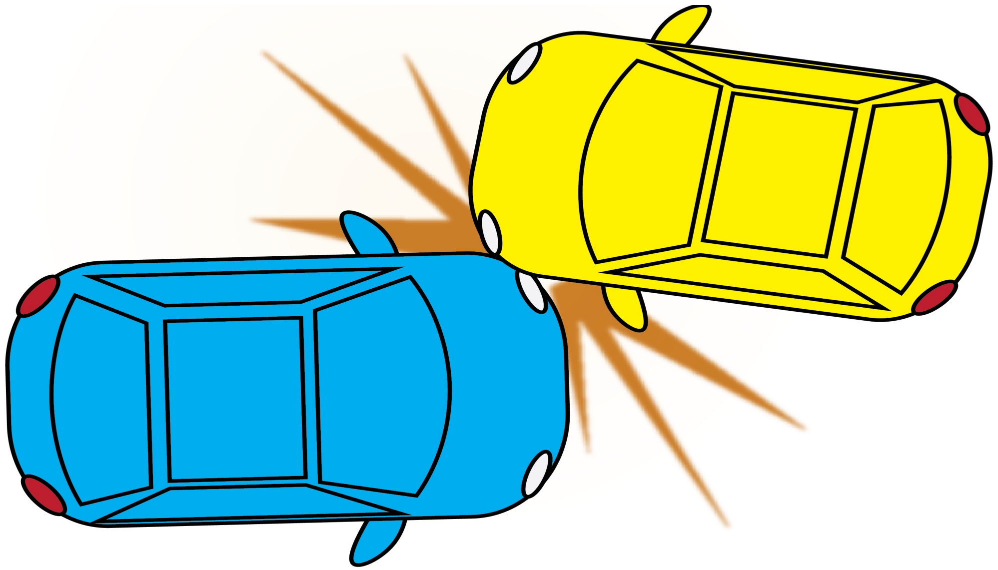
Severity Minimization Motion Planning for Autonomous Vehicles

Masoumeh Parseh

Scandinavian Conference on System & Software Safety,

November 2022, Göteborg, Sweden

Unavoidable Collisions



Overview of Presentation

- Introduction
- Research Questions
- Severity Minimization Motion Planning
- Final Words & Future work

Introduction

Background

- The majority of traffic accidents in the U.S are caused by human errors (94%).
- Crashes caused by human error are 50%.
- Waymo: 92% of simulated collisions were avoided (82%) or mitigated (10%).
- Traffic Safety is improved by Advanced Driver Assistance Systems (ADAS).

Introduction
Background

- Autonomous Vehicles (AVs) & challenges for Stakeholders.

- Safely manoeuvring the AV is a difficult task.

- Mitigation strategies:
  - Collision avoidance
  - Contingency planning
  - Motion planning in critical situations

Introduction
Objective

- Reducing harm & injuries for humans & increasing traffic safety.
- Focus shifted from collision avoidance to collision mitigation.
- Reconfiguring unavoidable collisions.

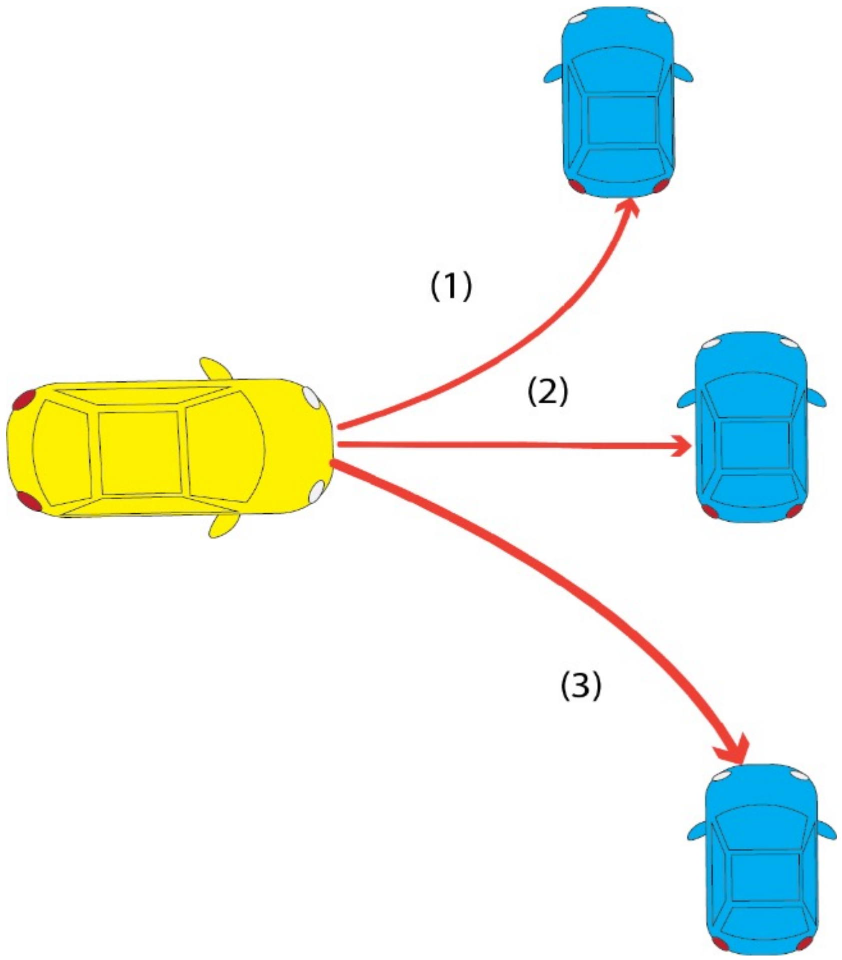


Figure 1. Unavoidable collision.

Research Questions

Q1

Which are the most important factors for motion planning and control for AV in unavoidable collision scenarios?

Q2

What is the effect of uncertainty on decision-making strategies & activation of a CMS?

Q3

To minimize severity across an entire accident, which are the necessary components for post-impact motion planning?

