ICTR 2023

HIT- HELLENIC INSTITUTE OF TRANSPORT

HELLENIC INSTITUTE OF TRANSPORTATION ENGINEERS

11th INTERNATIONAL CONGRESS on TRANSPORTATION RESEARCH

Clean and Accessible to All Multimodal Transport

Heraklion, Crete, September 20th - 22nd 2023

Modelling the behaviour of automated vehicles when interacting with jaywalkers

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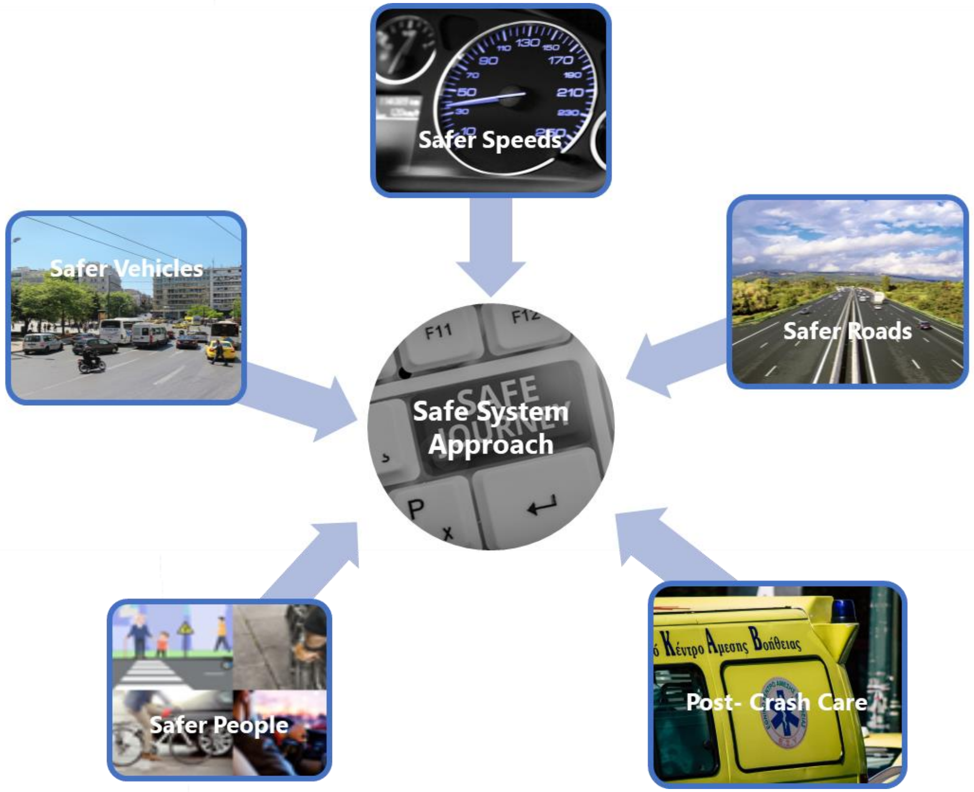
Introduction

- The advent of automation revolutionizes the transportation field
- Contribution towards safer vehicles and safer people
- Safe interaction between VRUs and equipped vehicles is a major road safety pilar
- Different types of intersection areas
  - Illegal crossing is considered the riskiest
- Need to understand the microscopic characteristics governing these encounters

