Supporting the AV-TEP Mission, Scenario-Based Testing Pillar, Scenarios team

by

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ABSTRACT

In today’s fact pacing world of ever evolving technology and introduction to autonomous and automated vehicles, the transportation industry has introduced a fusion of autonomy and comfort. Yet, lingering beneath this technological marvel is a fundamental query about safety and the trust we invest in these cutting-edge technologies. In response, a research expedition unfolds, venturing into the fascinating realm of scenario-based testing methodology.

This paper details a comprehensive report of the project employing CARLA simulator and Scenario Runner to simulate and analyze 4 of the 37 pre-crash scenarios outlined by the National Highway Traffic Safety Administration (NHTSA). The simulation journey aims to bridge the gap between the theoretical understanding of autonomous vehicle safety and the unpredictable realities of real-world driving.

In this exploration, digital vehicles navigate diverse scenarios, including encounters with pedestrians, obstacles, the influence of human traffic controllers, and other vehicles, across varied road and environmental conditions. The emphasis lies not only on technical validation but on understanding how automated driving systems respond to the nuanced challenges presented by these scenarios.

The report delves into the intricacies of each pre-crash scenario, shedding light on the performance of the simulated vehicles and the Scenario Runner's ability to accurately replicate the complexities of real-world driving. Through a methodical analysis, this paper aims to provide valuable insights into the efficacy of autonomous systems in handling critical situations and contributing to the ongoing discourse on the safety and reliability of automated vehicles.

TABLE OF CONTENTS

Page no.

LIST OF FIGURES

Figure **Page**

LIST OF SYMBOLS/NOMENCLATURE/ABBREVATIONS

Abbreviations	Definitions
ACA	Arizona Commerce Authority
ADS	Automated Driving Systems
AIS	Abbreviated Injury Scale
AV	Autonomous Vehicles
AV-TEP	Automated Vehicle Testing and Evaluation Process
CARLA	CAR Learning to Act
CAV	Connected and Automated Vehicles
CDS	Crashworthiness Data System
GES	General Estimates System
GPU	Graphics Processing Unit
IAM	Institute of Automated Mobility
LIDAR	Light Detection and Ranging
MAIS	Maximum Abbreviated Injury Scale
NHTSA	National Highway Traffic Safety Administration
RSS	Responsibility-Sensitive-Safety
mph	miles per hour

K = a fatality resulting from the crash
A = incapacitating injuries such as amputation, disabling, and/or more
B = the victim has minor injuries such as cuts or scrapes but are not incapacitating
C = there is possible injury, but on a lesser scale
O = there were no apparent injuries at the scene

1 INTRODUCTION

1.1 Statement of Purpose

In the ever-evolving automobile landscape, a notable shift from gas-powered to electric cars has occurred, accompanied by the seamless integration of automated driving systems (ADS). These ADS transcend specific operational domains, acing the Dynamic Driving Test with a blend of hardware and software. While autonomy brings comfort, public apprehension persists.

The project's essence lies in prioritizing scenarios faced by ADS during testing. Globally, leading automated vehicle manufacturers embrace scenario-based testing, a virtual realm challenging test vehicle digital twins with diverse obstacles.

The core focus is on crafting a robust dataset with varied driving scenarios, empowering ADS developers to test ego vehicle models comprehensively. Subsequent metrics validation becomes pivotal in assessing performance across diverse driving conditions.

As technology progresses, testing ADS safety proves increasingly challenging, demanding reliability demonstrated over billions of kilometers. Simulation emerges as a potent method, exposing ADS to risky situations and gauging effectiveness. This initiative significantly advances AV-TEP goals by contributing to safety case process development, aligning with the NHTSA's mission to enhance safety.

Crucially, the 37 NHTSA-defined pre-crash scenarios become the foundation for evaluating hazards affecting both automated systems and human drivers. Simulating these scenarios is a vital step, benefiting safety evaluation for self-driving cars and the broader conversation about seamless technology integration into daily life. This mission encapsulates a journey of innovation, safety commitment, and a shared vision for a safer future.

1.2 Scope of the Project

1.2.1 In Scope

An extremely important step in the development of CAVs is evaluating the crash typologies of automobiles. To create an accurate framework that can measure operational safety and implement a crash countermeasure system using crash data and scenarios to simulate an ADS system, this project aims to complete the NHTSA's pre-crash scenarios for light-duty vehicle modeling in the open-source CARLA simulator.

1.2.2 Excluded from Scope

Time constraints at this stage of the project made hardware procurement, creating unique urban driving environments, and simulating more crash scenarios outside of its purview. The report excludes crashes involving more than two vehicles. Additionally, evasive action scenarios, non-collision incidents, and vehicle failure were among the low-frequency crash types that were not included. Data from crashes that are not reported to the police is not included in these statistics.

This project does not involve any research or testing related to cameras, LIDARs, and other sensors in the ADs.