Research Questions

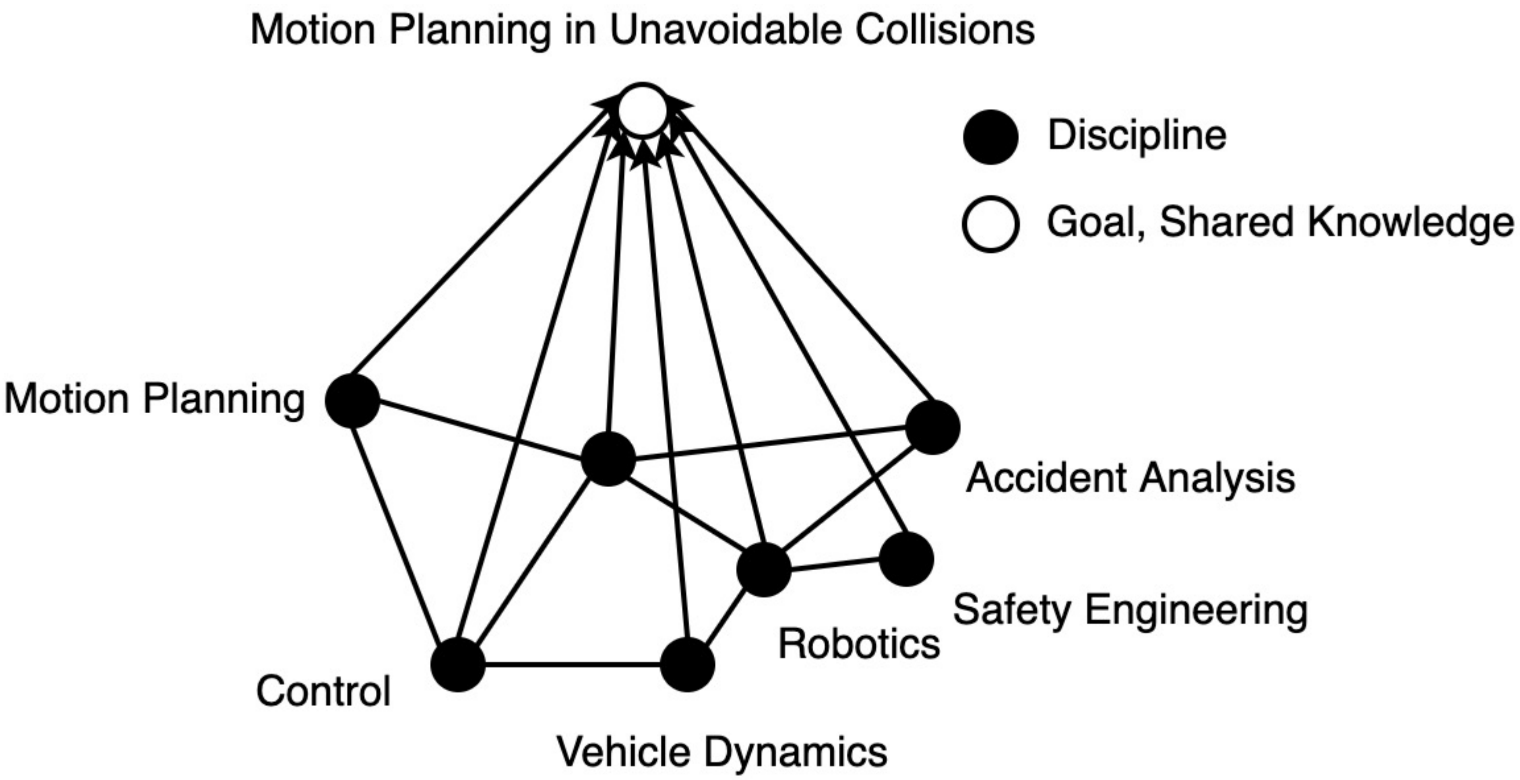


Figure 2. Relevant disciplines.

Severity Minimization Motion Planning

1. Accuracy of Vehicle Dynamics
2. Metrics for the Severity of Collision
3. Risk of Collision
4. Activation Time
5. Outcome of Decision-making
6. Severity of a Secondary Collision
7. Accuracy of Collision Models & Parameters
8. Execution Time

Pre-Crash motion planning:
Data-Driven Approach

1. Accuracy of Vehicle Dynamics

8. Execution Time

- Offline phase: Trajectory Generation

$$\underset{x(.),u(.)}{\text{minimize}} \quad \int_0^{t_f} ||S_g - S(t)||_2^2 dt + v_x(t_f)$$

$$\begin{aligned} \text{subject to} \quad & \dot{\boldsymbol{x}}(t) = f(\boldsymbol{x}(t), \boldsymbol{u}(t)), \\ & G(\boldsymbol{x}(t), \boldsymbol{u}(t)) \leq 0, \\ & \boldsymbol{x}(0) = \boldsymbol{x}_0, \\ & \boldsymbol{x}(t_f) = \boldsymbol{x}_T. \end{aligned}$$

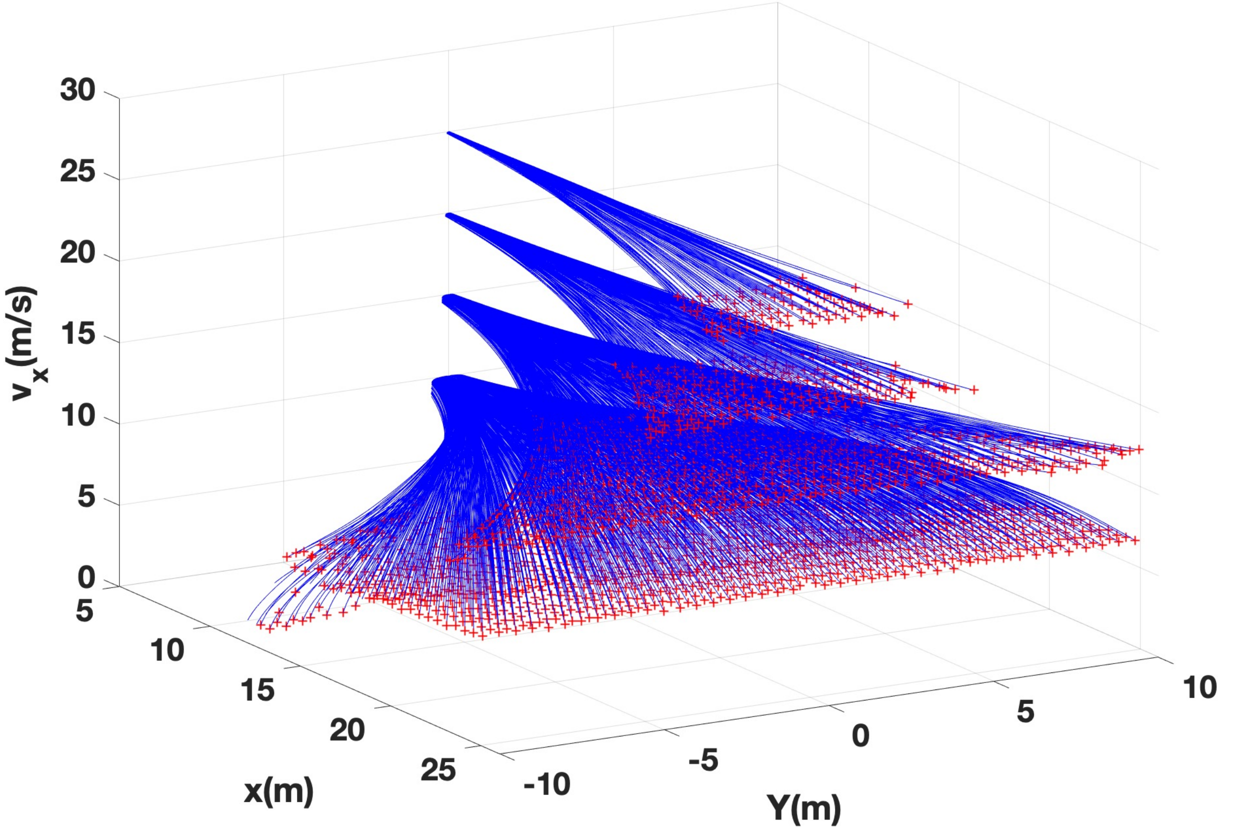


Figure 3. Trajectory library.

