



Urban Autonomy: Interaction Patterns of Autonomous Vehicles in the Bay Area

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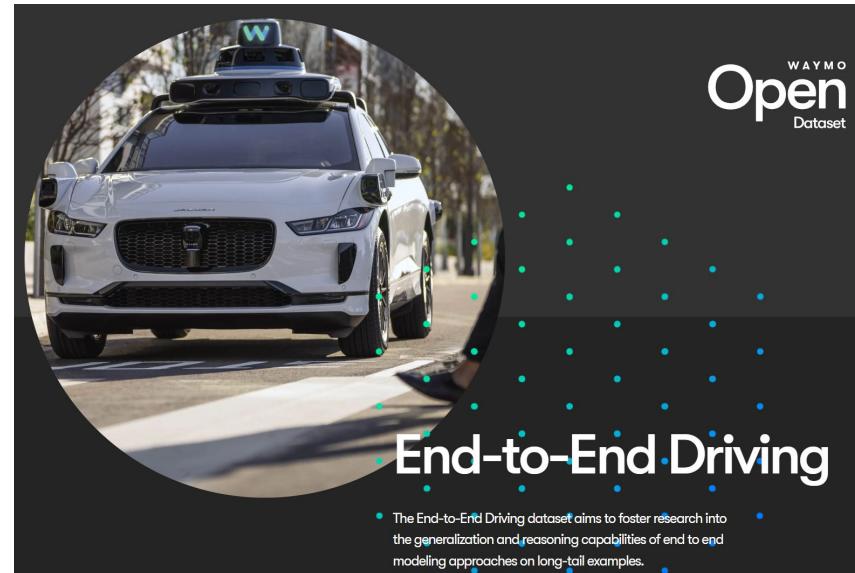
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Dataset Overview

Waymo Open Dataset - End to End Driving [1]

- **360° Visuals:** 8 camera views per frame and vehicle pose
- **Motion History:** 4 seconds of past trajectory data sampled at 4Hz
 - Position vector
 - Velocity vector
 - Acceleration vector
- **Ground Truth Labels:**
 - Future state positions
 - High Level Intent (Left / Right / Straight / Undecided)



[1] <https://waymo.com/open/data/e2e/>

Methodology

Data Ingestion

Data Selection: Selected a single, comprehensive test set from the massive Waymo Open Dataset cloud buckets to ensure manageable depth.

Streaming: Ingested the data via direct streaming of TensorFlow records.

Processing

Parsing: Decoded raw TF records to isolate vehicle kinematics (position, velocity, acceleration).

Contextualization: Extracted corresponding camera feeds and ground-truth intent labels for each frame.

Analysis

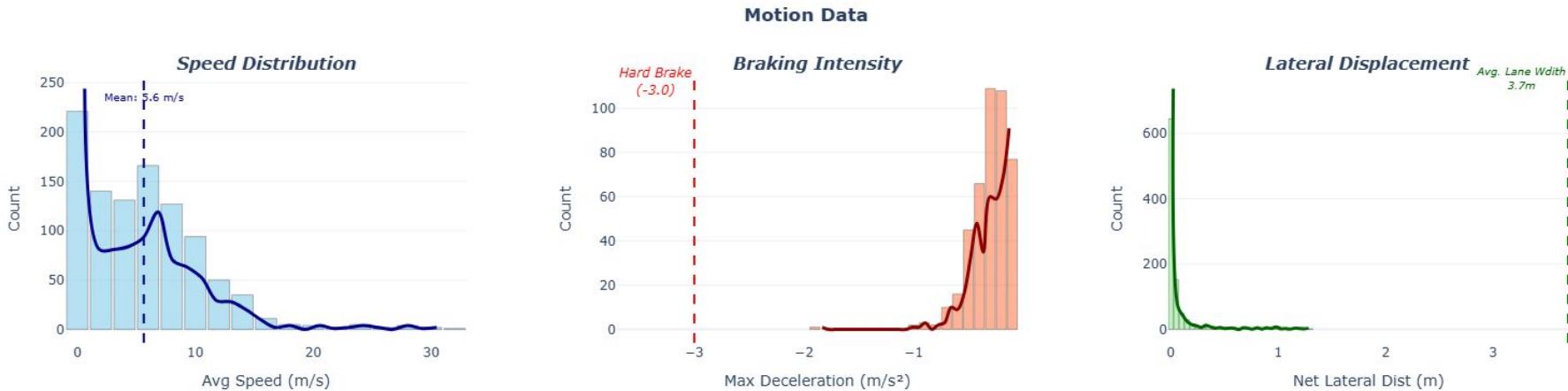
Feature Engineering: Calculated statistical distributions of motion data.