1.3 Ideology

The National Highway Traffic Safety Administration's (NHTSA) scenarios were the basis for the original concept and plan of action. Ten of the 37 pre-crash scenarios on the NHTSA poster (Figure 1) had already been created by the Institute of Automated Mobility (IAM) and were included in the dataset. The purpose of these ten situations was to provide an example of how the maneuver catalog, RSS controller, and other factors interacted. To test how alternative values might impact the situation, the parameter definition and assigned values were explored with. Twelve of the 27 scenarios that remained had adversaries that were outside the purview of the project, such as objects, animals, pedestrians, and human traffic controllers. From the remaining 12 scenarios, 4 scenarios were chosen for simulation in this project, which are:

- Running Red Light
- Vehicle(s) Turning – Same Direction
- Left Turn Across Path from Opposite Directions at Non-Signalized Junctions
- Straight Crossing Paths at Non-Signalized Junctions

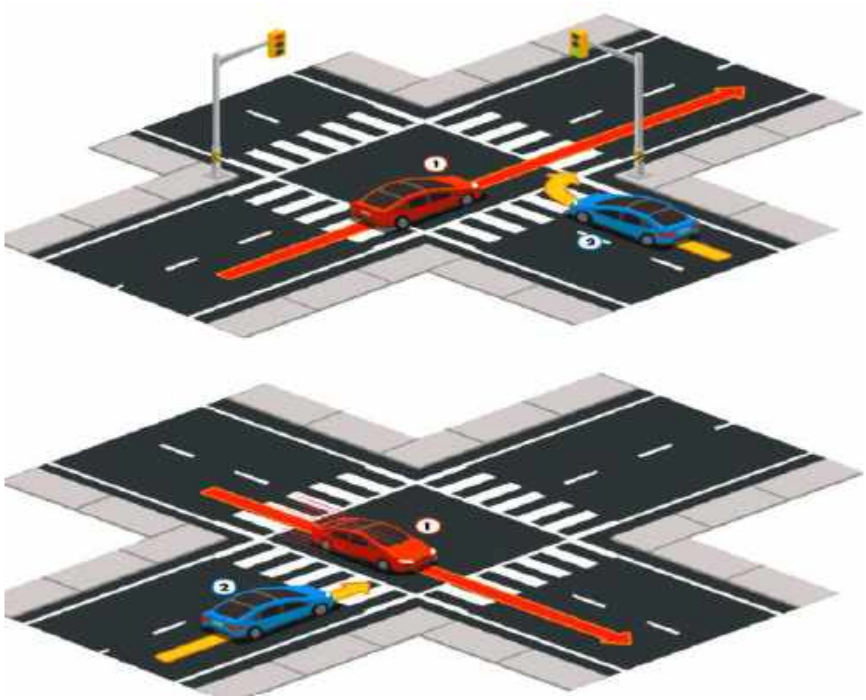

Figure 1: Example Pre-Crash Scenario

Reference: https://carlachallenge.org/challenge/nhtsa/

2 METHODOLOGY

2.1 **Hardware and Software Components**

The HP pavilion laptop equipped with an Intel Core i5 processor and NVIDIA GEFORCE GTX 1050 graphics card was used to run the software required for this project. A partition of 200 GB SSD was also used to dual boot the laptop with a Ubuntu Linux operating system.

An open-source CARLA simulator was used to develop and simulate the pre-crash scenarios. Ubuntu 20.04.3 LTS operating system had a partition space of 200gb allocated to dual boot the windows laptop.

2.2 **CARLA AND Scenario Runner**

An open-source simulator for autonomous driving is called CARLA. It was created from the ground up to function as a versatile and modular API to handle a variety of jobs related to the autonomous driving problem. Roads and urban environments are defined by CARLA using the OpenDRIVE standard, which is based on Unreal Engine. As seen in the graphic, an API available in Python and C++ provides control over the simulation.

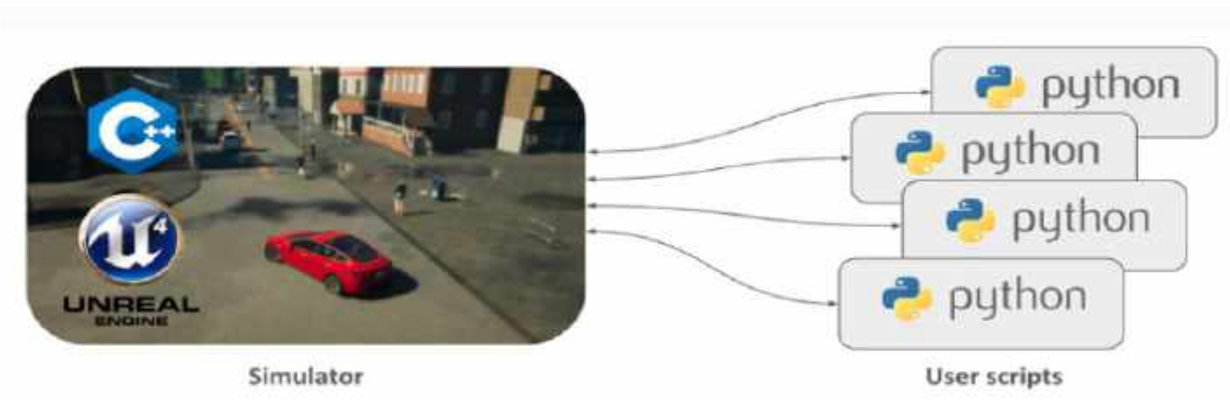

Figure 2: CARLA Simulator

Source: carla.readthedocs.io

Among the CARLA's essential components is Scenario Runner.
This application makes it easier to create, modify, and run different driving scenarios that are us ed to test and assess autonomous car systems.
Before implementing these systems in the actual world, users can thoroughly test and improve t he performance of their autonomous driving algorithms in a simulated environment by using Sc enario Runner.