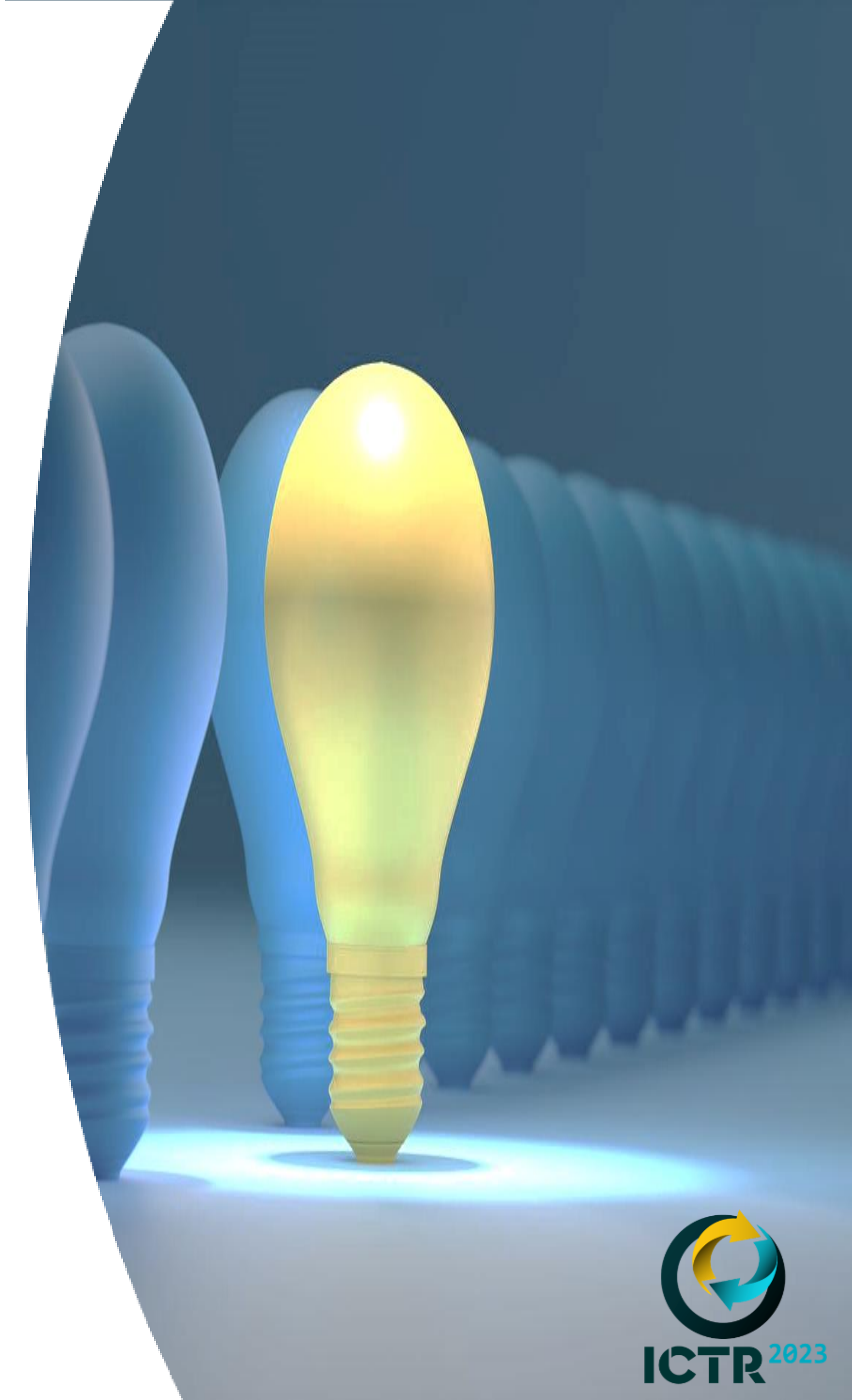


Objectives

- Identification of the most critical and appropriate indicators for describing the vehicle-pedestrian interaction

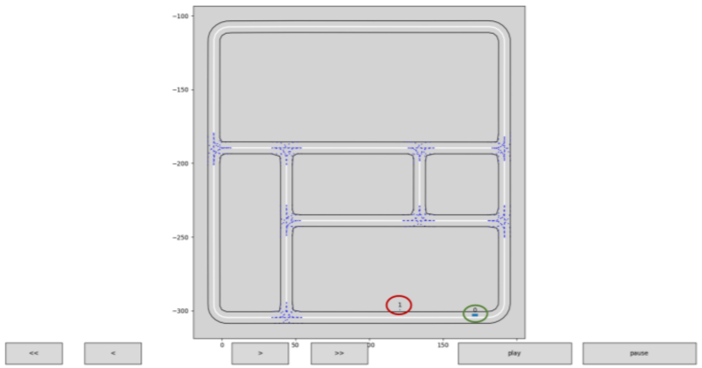
- Classify the interactions in different severity levels