Data-Driven Approach

② Metrics for the Severity of Collision

- Online phase: Trajectory selection
- Accident data: impact location & the injury severity

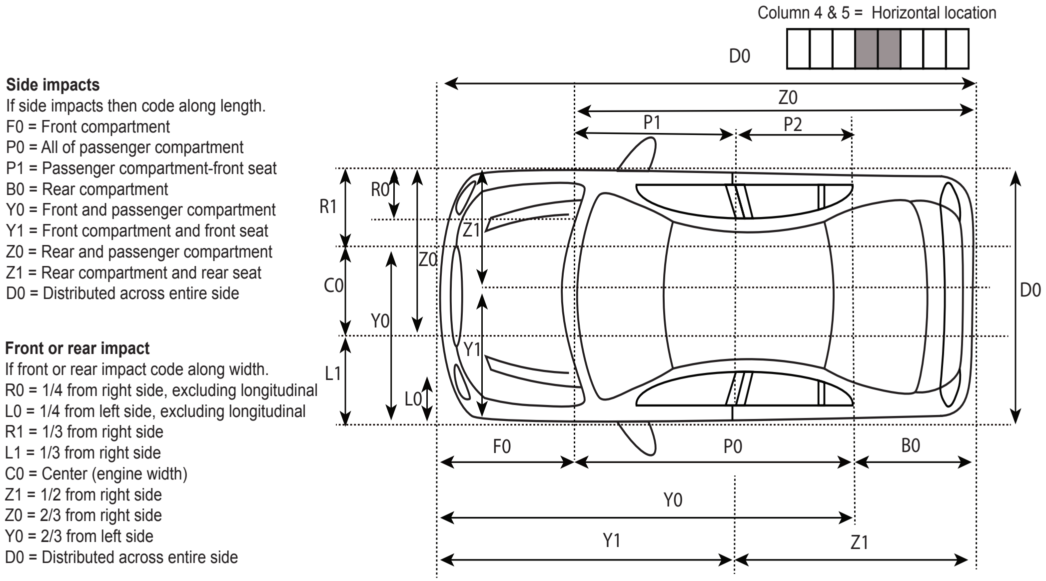


Figure 4. Horizontal collision location classification.

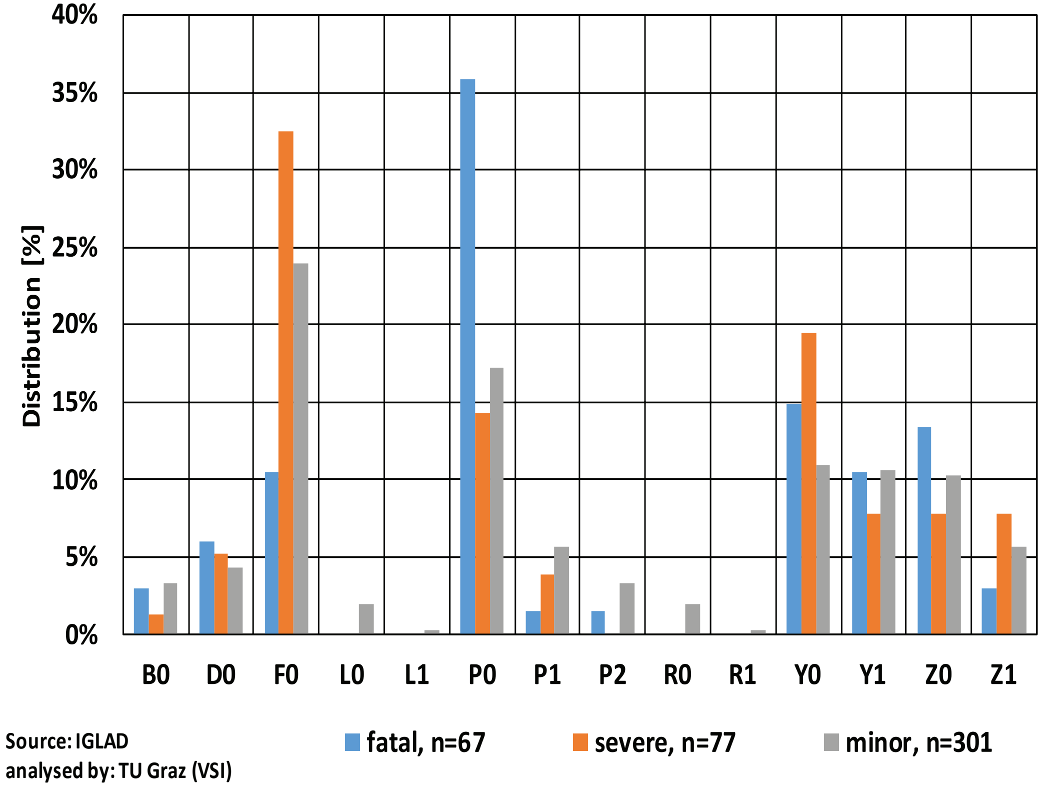


Figure 5. Collision location of passenger car side-impacted.

Data-Driven Approach

- ORFS: To classify collisions according to their associated injury severity

Table 1. Risk Estimation-Odds Ratio

Collision Location	Description	Fatal	Severe	Minor	Total	ORFS
B_0	Rear compartment	2	1	10	58	0.61
D_0	Distributed across entire side	4	4	13	27	1.30
F_0	Front compartment	7	25	72	242	0.91
L_0	1/4 from left side	0	0	6	8	0.0
L_1	1/3 from left side	0	0	1	2	0.0
P_0	All of passenger compartment	24	11	52	125	1.54
P_1	Passenger compartment-front seat	1	3	17	49	0.48
P_2	Passenger compartment-rear seat	1	0	10	22	0.20
R_0	1/4 from right side	0	0	6	11	0.0
R_1	1/3 from right side	0	0	1	2	0.0
Y_0	Front and passenger compartment	10	15	33	84	1.71
Y_1	Front compartment and front seat	7	6	32	80	0.83
Z_0	Rear and passenger compartment	9	6	31	70	1.01
Z_1	Rear compartment and rear seat	2	6	17	46	0.98

$$F(P(t_c)) = \begin{cases} 12 & \text{front and passenger compartment } (Y_0) \\ 11 & \text{all of passenger compartment } (P_0) \\ 10 & \text{distributed across entire side } (D_0) \\ 9 & \text{rear and passenger compartment } (Z_0) \\ 8 & \text{rear compartment and rear seat } (Z_1) \\ 7 & \text{front compartment } (F_0) \\ 6 & \text{front compartment and front seat } (Y_1) \\ 5 & \text{rear compartment } (B_0) \\ 4 & \text{passenger compartment-front seat } (P_1) \\ 3 & \text{passenger compartment-rear seat } (P_2) \\ 2 & \text{front to front collision} \\ 1 & \text{front to rear collision} \end{cases}$$