Because of its flexibility and adaptability, Scenario Runner is a priceless tool for anybody working to advance autonomous vehicle technologies. It offers a safe yet authentic environment for ext ensive testing and development.

Figure 3: Scenario Runner

Reference: https://github.com/carla-simulator/scenario_runner

2.3 **Responsibility Sensitive Safety (RSS) Agent**

The Responsibility-Sensitive Safety (RSS) model shown in figure 4 is designed to formalize and contextualize human judgment regarding all multi-agent driving situations and dilemmas. RSS formalizes terms like dangerous situations, proper response, and notion of blame in a mathematical way. From a planning and decision-making perspective, RSS ensures that the AD system will not issue a command that would lead to an accident. RSS continuously monitors the *current* state of the environment, to determine if the ego vehicle is currently in a safe state. A state is regarded as *safe*, if the ego vehicle is not causing a collision with another object, under the worst-case assumption that the ego vehicle will accelerate (depending on the situation this can be also a deceleration) at maximum possible speed during its response time. RSS differentiates between longitudinal and *l*atera*l* conflicts. A longitudinal conflict means that the distance between the ego vehicle and an object in front or in the back of the ego vehicle is smaller than the longitudinal safety distance. Similarly, a lateral conflict arises if the distance to the left or right of the ego vehicle to another object is less than the required lateral safety margin.

Depending on the type of conflict, RSS requires a different response. The ad-rss-lib receives an object list, with information about all objects in the surrounding environment of the ego vehicle. Then, the ad-rss-lib creates an object - ego vehicle pair, for each object. This pair is usually referred to as "Situation". For all situations, the RSS checks are performed, and a proper response is calculated. Finally, one overall response is computed by the ad-rss-lib, and the corresponding actuator command restrictions (i.e., lateral, and longitudinal acceleration restrictions) are sent out.

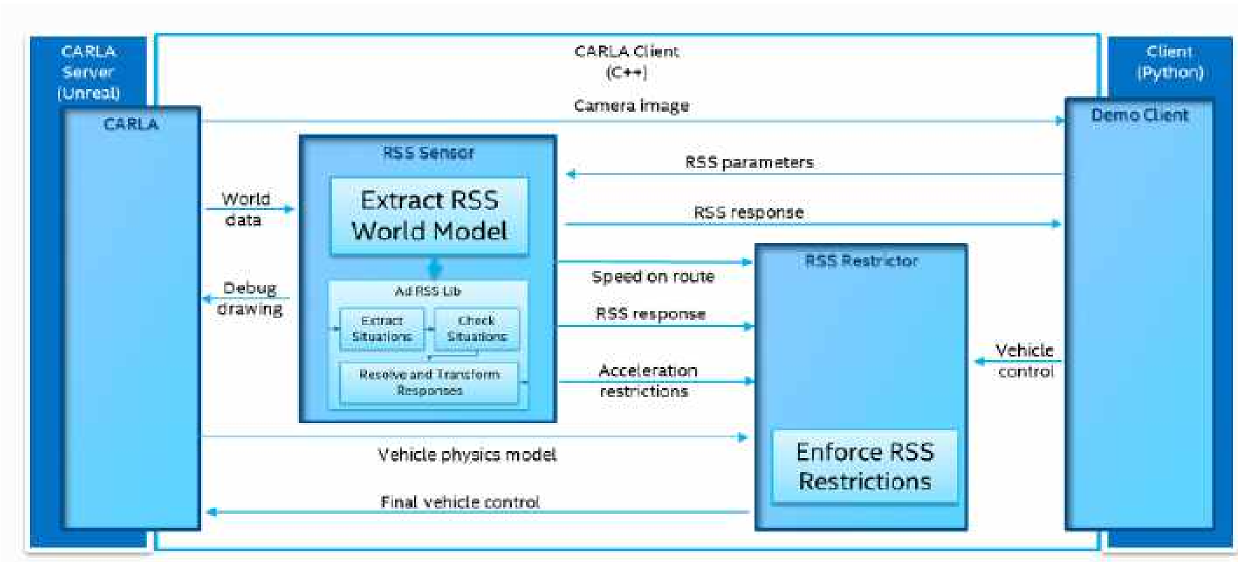

Figure 4: ad-rss-lib (implemented in the library) and its interfaces to the outside world

Reference: Responsibility Sensitive Safety (RSS) Agent

2.4 **XODR Viewer**

The XODR viewer is an online Open DRIVE-file (*.xodr*) viewer. Traffic lights, stops and yields will be generated on the fly. Pedestrians will navigate over the sidewalks and crosswalks that appear in the map. All of these elements, and every detail on the road, are based on the OpenDRIVE file. As the standalone mode uses the. xodr directly, any issues in it will propagate to the simulation. This could be an issue especially at junctions, where many lanes are mixed. This repository is primarily for posting and tracking issues, as well as discussing feature requests. The core of the viewer is a closed source with only the public assets being hosted here. The viewer is implemented in C++, using WebGL and is based on the open-source C++ library libOpenDRIVE as shown in figure 5.