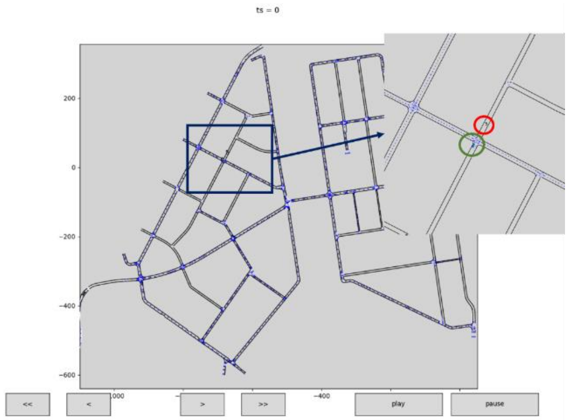
- Deeper understanding of the AV-pedestrian interaction process dynamics based on Inverse Reinforcement Learning principles

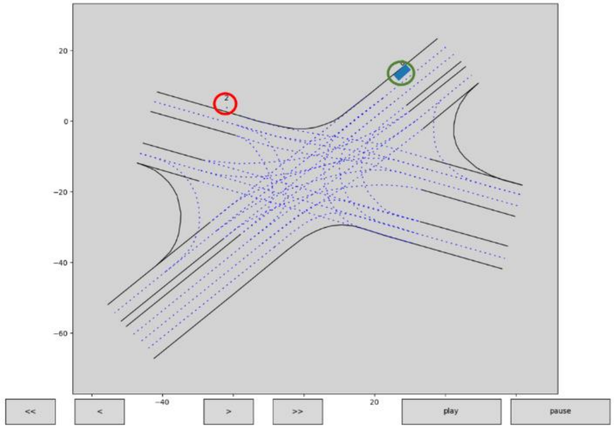


The Experiment

- Virtual Experiment led by FZI Research Centre for Information Technology
- Level 4 automated vehicle
- Human expert immersed into the scene via a virtual reality (VR) headset
- Road crossing at a random location of the network
- Data collection in 3 different phases and networks







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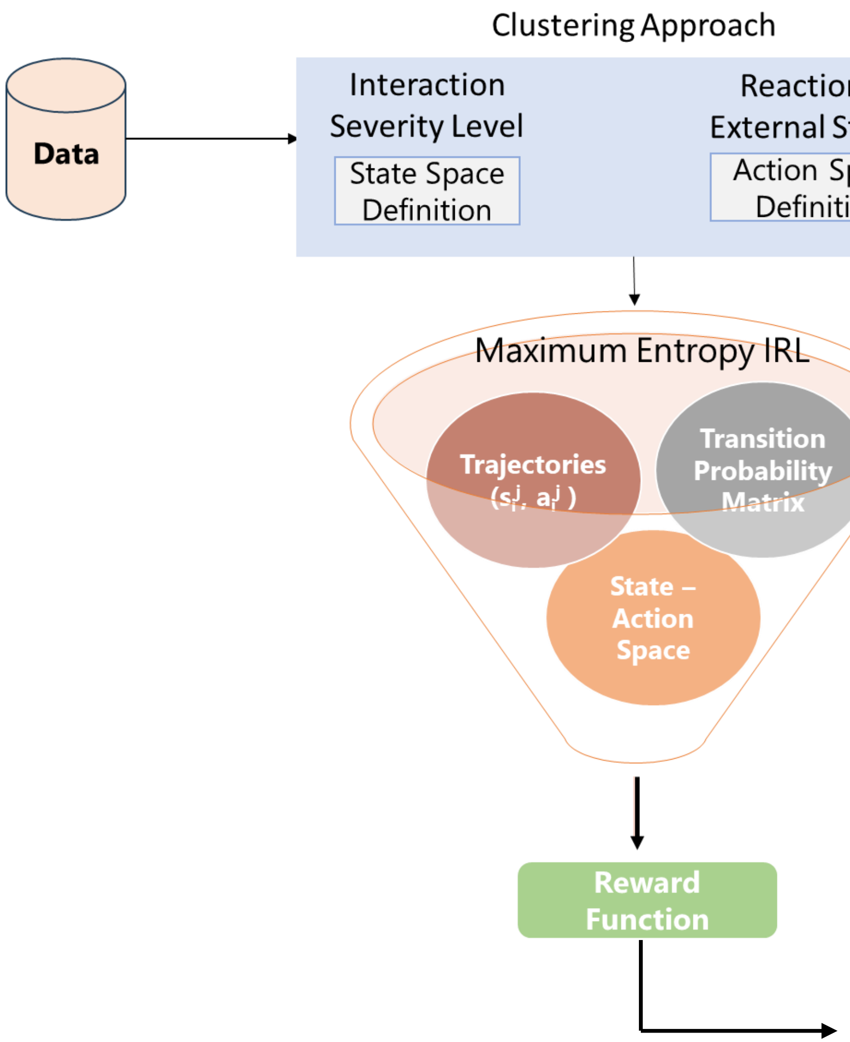
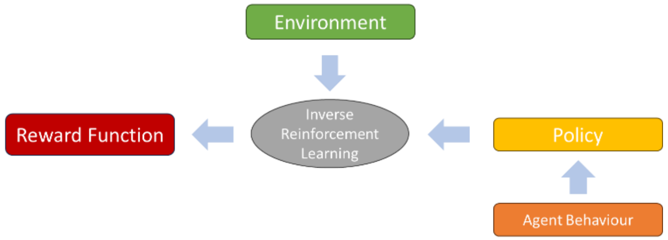
Data Collection