$$\boxed{J = \underbrace{W_1 \times V_{rel_n}(t_c)}_{J_0} + F(P_n(t_c)),}$$

Data-Driven Approach

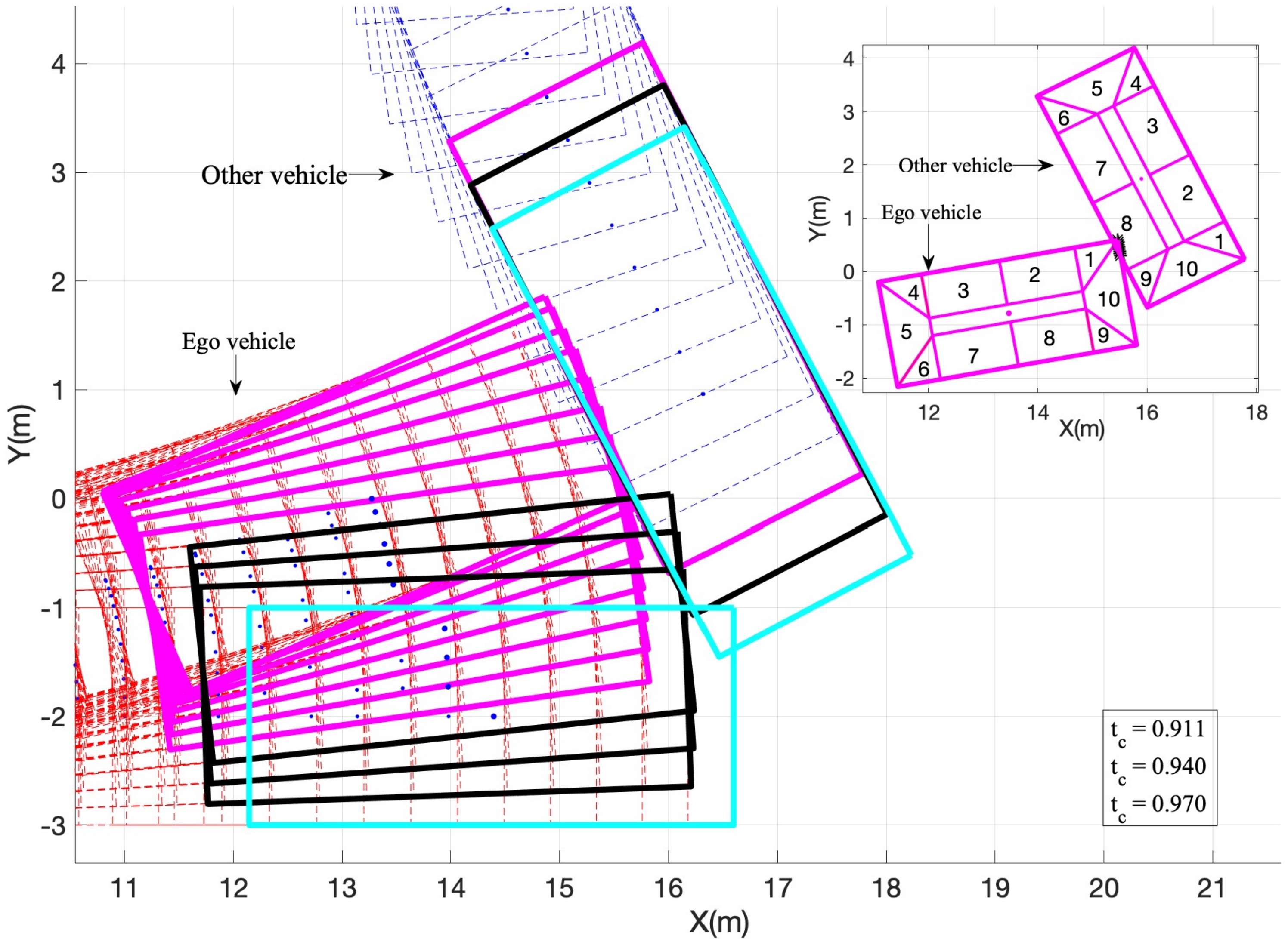


Figure 6. Collision between different trajectories of ego and target vehicle at different time steps.

Data-Driven Approach

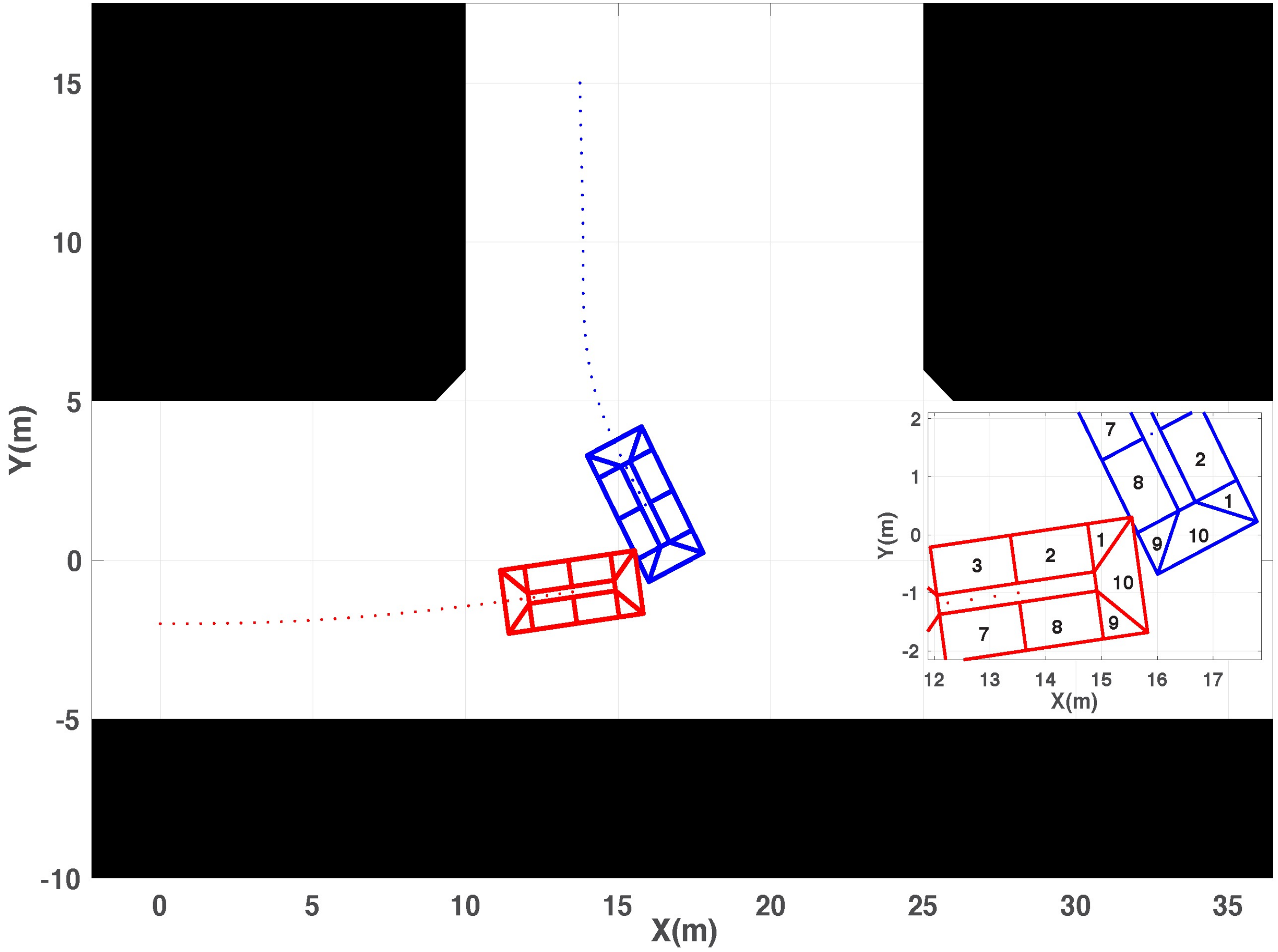


Figure 7. The least severe collision scenario.