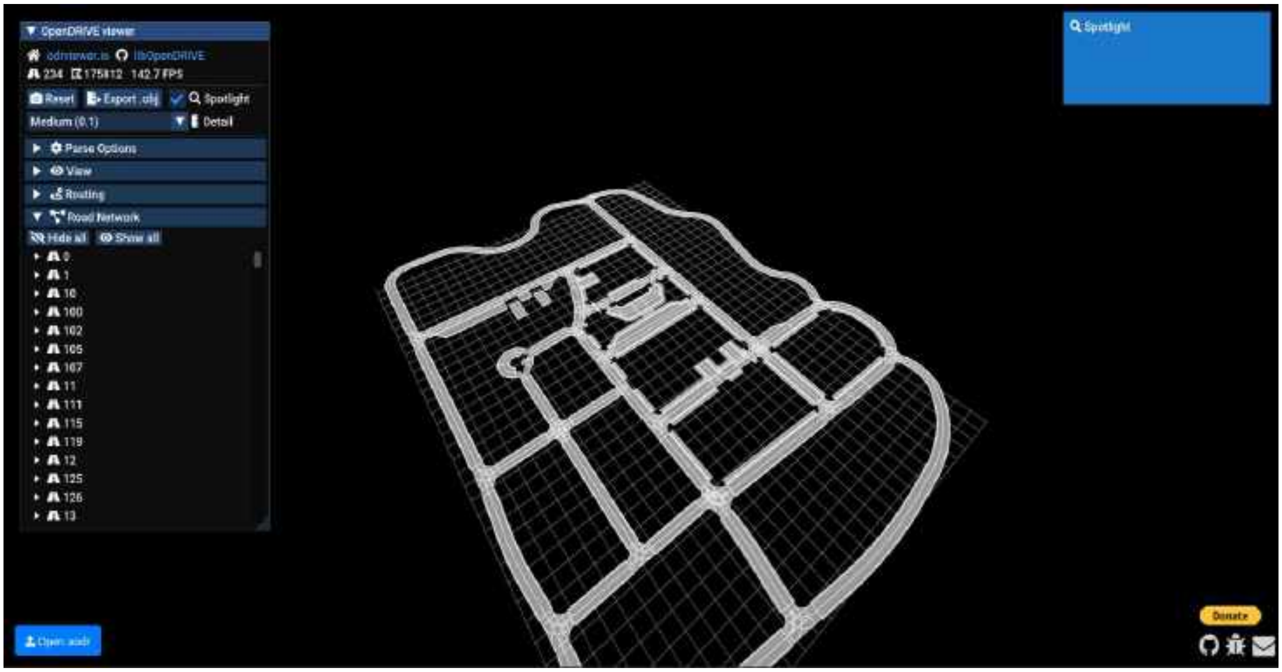

Figure 5: Online XODR Viewer

Reference: https://odrviewer.io/

The XODR Viewer is used to get a high-level overview of the maps used in Carla. Provides specifics such as the world map coordinates, road ID, turnings, intersections, road signs, and road coordinates helping us understand the nature of roads, lanes, and signals, etc.

3 PROJECT REVIEW

3.1 Introduction to Scenarios

NHTSA's typology consists of pre-crash scenarios, as shown in figure 6, that depict vehicle movements and dynamics as well as the critical event occurring immediately prior to crashes involving at least one light vehicle (i.e., passenger car, sports utility vehicle, van, minivan, and light pickup truck). The goal of this typology is to establish a common vehicle safety research foundation for public and private organizations, which will allow researchers to determine which traffic safety issues should be of priority to investigate and to develop concomitant crash avoidance systems. Its main objectives are to:

1. Identify all common pre-crash scenarios of all police-reported crashes involving at least one light vehicle.
2. Quantify the severity of each pre-crash scenario in terms of frequency of occurrence, direct economic cost, and functional years lost.
3. Portray each scenario by crash contributing factors and circumstances in terms of the driving environment, driver, and vehicle.
4. Provide nationally representative crash statistics that can be annually updated using GES and CDS crash databases.

1	Vehicle Failure
2	Control Loss With Prior Vehicle Action
3	Control Loss Without Prior Vehicle Action
4	Running Red Light
5	Running Stop Sign
6	Road Edge Departure With Prior Vehicle Maneuver
7	Road Edge Departure Without Prior Vehicle Maneuver
8	Road Edge Departure While Backing Up
9	Animal Crash With Prior Vehicle Maneuver
10	Animal Crash Without Prior Vehicle Maneuver
11	Pedestrian Crash With Prior Vehicle Maneuver
12	Pedestrian Crash Without Prior Vehicle Maneuver
13	Pedalcyclist Crash With Prior Vehicle Maneuver
14	Pedalcyclist Crash Without Prior Vehicle Maneuver
15	Backing Up Into Another Vehicle
16	Vehicle(s) Turning – Same Direction
17	Vehicle(s) Parking – Same Direction
18	Vehicle(s) Changing Lanes – Same Direction
19	Vehicle(s) Drifting – Same Direction
20	Vehicle(s) Making a Maneuver – Opposite Direction
21	Vehicle(s) Not Making a Maneuver – Opposite Direction
22	Following Vehicle Making a Maneuver
23	Lead Vehicle Accelerating
24	Lead Vehicle Moving at Lower Constant Speed
25	Lead Vehicle Decelerating
26	Lead Vehicle Stopped
27	Left Turn Across Path From Opposite Directions at Signalized Junctions
28	Vehicle Turning Right at Signalized Junctions
29	Left Turn Across Path From Opposite Directions at Non-Signalized Junctions
30	Straight Crossing Paths at Non-Signalized Junctions
31	Vehicle(s) Turning at Non-Signalized Junctions
32	Evasive Action With Prior Vehicle Maneuver
33	Evasive Action Without Prior Vehicle Maneuver
34	Non-Collision Incident
35	Object Crash With Prior Vehicle Maneuver
36	Object Crash Without Prior Vehicle Maneuver
37	Other

