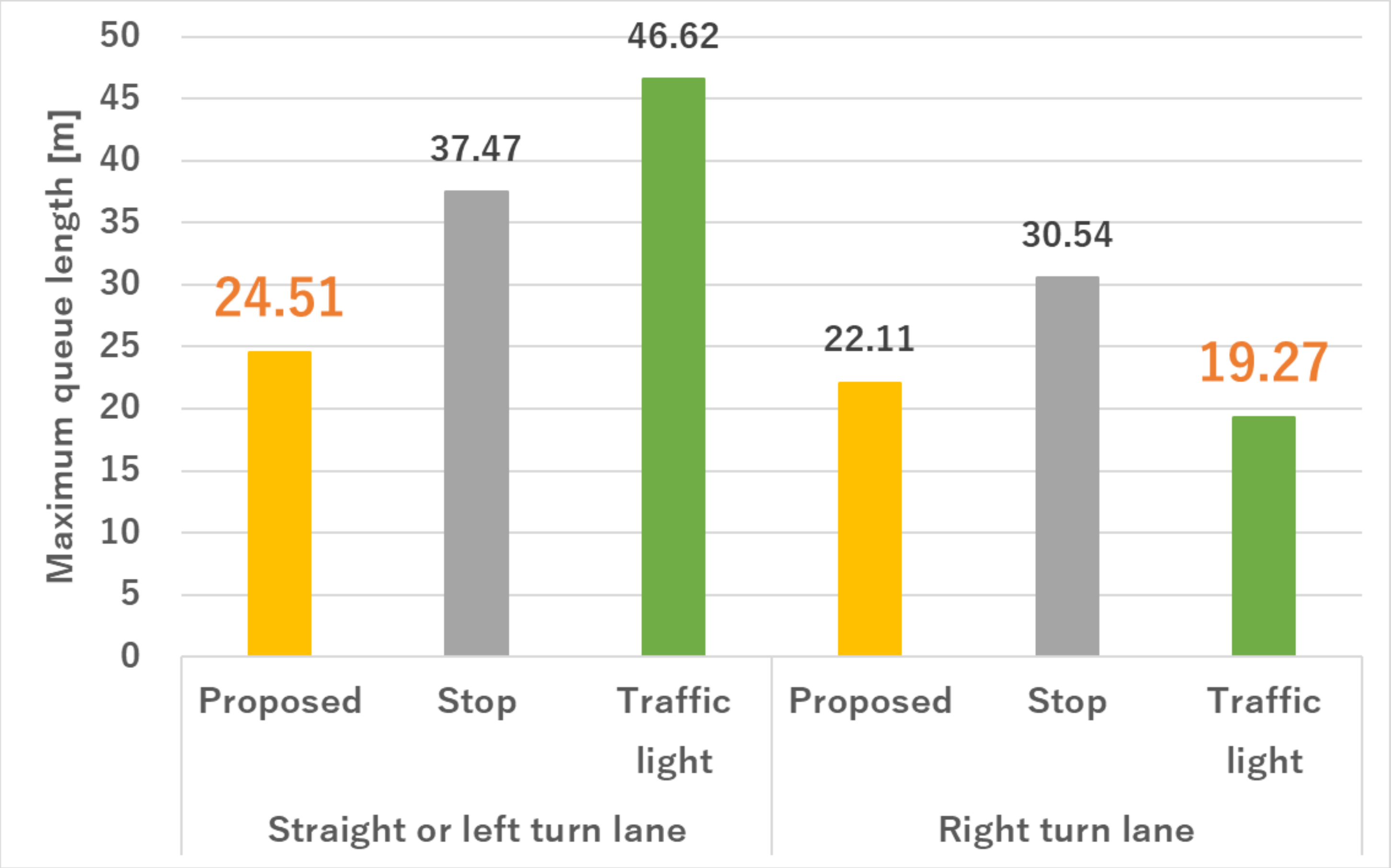
Our method was the smallest



Comparison of Maximum Queue Length

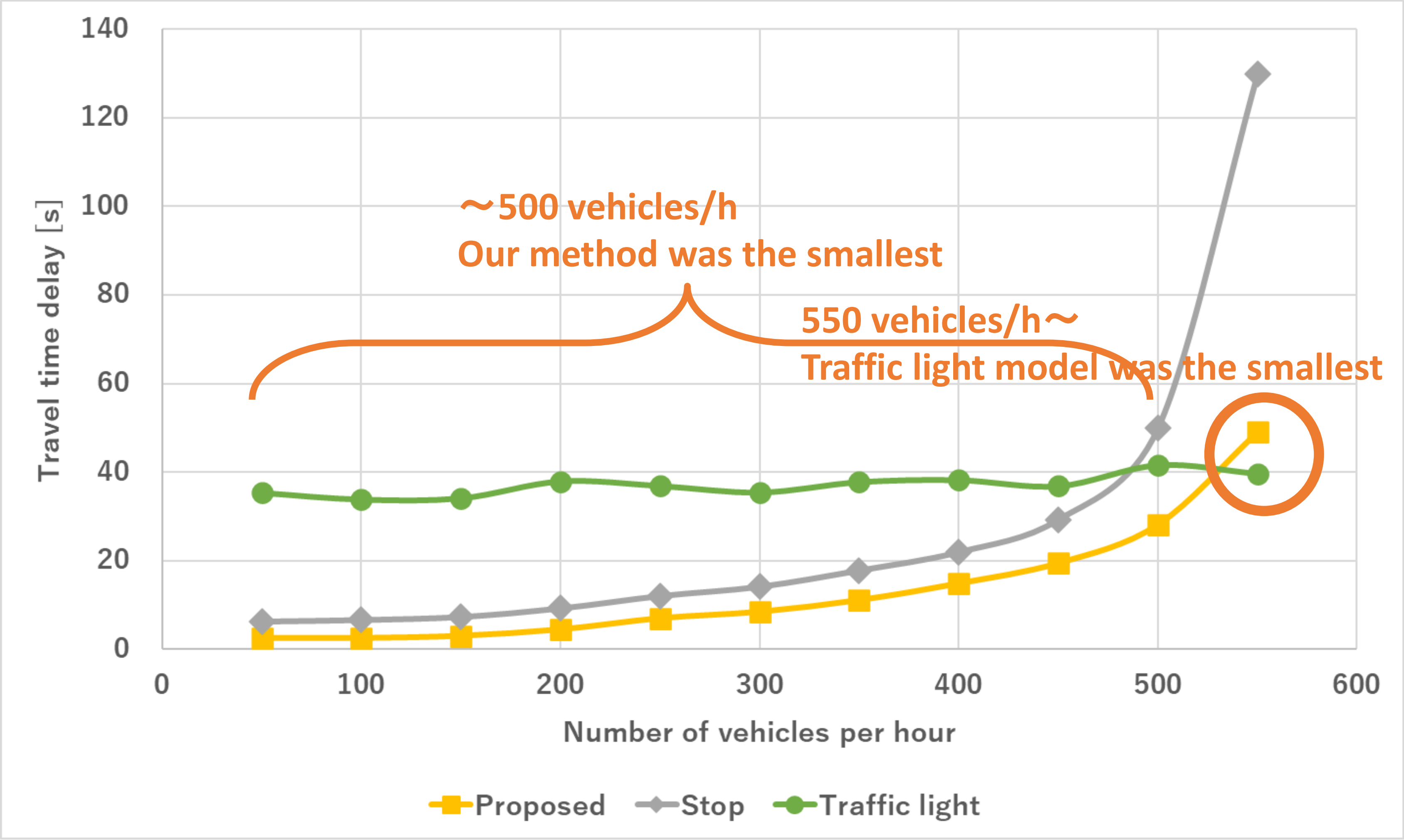
- Traffic volume: 500 vehicles/h
- Penetration rate: 70 %

Our method was the smallest (Straight or left turn lane)