Decision-Making under Uncertainty

3 Risk of Collision

4 Activation Time

- Reducing collision severity while not increasing collision probability
- Varying collision probability threshold applied to all/parts of trajectories

5 Outcome of Decision-making

- Method 1: Severity at threshold
- Method 2: Severity at maximum collision probability
- Method 3: Equal severity & probability

Decision-Making under Uncertainty

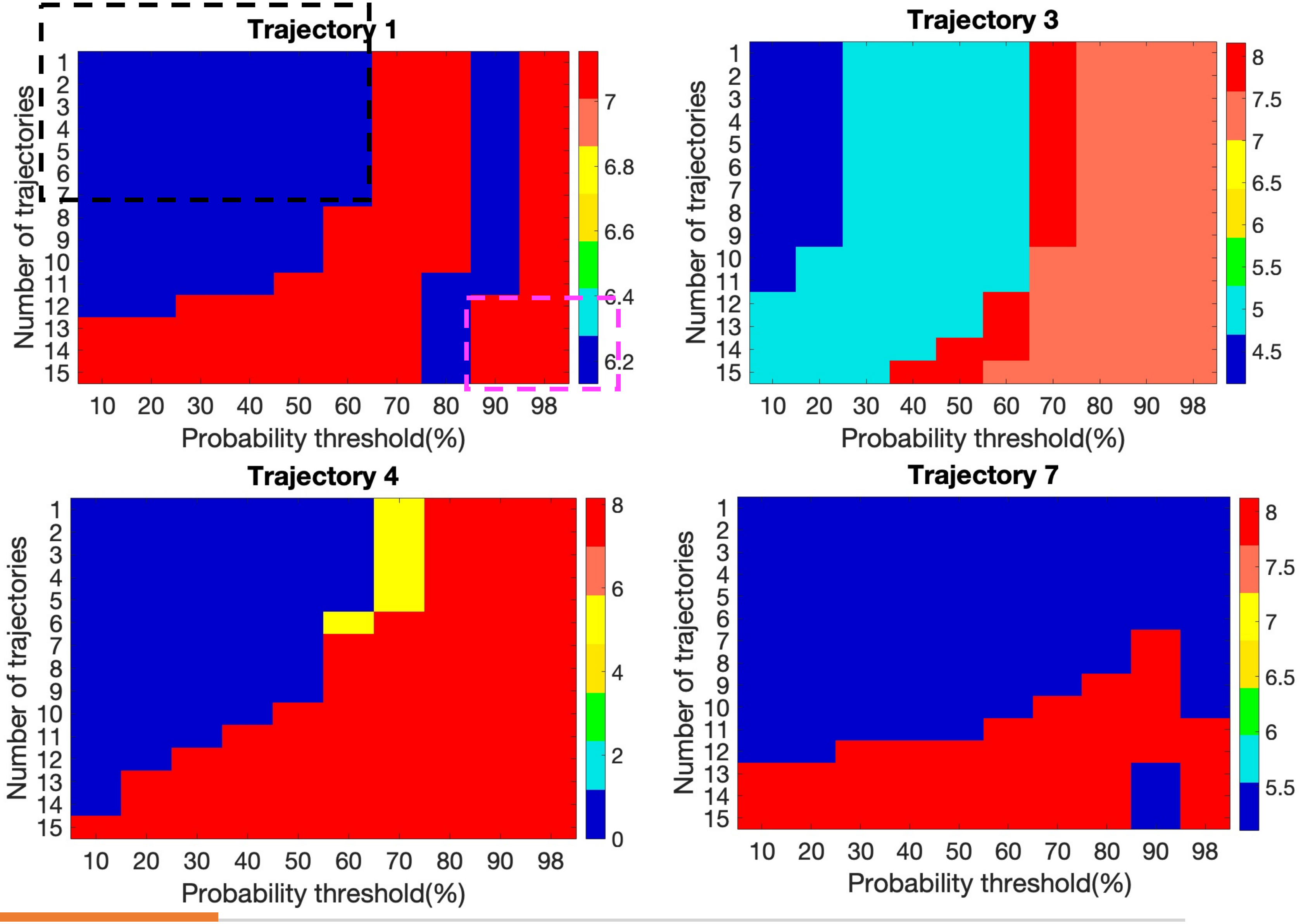


Figure 8. Severity outcomes of reconfigured collisions

Decision-Making under Uncertainty

Figure 9.
Acting early (a) v.s acting late (b) and available choices.