- Vehicle Action refers to a vehicle decelerating, accelerating, starting, passing, parking, turning, backing up, changing lanes, merging, and successful corrective action to a previous critical event.
- Vehicle Maneuver denotes passing, parking, turning, changing lanes, merging, and successful corrective action to a previous critical event.

Figure 6: NHTSA’s 37 precrash scenarios

3.2 Scenario Development

Scenario 1- Running a Red Light

***Typical Scenario*:**
Vehicle is going straight in an urban area, in daylight, under clear weather conditions, with a posted speed limit of 35 mph; vehicle then runs a red light, crossing an intersection and colliding with another vehicle crossing the intersection from a lateral direction as shown in figure 7.

***Factor Over-Representation*:**

Urban area, inattention, female driver, and younger and older drivers are over-represented (based on a simple comparison of percentages).

***Dynamic Variations*:**

Vehicle runs a red light while turning left and collides with another straight crossing vehicle from a lateral direction.

***Scenario Severity*:**

The table below quantifies the annual severity of this crash scenario in terms of five different metrics based on 2004 GES statistics. This table also provides the ratios of people involved by maximum injury severity using the KABCO and AIS injury scales. About 1.18 percent of all people involved in this crash scenario suffered high-level MAIS 3+ injuries (serious, severe, critical, or fatal).

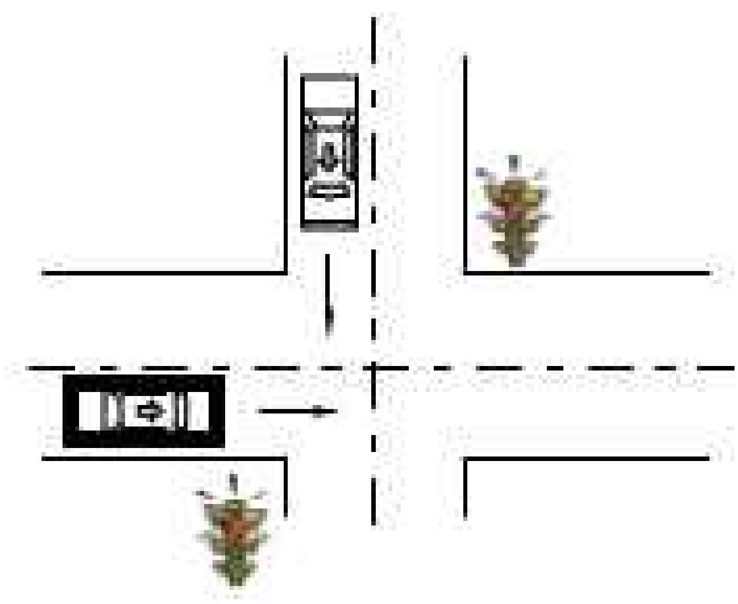

Figure 7: Running a Red Light

Crash Severity		Scenario	Scenario/All
No. of crashes		254,000	4.27%
No. of vehicles involved		528,000	4.94%
No. of people involved		740,000	4.92%
Societal Cost	Economic cost	$6,627,000,000	5.53%
	Functional years lost	135,000	4.87%
KABCO Injury Scale	None	0.726	0.888
	Possible	0.169	1.546
	Non-incapacitating	0.073	1.522
	Incapacitating	0.025	1.283
	Fatal	0.001	0.457
	Unknown	0.006	1.666
	Died prior	-	-
AIS Injury Scale	None	0.709	0.909
	Minor	0.249	1.320
	Moderate	0.030	1.422
	Serious	0.009	1.393
	Severe	0.001	1.366
	Critical	0.001	1.319
	Fatal	0.001	0.453
	Injured people per crash	0.848	1.528

Figure 8: Scenario 1 Severity

Scenario 2 - Vehicle(s) Turning – Vehicles Traveling in Same Direction

***Typical Scenario*:**

Vehicle is turning left at an intersection in an urban area, in daylight, under clear weather conditions, with a posted speed limit of 35 mph; and then cuts across the path of another vehicle initially traveling in the same direction as shown in figure 9.

***Factor Over-Representation*:**

Clear weather, dry road, low-speed road, and younger drivers are over-represented (based on a simple comparison of percentages).

***Dynamic Variations*:**

Vehicle is turning right and cuts across the path of another vehicle initially traveling in the same direction.