Metric Definition: Formulated and computed the **Interaction Score** to quantify safety and comfort in real-time.

Visualization

Scenario Validation: Generated trajectory plots and matched them with ego-centric camera views to visually verify high-interaction events.

Distribution of Motion Data



Takeaway: The vehicle exhibits conservative behavior with minimal outliers. However, isolated statistics miss context; we must next correlate these factors to identify specific driving scenarios.

Driving Scenario Classification

01

Potential Accidents

- Strong Braking
- Swerving to avoid

02

Aggressive Driving

- Intent to swerve
- Stomping on brakes
- Aggressive Acceleration

03

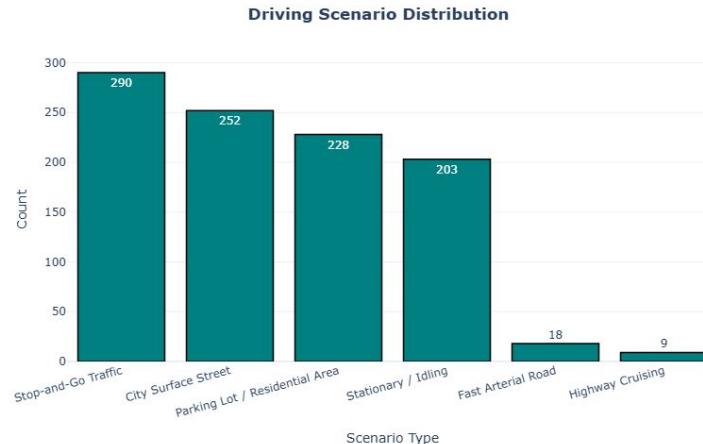
Complicated Driving

- Lane Weaving or Drifting
- Lane Change and Turning
- Stop and Go Traffic

04

Typical Driving

- Highway Cruising (> 55 mph)
- Fast Arterial Roads (< 55 mph)
- City Streets (< 35 mph)
- Parking or Residential (< 15 mph)
- Stationary or Idling (< 3 mph)



Takeaway: The dataset is dominated by "Typical Driving" with zero accidents. Since we cannot measure safety by counting crashes, we need a continuous metric to assess ride quality in these everyday scenarios.

Interaction Score

Sustained Braking

Instances of deceleration exceeding 1 m/s^2

Unexpected Motions

Intent to turn while maintaining high speeds.

Jerky Movements

Peak jerk intensity recorded during the frame.

Drastic Lateral Movements

Significant lateral displacement at high speeds.



Interaction Score

A composite metric identifying scenarios where driving behavior becomes **unsafe** or **uncomfortable** for passengers.