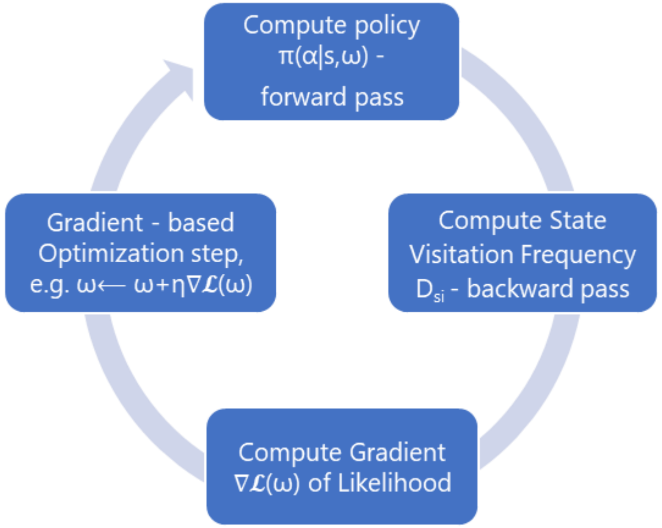
- **Kinematic characteristics** of the two agents
- **Spatial and temporal** distances
- **Phase 1:** 21 pair of trajectories
- **Phase 2:** 21 pair of trajectories
- **Phase 3:** 45 pair of trajectories
- **Final dataset:** 50 trajectories
  - Pedestrian passes first

Field	Description	Unit
Timeframe	data is collected every 100 ms	ms
Agent -type	"car" or "pedestrian"	-
x,y	the x and y position of the agent	m
vx, vy	speed values of the agent in the x and y dimension	m/s
psi_rad	the yaw angle of the agent	rad
length	length of the agent	m
width	width of the agent	m
ax, ay	acceleration/deceleration values of the agent in the x and y dimension	m/s^2
time-headway	the temporal distance of the agent from its preceding vehicle	s
gap	the spatial distance of the agent from its preceding vehicle	m
lateral_position	the distance of the central axis of the vehicle from the central axis of the lane	m
side_distance	the distance from the central axis of the agent from the side object	m
mode	this parameter describes whether automation mode is on or manual vehicle control is applied. Since automation can be activated only in case the agent-type is a car, this parameter takes the values "automated" and "simulated" if automated function is on and off respectively. For pedestrians, the only value for this parameter is "simulated".	-