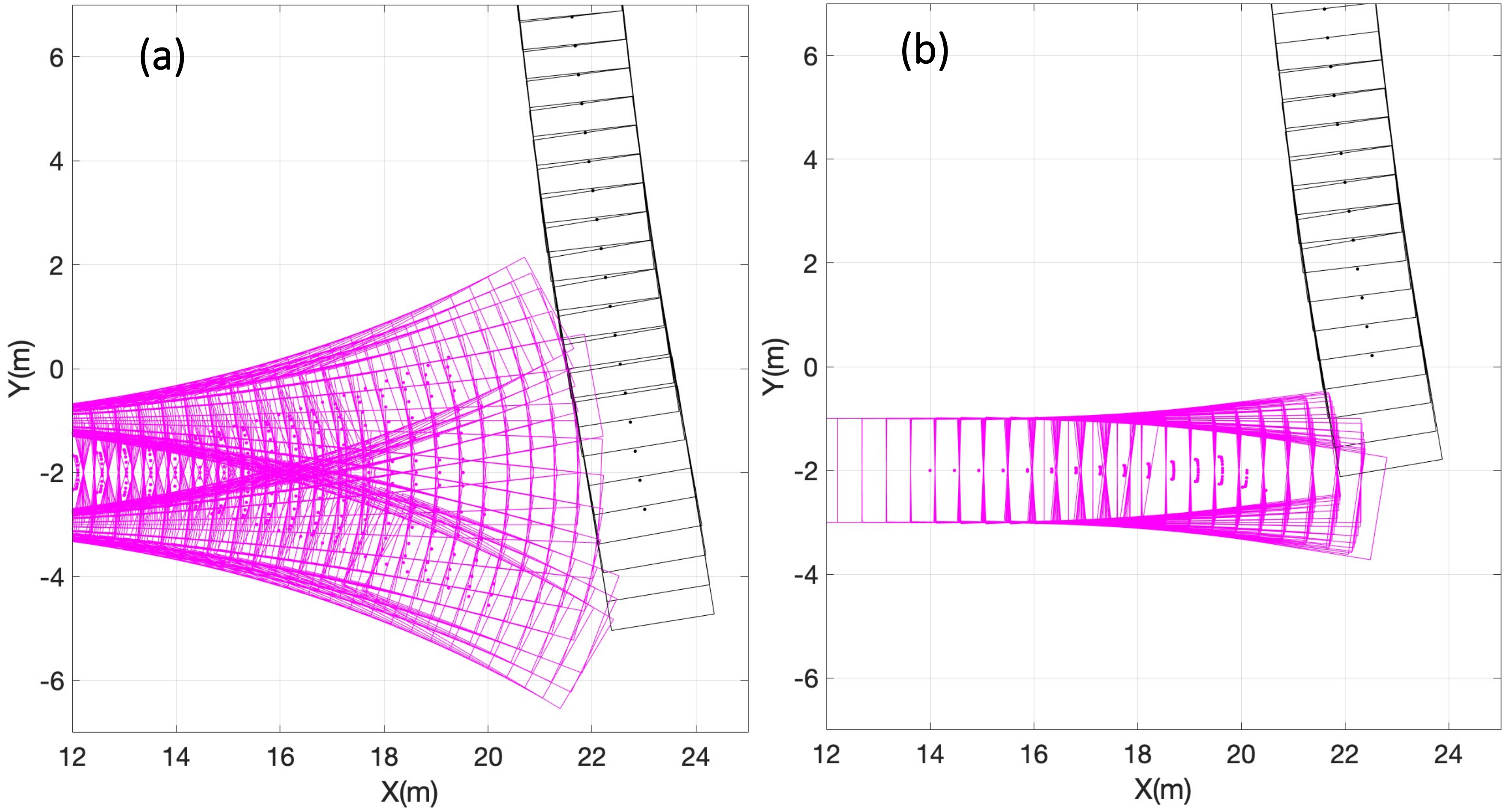
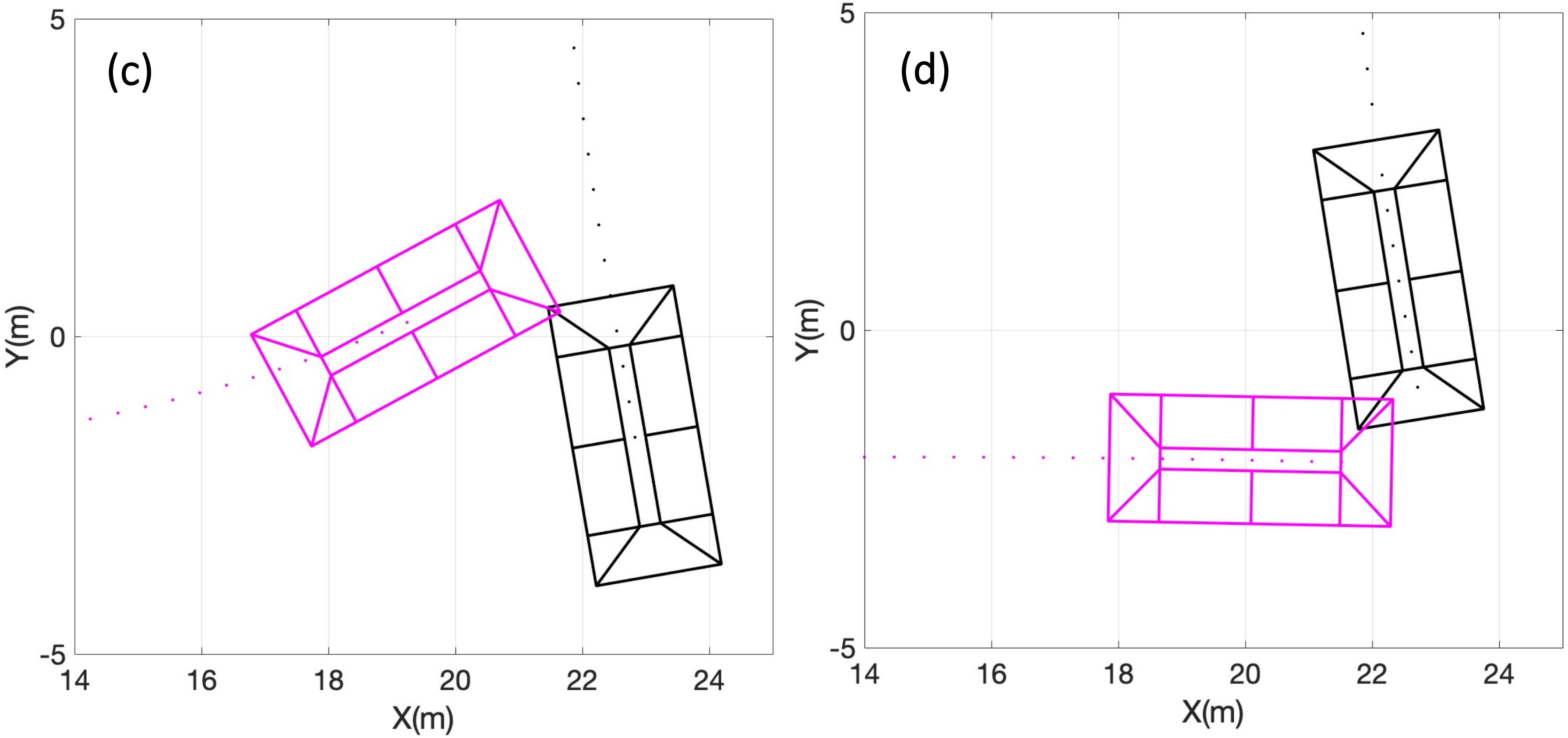
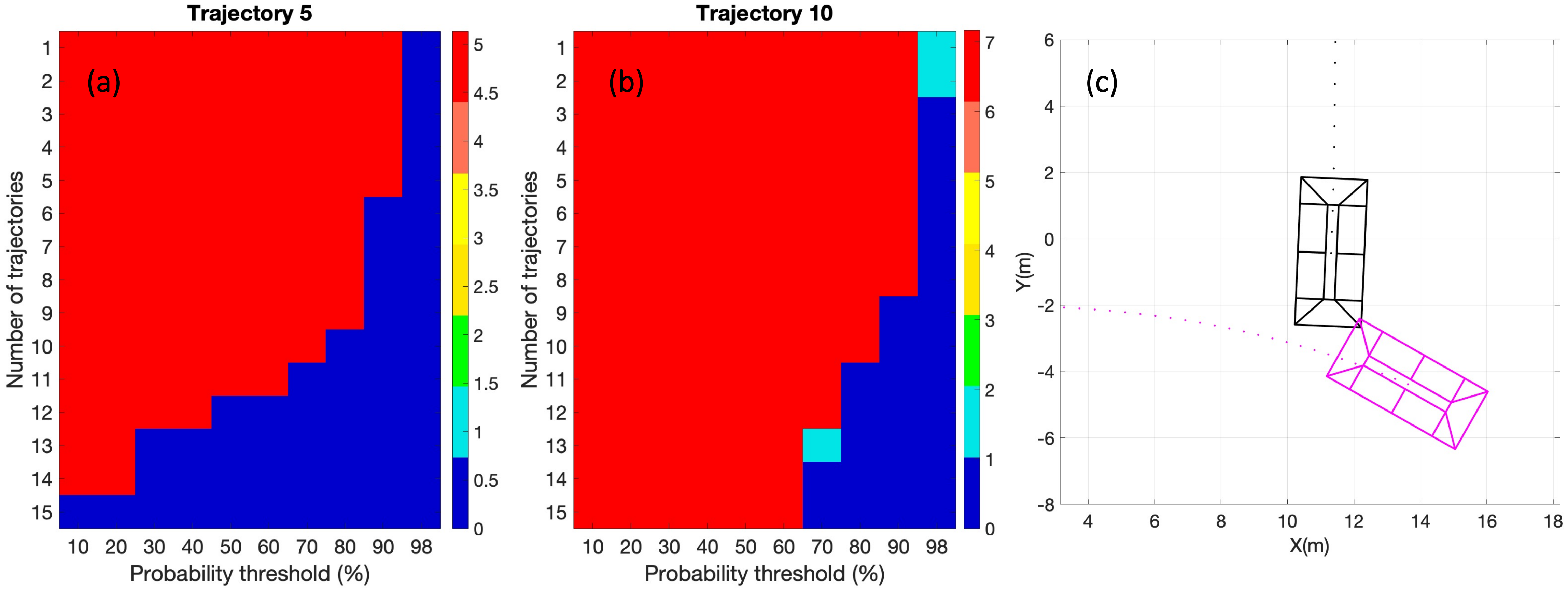


Figure 9. Collisions at acting early (c) and acting late (d).