Interaction Score Distribution

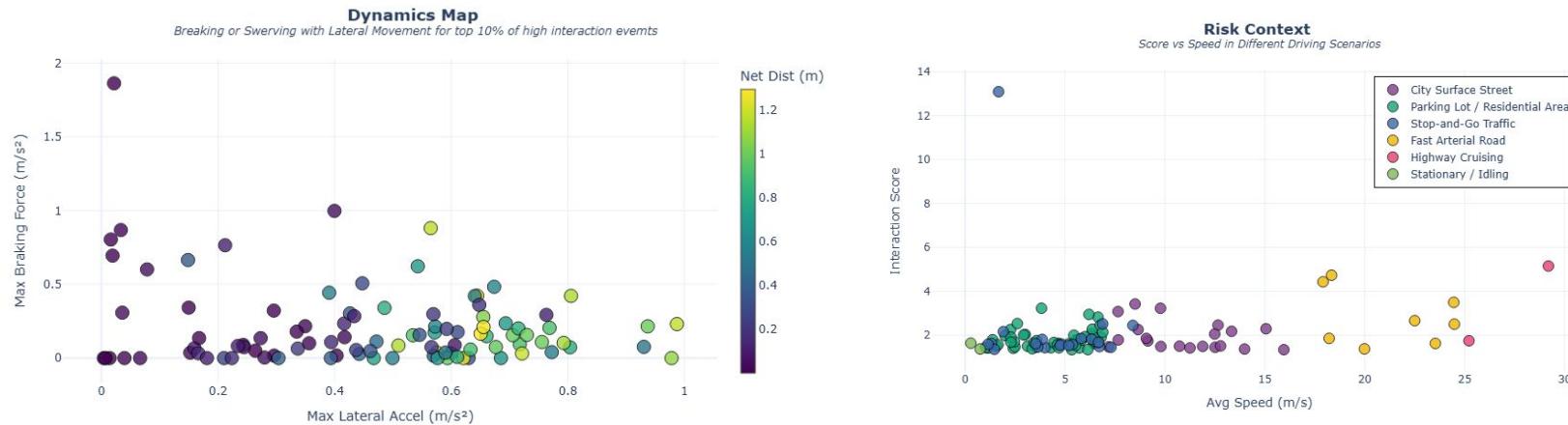


Scenario	Median	IQR	Max	Min
Fast Arterial	0.9652	2.1720	4.7340	0.2104
Highway	0.8472	0.8300	5.1521	0.4506
Residential	0.6009	0.8837	3.2304	0.0890
Stop and Go	0.4699	0.3745	13.0888	0.0637
City	0.4680	0.3768	3.4239	0.1394
Stationary	0	0	1.6402	0

High Score indicates unsafe or uncomfortable driving style.

Lower score indicates typical driving style.

Analysis of High Interaction

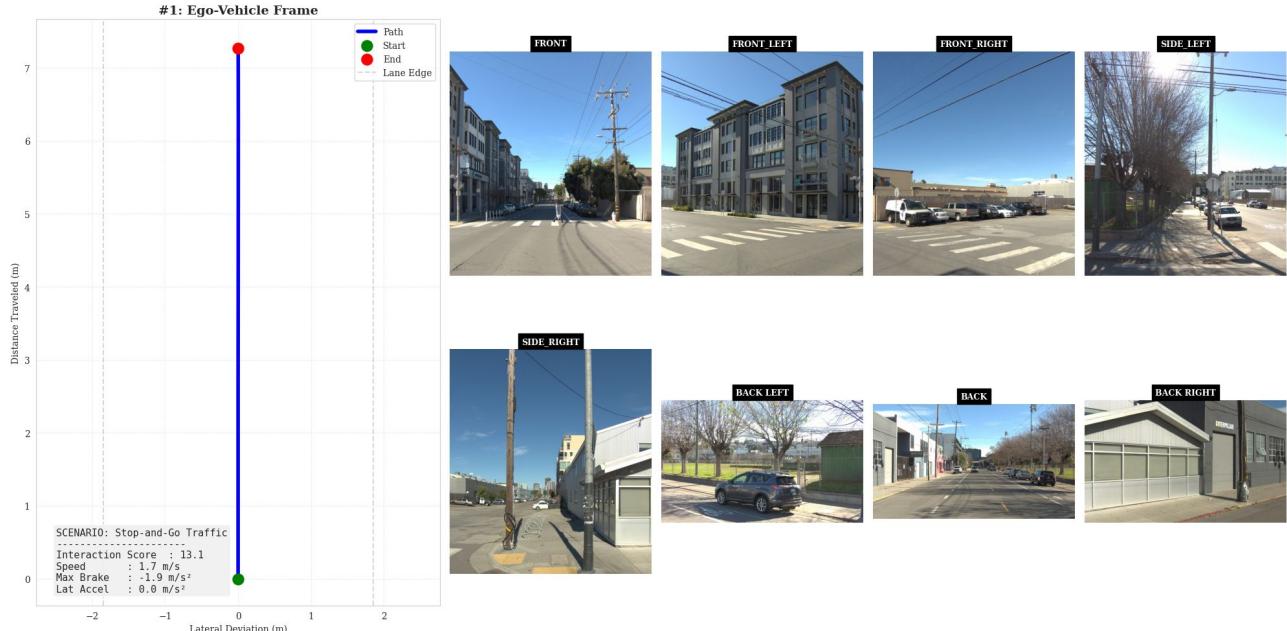


Analysis of the top 10% most complex scenarios confirms the AV prioritizes stability:

- No Panic Reactions (Left): Even in high-stress events, the vehicle exhibits zero hard braking ($>3 m/s^2$) or evasive swerving.
- Speed Modulation (Right): The AV successfully manages high interaction by lowering speeds, primarily in City and Residential environments.

Visualizing Top 3 Scenarios

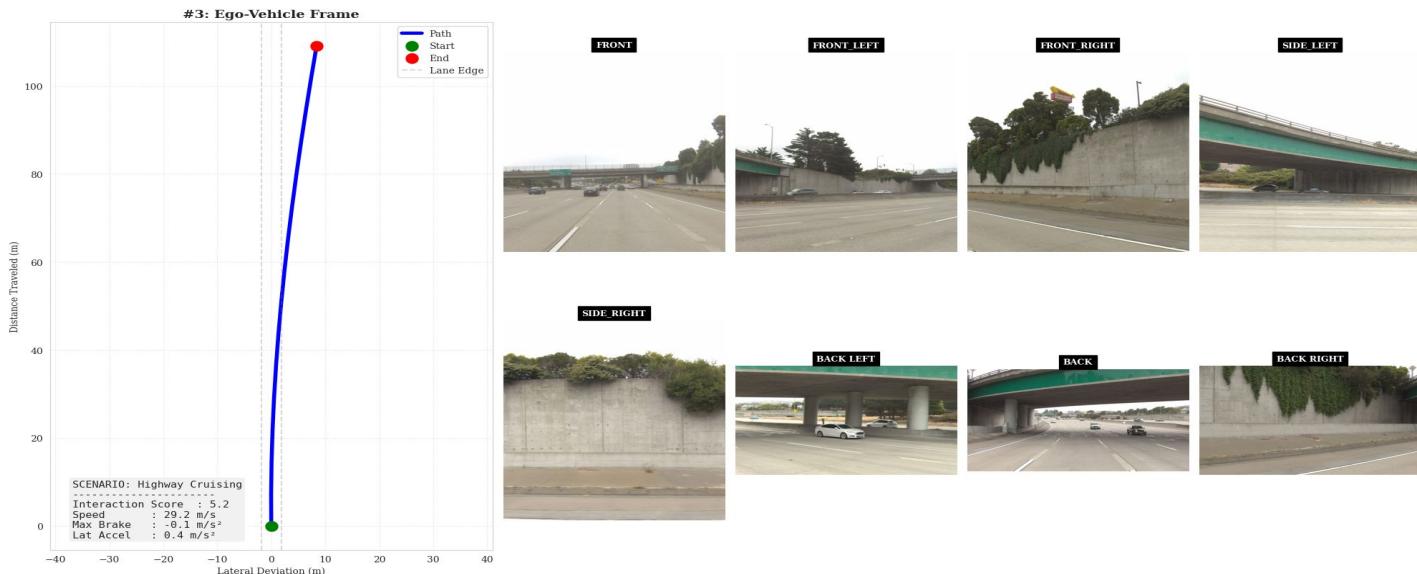
Interaction Score	13.1
Driving Scenario	Stop and Go
Speed	1.7m/s
Max Brake	1.9m/s ²
Lateral Accel	0.0m/s ²



High interaction score driven by sharp deceleration (1.9 m/s^2) to yield to the oncoming vehicle visible in the Back-Left frame, despite low travel speed.