Methodological Overview



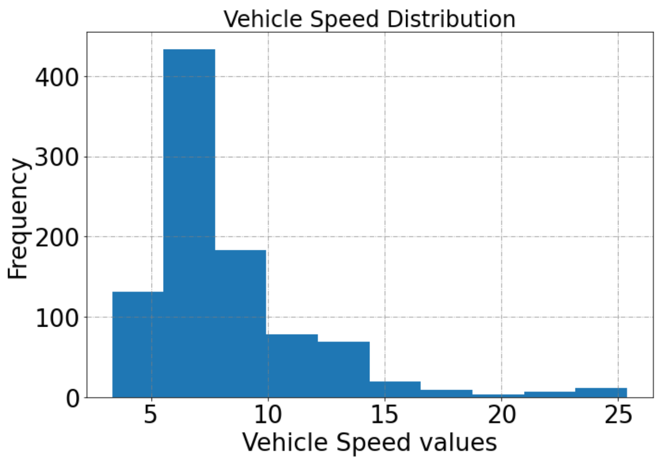


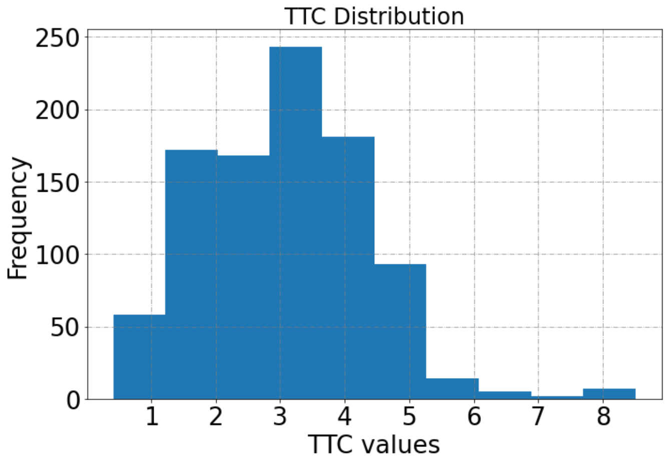


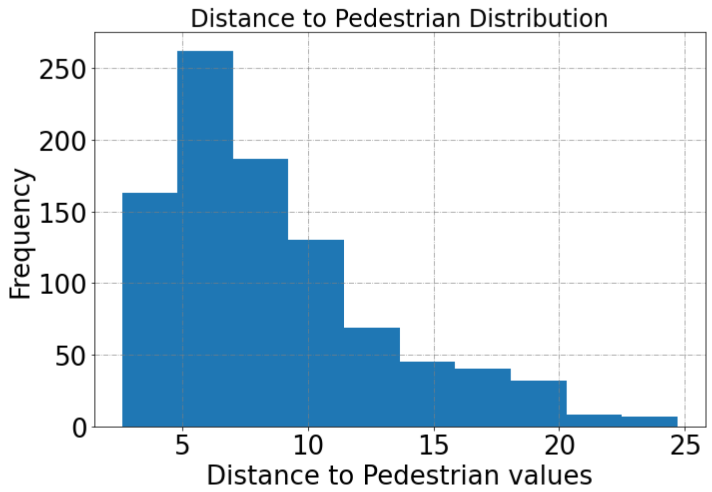
Understand the vehicle dynamics and behavior during the interaction

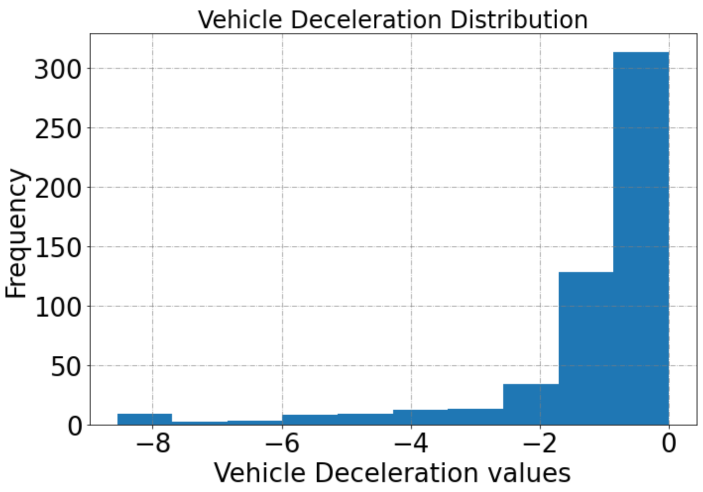
Understand the goals the vehicle agent wants to achieve