Decision-Making under Uncertainty

Figure 10. Severity outcomes of reconfigured collisions (a), (b). Example scenario based on Method 1-2 (c).



Decision-Making under Uncertainty:
Quantitative Results

1) Differences in severity of collisions considering decision-making strategies

- No distribution of severity values were similar.

2) Differences in severity of collisions (lower & higher prediction horizon)

- Statistically significantly different but also varies between methods

Post-impact Motion Planning

⑥ Severity of a Secondary Collision

⑦ Accuracy of Collision Parameters

- Models from vehicle dynamics and accident reconstruction

- Post-impact motions of the vehicles are inputs for the cost function.

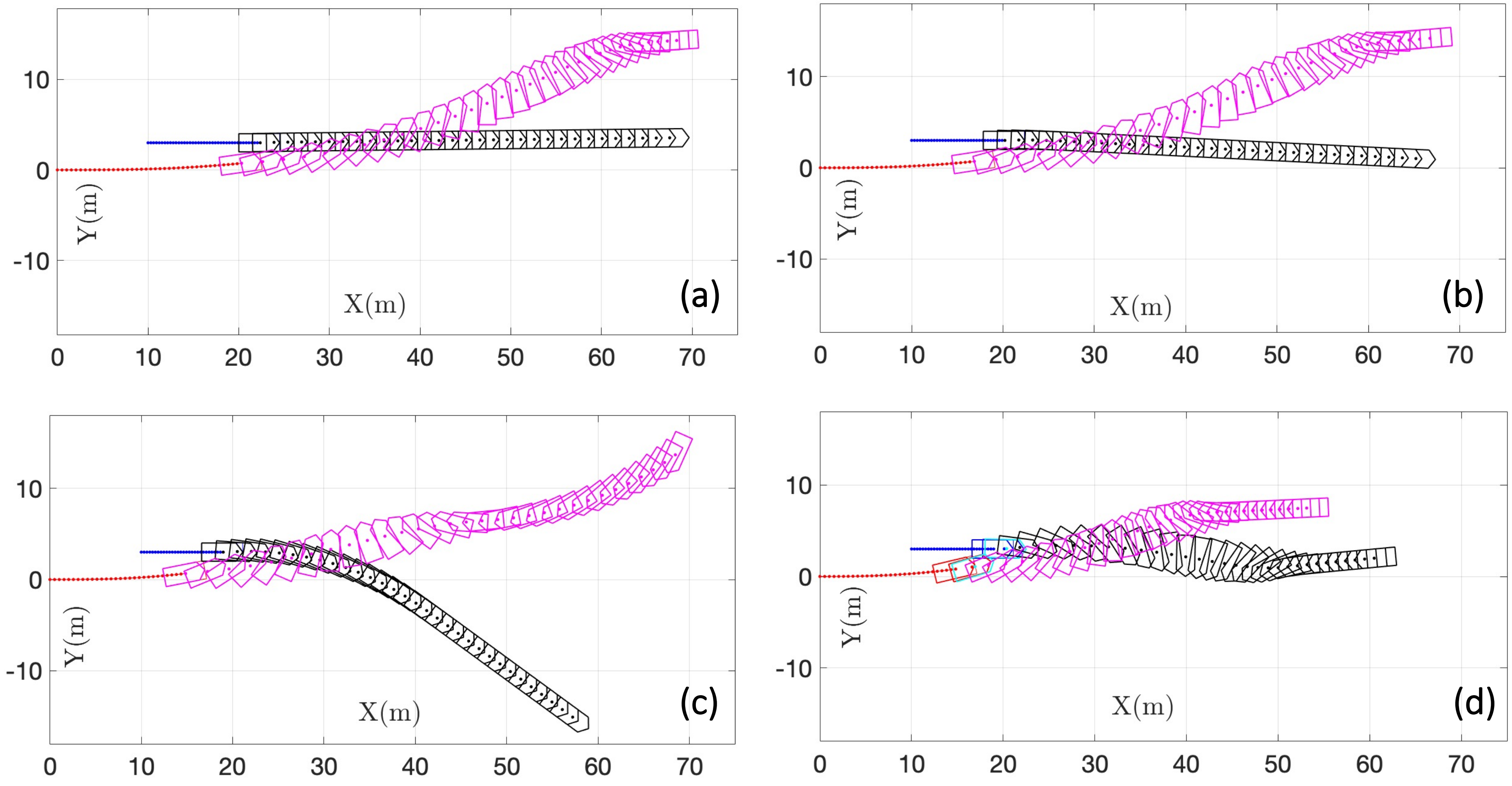
$$J = \left(\underbrace{w_1 \sum_{k=1}^{N} (Y_{ref} - Y_k)^2}_{Y_c} + \underbrace{w_2 \sum_{k=1}^{N} (\psi_{ref} - \psi_k)^2}_{\psi_c} + \underbrace{w_3 \sum_{k=1}^{N} \omega_{zk}^2}_{\omega_{zc}} + \underbrace{w_4 \sum_{k=1}^{N} (\beta_{ref} - \beta_k)^2}_{\beta_c} \right)^{\frac{1}{2}}$$

Post-impact Motion Planning

Table 2. Cost

Scenario	Cost
a	4.065
b	13.45
c	110.13
d	24.02

Figure 11. Different impact scenarios.