Visualizing Top 3 Scenarios

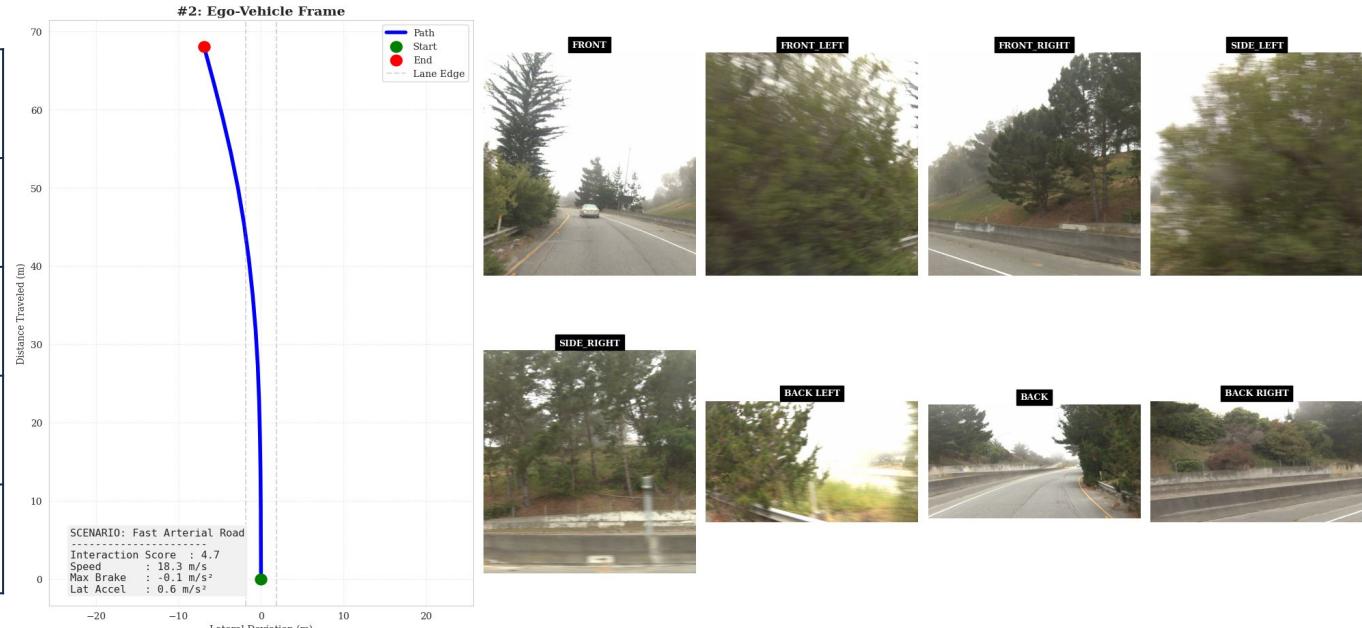
Interaction Score	5.2
Driving Scenario	Highway Cruising
Speed	29.2m/s
Max Brake	0.1m/s ²
Lateral Accel	0.4m/s ²



Score dominated by high highway velocity (29.2 m/s) combined with the necessary lateral adjustments to follow the road's curvature.

Visualizing Top 3 Scenarios

Interaction Score	4.7
Driving Scenario	Fast Arterial
Speed	18.3m/s
Max Brake	0.1m/s ²
Lateral Accel	0.6m/s ²



Score driven by the heightened lateral forces (0.6 m/s^2) required to negotiate strong road curvature while maintaining sustained arterial speeds.

Conclusion and Future Work

Conclusion

- **Conservative Profile:** Our analysis of the Waymo Open Dataset confirms that AVs in the Bay Area exhibit highly conservative driving patterns.
- **Passenger Experience:** The metrics validate that the vehicle prioritizes stability, ensuring a safe and comfortable ride with minimal aggressive maneuvers.

Future Work

- **Geospatial Analysis:** Incorporate GPS (lat/long) data to isolate driving behaviors in specific sensitive zones (e.g., school zones, complex intersections).
- **Anomaly Detection:** Scale the analysis to a larger dataset to identify rare "corner cases" and anomalies that averages might miss.
- **Outcome Validation:** Utilize future-state trajectory data to retrospectively evaluate decision quality, determining if the AV made the optimal choice.

Thank you!