Change in Travel Time Delay with Traffic Volume

- Penetration rate: 70 %



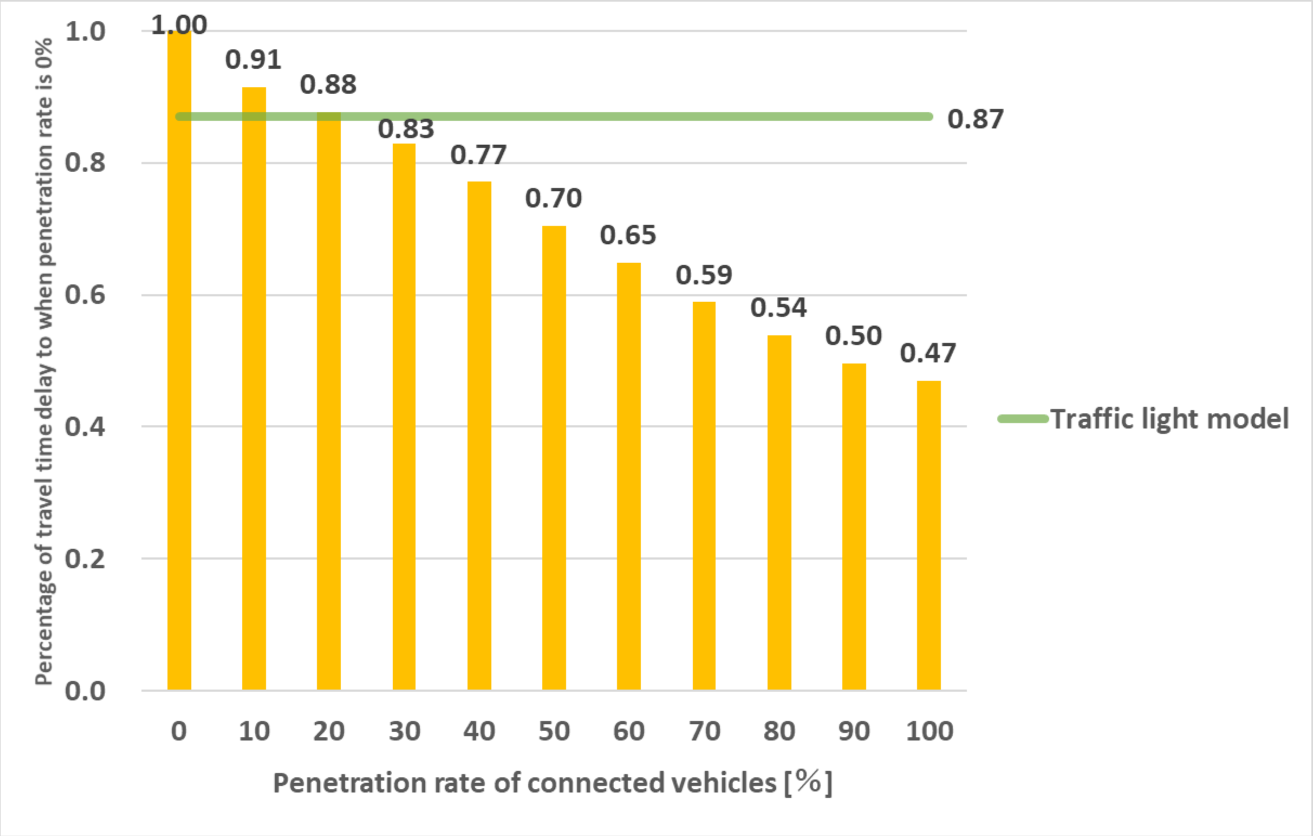
Decrease in Travel Time Delay with Penetration Rate

- Traffic volume: 500 vehicles/h
- expressed as relative values
  (with 0 % penetration rate being 1.00)

Decreased monotonically
as penetration rate increased

- **When 50 % penetration rate: 30 % down**
- **When 90 % penetration rate: 50 % down**

30 % penetration rate or more
lower than the traffic light model



DISCUSSION

DISCUSSION

- Intersection traffic efficiency was improved by our method
  - Traffic volume ～500 vehicles/h
    - → effective at intersections with average traffic volume
  - Penetration rate of CVs 30 %～
    - →effective even during the early stages of connected vehicles introduction
  - Our method uses only V2V communication
    - →no need to install and maintain roadside devices such as traffic lights

- Efficiency was not improved at intersections with heavy traffic
  - Need another advanced method at Intersections in urban areas

- Safety can be ensured by setting the TTC dynamically
  in accordance with characteristics of drivers and vehicles

CONCLUSION

CONCLUSION

- Background
  - ✓Connected Vehicles and autonomous driving technology
  - ✓Looking ahead to the time when CVs and Non-CVs will share the same road
- Purpose
  - ✓We developed a method that enables CVs traverse the intersection efficiently based on information from other CVs in the mixed CVs and Non-CVs situation
- Evaluation
  - ✓Using a traffic flow simulator
  - ✓Compared with conventional intersection mediation method
- Result
  - ✓Our method improve efficiency of average traffic volume intersections and can ensure safety

Thank You for Your Kind Attention !

For any question or comment, please contact

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