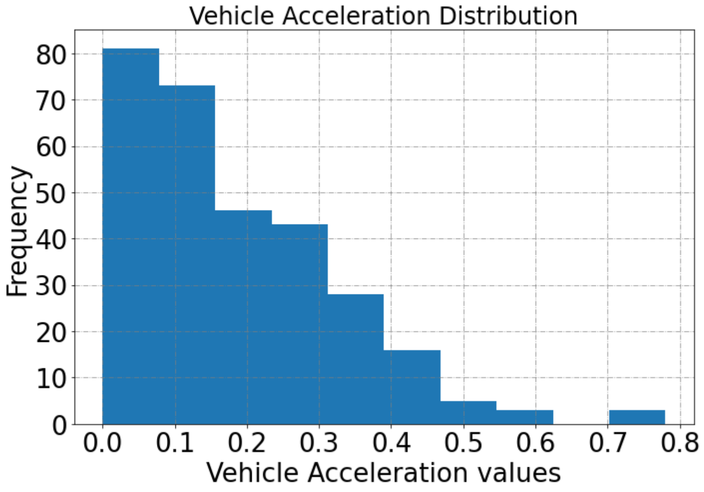
Descriptive Statistics





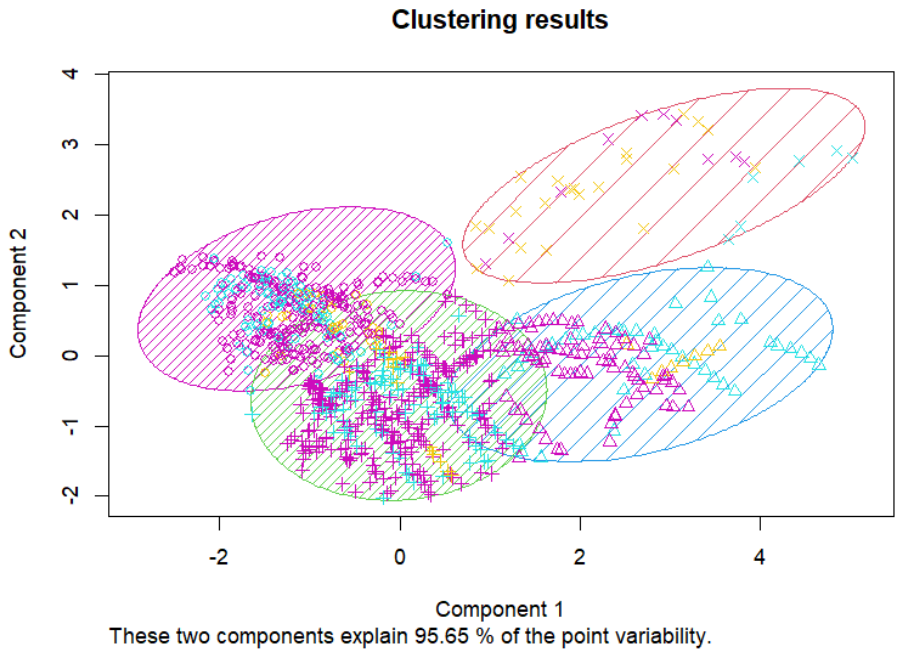






Vehicle State Space Definition

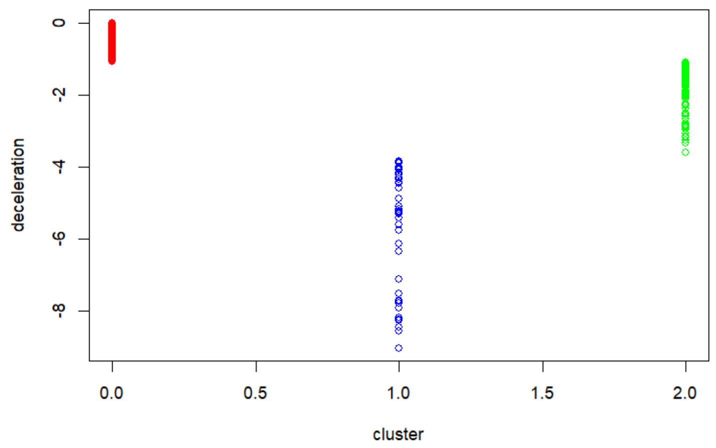
- Combination of time-, distance – and speed - based indicators
- Data driven unsupervised learning
  - K – means Clustering
- Vehicle Speed, Gap and Time to Collision (TTC)
- Definition of the severity of the interaction process
- Number of clusters=4
- Silhouette Coefficient = 0.462



	Average Speed	Maximum Speed	Standard Deviation of Speed	Average Distance	Maximum Distance	Standard Deviation of Distance	Average TTC	Maximum TTC	Standard Deviation of TTC	Sate Characterization
Cluster 0	6.91	13.24	1.61	5.60	9.5	1.51	1.83	2.65	0.54	**Unsafe**
Cluster 1	12.45	18.14	1.78	16.17	24.7	3.01	4.01	4.95	0.54	**Safe**
Cluster 2	7.11	12.01	1.58	7.90	13.06	2.34	3.64	4.96	0.58	**Safe**
Cluster 3	19.82	25.37	3.78	14.56	22.69	3.55	2.15	3.17	0.41	**Critical**