***Scenario Severity*:**

The table below quantifies the annual severity of this crash scenario in terms of five different metrics based on 2004 GES statistics. This table also provides the ratios of people involved by maximum injury severity using the KABCO and AIS injury scales. About 0.44 percent of all people involved in this crash scenario suffered high-level MAIS 3+ injuries (serious, severe, critical, or fatal).

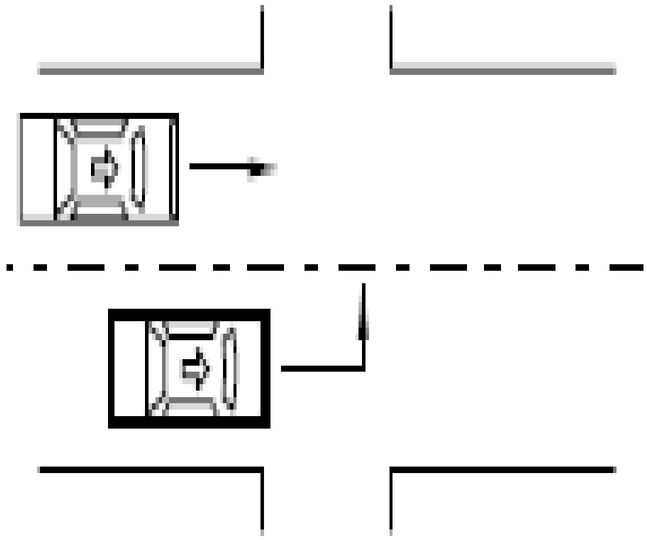

Figure 9: Vehicle(s) Turning – Vehicles Traveling in Same Direction

Crash Severity		Scenario	Scenario/All
No. of crashes		222,000	3.73%
No. of vehicles involved		446,000	4.17%
No. of people involved		641,000	4.26%
Societal Cost	Economic cost	$2,810,000,000	2.34%
	Functional years lost	47,000	1.68%
KABCO Injury Scale	None	0.900	1.100
	Possible	0.066	0.608
	Non-incapacitating	0.023	0.470
	Incapacitating	0.009	0.455
	Fatal	0.0003	0.190
	Unknown	0.002	0.574
	Died prior	-	-
AIS Injury Scale	None	0.846	1.084
	Minor	0.137	0.728
	Moderate	0.012	0.568
	Serious	0.003	0.521
	Severe	0.0004	0.485
	Critical	0.0002	0.465
	Fatal	0.0003	0.189
	Injured people per crash	0.444	0.801

Figure 10: Scenario 2 Severity

Scenario 3 - Straight Crossing Paths at Non-Signalized Junctions

Typical Scenario:

Vehicle stops at a stop sign in an urban area, in daylight, under clear weather conditions, at an intersection with a posted speed limit of 25 mph, and t proceeds against lateral crossing traffic as shown in figure 11.

Factor Over-Representation:

Rural area, low-speed road, vision obscured, female, and younger and older drivers are over-represented (based on a simple comparison of percentages).

Dynamic Variations:

Vehicle is going straight through an uncontrolled intersection and then cuts across the path of another straight crossing vehicle from lateral direction. Another scenario involves both vehicles first stopping and then proceeding on straight crossing paths.

Scenario Severity:

The table below quantifies the annual severity of this crash scenario in terms of five different metrics based on 2004 GES statistics. This table also provides the ratios of people involved by maximum injury severity using the KABCO and AIS injury scales. About 1.21 percent of all people involved in this crash scenario suffered high level MAIS 3+ injuries (serious, severe, critical, or fatal).

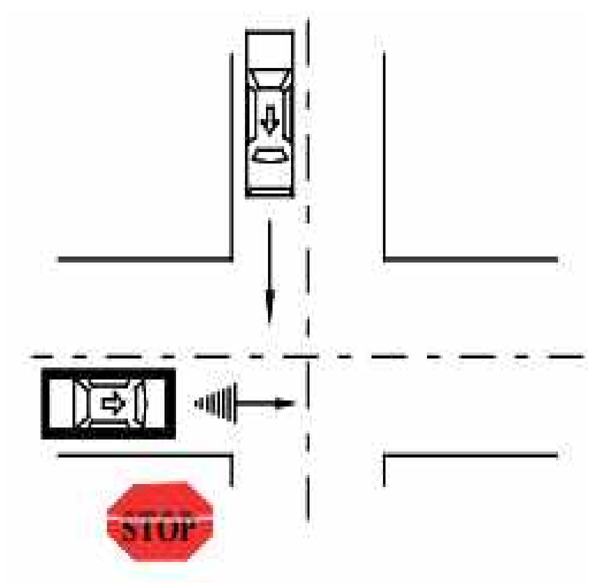

Figure 11: Straight Crossing Paths at Non-Signalized Junction

Crash Severity		Scenario	Scenario/All
No. of crashes		222,000	3.73%
No. of vehicles involved		446,000	4.17%
No. of people involved		641,000	4.26%
Societal Cost	Economic cost	$2,810,000,000	2.34%
	Functional years lost	47,000	1.68%
KABCO Injury Scale	None	0.900	1.100
	Possible	0.066	0.608
	Non-incapacitating	0.023	0.470
	Incapacitating	0.009	0.455
	Fatal	0.0003	0.190
	Unknown	0.002	0.574
	Died prior	-	-
AIS Injury Scale	None	0.846	1.084
	Minor	0.137	0.728
	Moderate	0.012	0.568
	Serious	0.003	0.521
	Severe	0.0004	0.485
	Critical	0.0002	0.465
	Fatal	0.0003	0.189
	Injured people per crash	0.444	0.801

Figure 12: Scenario 3 Severity

Scenario 4 - Vehicle(s) Turning at Non-Signalized Junctions

***Typical Scenario*:**

Vehicle stops at a stop sign in a rural area, in daylight, under clear weather conditions, at an intersection with a posted speed limit of 35 mph; and proceeds to turn left against lateral crossing traffic as shown in figure 13.