Post-impact Motion Planning: Sensitivity analysis-contact friction

Figure 12. Pre-impact scenario

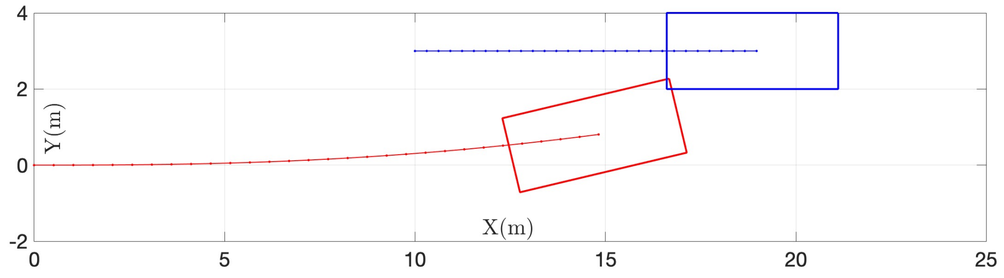


Table 3. Cost

Scenario	Cost
a	24.02
b	27.41

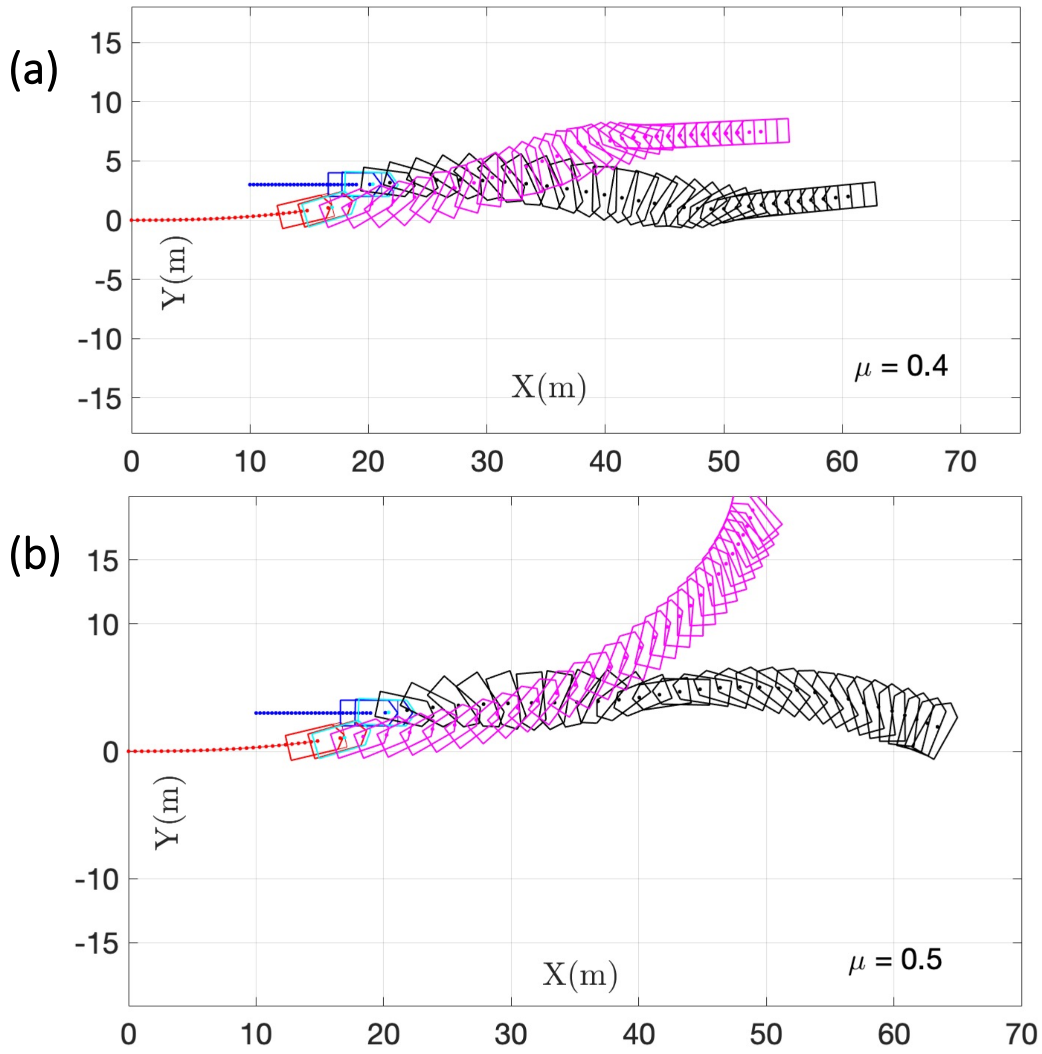


Figure 13. Sensitivity of post-impact motions for various values of contact friction

Post-impact Motion Planning:
Sensitivity analysis-contact plane

Table 4. Cost

Scenario	Cost
a	24.02
b	48.88

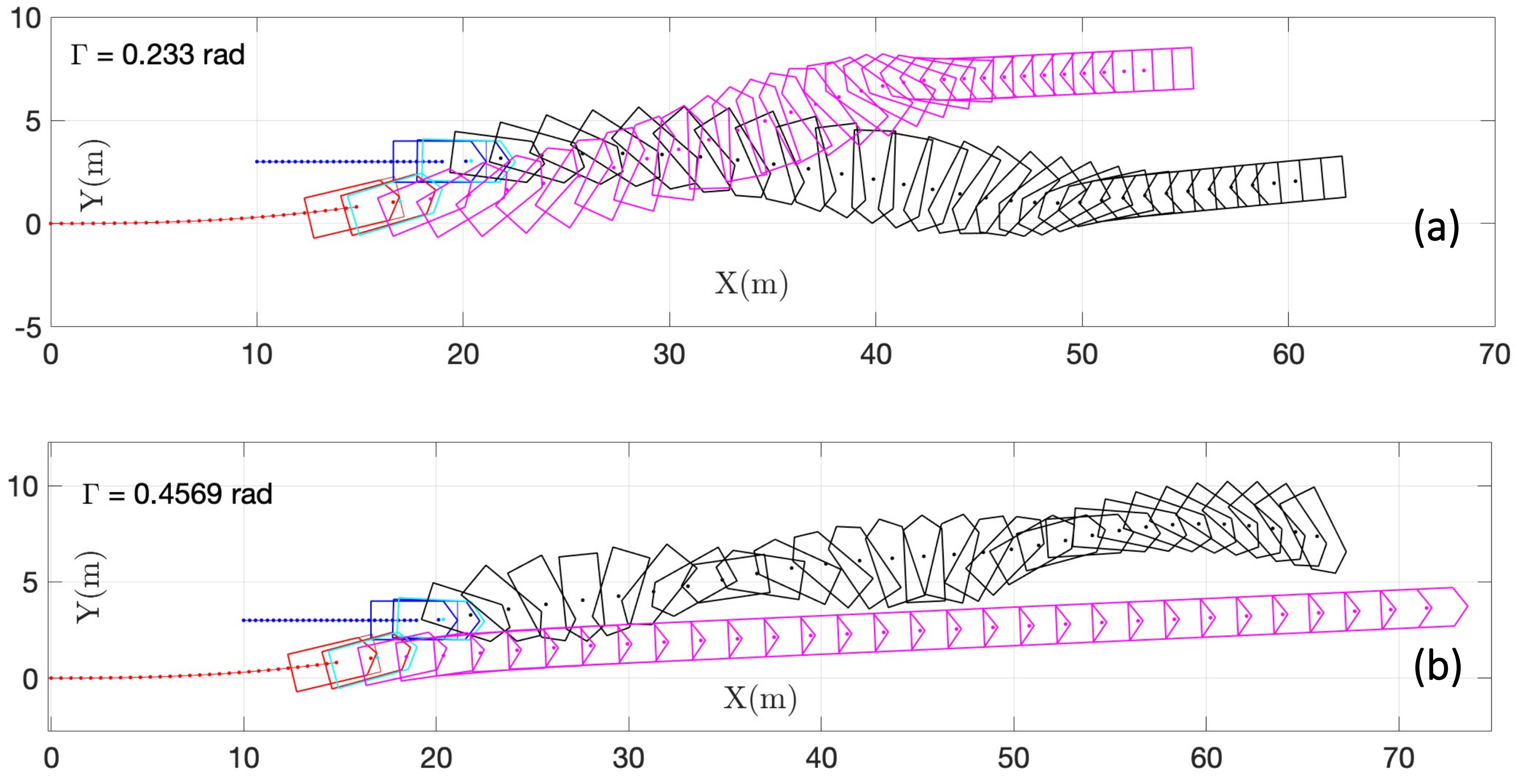


Figure 14. Sensitivity of post-impact trajectories to contact plane angle.

Final Words

- Motion planning framework that quantifies the concept of occupant protection.
- Charactristics of motion planning in unavoidable collision.
- Safety regulators addressing decision-making for AVs in unavoidable collisions.
- Changing the distribution of accident types and new collision patterns.
- Recording of reconfigured collisions and trajectories near collisions.
- Sharing data across the automotive industry.

Future Research

- Motion planning in unavoidable collisions & motion planning in critical situations.
- Other crash factors, evaluations in other scenarios, vulnerable road users.
- Minimizing collision severity across the entire accident.
- Experimental testing on the real vehicle.