Vehicle Action Space Definition

- Critical parameter to define the driver reaction to the external stimuli
  - Acceleration/Deceleration
- Based on k-means clustering results:
  - 1 levels of acceleration
  - 3 levels of deceleration (smooth, harsh, emergency)
- 5 actions
  - Do nothing
  - Acceleration
  - Smooth deceleration (>-1.08m/s^2)
  - Harsh deceleration (<-3.6m/s^2)
  - Emergency deceleration (<-8.45m/s^2)

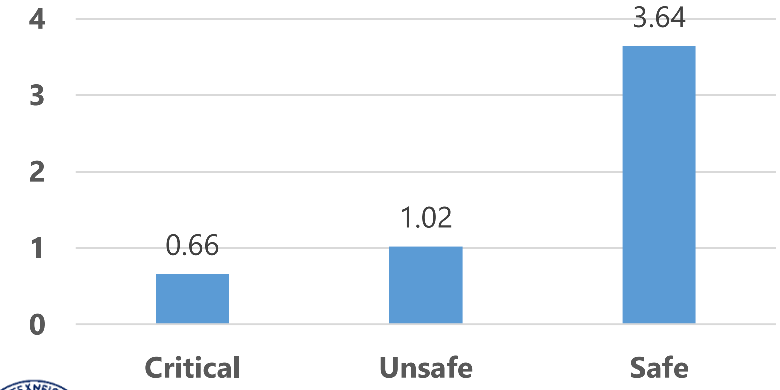


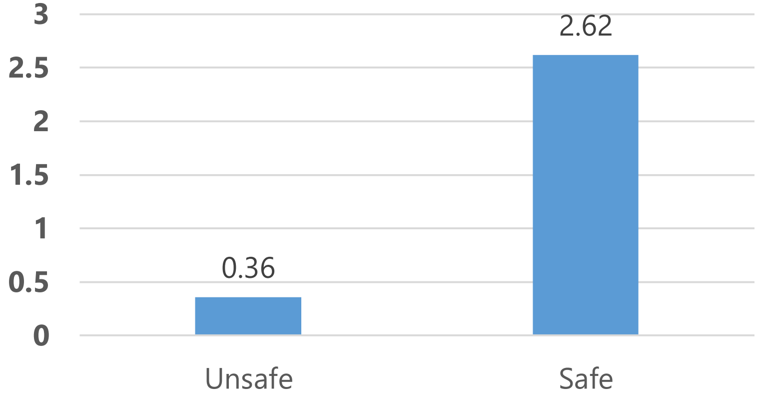
	Average Deceleration	Maximum Deceleration	Standard Deviation of Deceleration	Action Characterization
Cluster 0	-0.46	-1.08	0.33	**Smooth**
Cluster 1	-1.73	-3.60	0.56	**Harsh**
Cluster 2	-5.66	-8.45	1.65	**Emergency**

Actions	**Value**
Cruising (no change in speed)	0
Acceleration	(0, 0.78]
Smooth deceleration	[-1.08, 0)
Harsh deceleration	[-3.6, -1.08)
Emergency deceleration	[-8.45, -3.6)

MaxEnt IRL Results

- As the risk level increases the reward decreases and the vehicle "driver" gest penalized
- The expert adopts the vehicle dynamics to be more frequent under the state "safe"
- The experts goal is to take actions for avoiding the "critical" and "unsafe" states
- The reward function can be used to learn but not copy the expert' policy





Conclusions

- Clustering approach allows easier and more reliable interpretation of the reward function
- Need for additional parameter for improving the vehicle state space definition
- As expected, safer states tend to give higher rewards to the vehicle “driver”
- The transition to unsafe and dangerous states penalizes the vehicle “driver”

Further Research

- Consideration of additional parameters for improving clustering results and vehicle state space definition
  - Better depict the collision proximity and severity
- Optimization of vehicle control strategy
  - Reinforcement Learning principles
  - Model – based algorithm
- Impact assessment of the proposed strategy through simulation
  - Traffic efficiency
  - Safety
  - Environment

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