***Factor Over-Representation*:**

Rural area, intersection and driveway/alley locations, low-speed road, vision obscured, inattention, female, and younger and older drivers are over-represented (based on a simple comparison of percentages).

***Dynamic Variations*:**

Vehicle stops at a stop sign and then proceeds to turn right against lateral crossing traffic.

***Scenario Severity*:**

The table below quantifies the annual severity of this crash scenario in terms of five different metrics based on 2004 GES statistics. This table also provides the ratios of people involved by maximum injury severity using the KABCO and AIS injury scales. About 0.71 percent of all people involved in this crash scenario suffered high-level MAIS 3+ injuries (serious, severe, critical, or fatal).

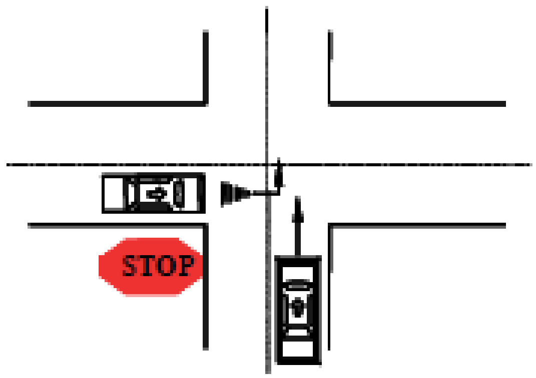

Figure 13: Vehicle(s) Turning at Non-Signalized Junctions

Crash Severity		Scenario	Scenario/All
No. of crashes		435,000	7.32%
No. of vehicles involved		872,000	8.15%
No. of people involved		1,212,000	8.07%
Societal Cost	Economic cost	$7,343,000,000	6.13%
	Functional years lost	138,000	5.00%
KABCO Injury Scale	None	0.843	1.030
	Possible	0.101	0.925
	Non-incapacitating	0.038	0.788
	Incapacitating	0.015	0.778
	Fatal	0.001	0.331
	Unknown	0.003	0.736
	Died prior	-	-
AIS Injury Scale	None	0.801	1.027
	Minor	0.174	0.921
	Moderate	0.018	0.851
	Serious	0.006	0.823
	Severe	0.001	0.790
	Critical	0.0003	0.784
	Fatal	0.001	0.328
	Injured people per crash	0.554	0.998

Figure 14: Scenario 4 Severity

4 RESULTS

4.1 Maps

Carla provides several maps in the form of towns which can be used for creating the scenarios. The town used for the purpose of scenario 1, Running past Red Light is Town 06. Town 6 is a low-density town set into a coniferous landscape exhibiting a multitude of large, 4-6 lane roads and special junctions like the Michigan Left.

Town 6 is part of the additional maps package that should be **downloaded with the CARLA package**. Move the downloaded ZIP file into the ***Import*** folder of the extracted CARLA package then run the ***Import Assets*** script. The road network exhibits 4 large parallel roads with 4 to 6 lanes, interconnected by several slip roads and junctions as shown in figure 15 below.

Figure 15: Town 06 Aerial View

Reference: https://carla.readthedocs.io/en/0.9.10/core_map/

The second and the third scenarios, Vehicle(s) Turning – Vehicles Traveling in Same Direction, and Straight Crossing Paths at Non-Signalized Junctions utilize Town05. Town 5 is an urban environment set into a backdrop of conifer-covered hills with a raised highway and large multilane roads and junctions. The roads consist of numerous dual-lane urban roads intersecting at numerous large junctions. Junctions on each side of the town allow access to a raised highway that serves as a ring road as shown in Figure 16. The town has various features like commercial buildings, a road that extends beneath a commercial building in one location, a car park occupying one city block, the town also has a building under construction.

Figure 16: Town 05 Aerial View

Reference: *https://carla.readthedocs.io/en/0.9.10/core_map/*

The fourth and final scenario, Vehicle(s) Turning at Non-Signalized Junctions uses Town07. Town 7 imitates a quiet rural community, a green landscape filled with cornfields, barns, grain silos and windmills.

Town 7 is part of the additional maps package that should be downloaded with the CARLA package. Move the downloaded ZIP file into the *Import* folder of the extracted CARLA package then run the *Import Assets* script. The road network is small and contains a simple set of junctions and unmarked roads with a couple of residential parking streets as shown in Figure 17. The buildings include wooden barns and farm buildings. There are some structures expected only in rural farming environments like grain silos and windmills. There is also a small body of water spanned by a short road bridge. The some of the roads are lined by corn fields.

Figure 17: Town 07 Aerial View

Reference: https://carla.readthedocs.io/en/0.9.10/core_map/

4.2 **Results of Simulation**

Scenario 1:

Figure 18: Running the red light

Scenario 2:

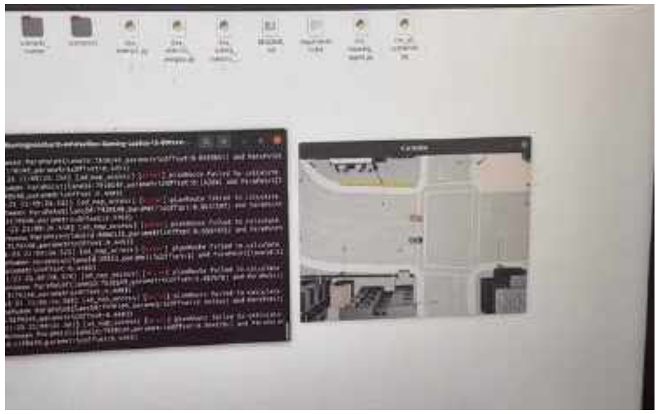

Figure 19: Snapshot of Scenario 2

Scenario 3:

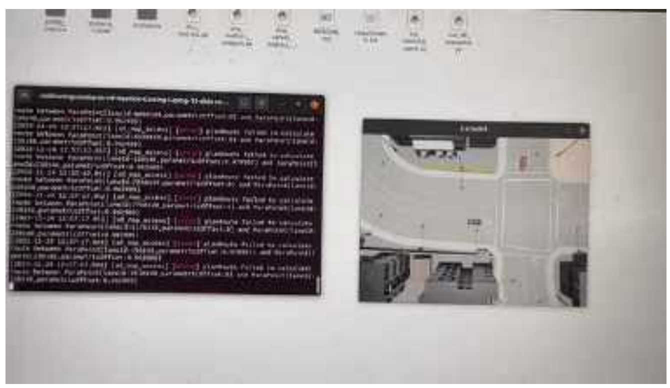

Figure 20: Snapshot of Scenario 3

Scenario 4:

Figure 21: Snapshot of Scenario 4

CHALLENGES

5.1 Issues

- The installation and setup of CARLA and Scenario Runner proved more time-consuming than anticipated due to missing key controller files, like agent.py, misc.py, and J3237 repository files in our onboarding document.

- Configuring paths for CARLA and Scenario Runner folders in the bashrc file was necessary for proper functionality. Locating vehicle coordinates posed challenges as the xodr viewer lacked precise annotation.

- The Ubuntu crash added an additional layer of complexity.

- Dealing with the rss_roaming_agent.py file proved challenging without prior familiarity with its contents.

- Updating graphic drivers is crucial, as errors may arise if not done regularly.

- Furthermore, running scenarios multiple times may lead to crashing of CARLA, highlighting the need for careful execution and debugging.

5.2 Debugging these Issues

- For a seamless setup, it is crucial to ensure the proper installation of Ubuntu, whether it's version 20 or the latest 22, with updated graphic drivers to optimize performance.

- Python version 3.7 is a prerequisite for compatibility.

- Harmonizing versions is key; both CARLA and Scenario Runner should align, and their paths in the bash rc file must be accurate.

- Careful installation of all necessary files, including, .py,. xosc, and others, is paramount before delving into scenario development.

- This meticulous preparation ensures a stable environment, minimizing potential hiccups and ensuring a smooth workflow for effective development and testing

6 CONCLUSIONS

In our journey through the exciting realm of autonomous and automated vehicles, this research project set out to explore the practicality of scenario-based testing. Using the CARLA simulator and Scenario Runner, this project aimed to simulate and analyze how autonomous vehicles

handle real-world challenges outlined by the National Highway Traffic Safety Administration (NHTSA).

This project successfully navigated a variety of scenarios, from dealing with pedestrians and obstacles to interacting with human traffic controllers and other vehicles, all against different road and environmental conditions. Beyond just technical checks, there was a desire to understand how these automated driving systems tackle the subtleties of complex scenarios.

The approach involved blending hardware and software, relying on an HP Pavilion laptop equipped with an Intel Core i5 processor and NVIDIA GEFORCE GTX 1050 graphics card. CARLA, an open-source autonomous driving simulator, and Scenario Runner were the key players in crafting and executing these scenarios.

Integrating Responsibility Sensitive Safety (RSS) added an extra layer of safety, incorporating a mathematical model to ensure safe distances, cutting in, right of way, limited visibility, and avoiding crashes. The XODR Viewer helped gain insights into the maps used in CARLA, providing a clearer understanding of road structures and coordinates.

The project zeroed in on four specific scenarios—Running a Red Light, Vehicles Turning in the Same Direction, Straight Crossing Paths at Non-Signalized Junctions, and Vehicles Turning at Non-Signalized Junctions. The detailed simulations allow to quantify the severity of each scenario.

In essence, this project offers valuable insights into how well autonomous systems handle critical situations. By combining theoretical knowledge with practical simulations, has laid the groundwork for ongoing conversations about the safety and reliability of automated vehicles. The dataset developed isn't just a technical playground; it's a dynamic space for ADS developers to innovate and enhance the safety of autonomous vehicles on our roads.

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