Defensive Driving Efficacy Project Final Report
CS4632: Modeling and Simulation

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Contents

1 Abstract

The goal of my simulation model is a simple and humble one: an answer to the question of *whether defensive driving techniques are effective at reducing damage and injury in automobile accidents.* Everything that is done over the course of this model is to answer that question with a sincere series of trials.

When first beginning the process of creating the simulation model, research was undergone to determine which variables concerning defensive drive efficacy could be practically tested. After research, three variables were decided on: Following Distance (the distance between two traveling vehicles), Vehicle Speed (the velocity of involved vehicles), and Reaction Time (the measure of how long it takes a driver to react if distracted). All of the simulation runs conducted throughout the simulation model reflect the effect each of these variables have on the outcome of an automobile incident with the potential for a collision.

The structure of the simulation model consists of scripts that are used within the BeamNG physics engine to create driving scenarios; **none of these scripts work without BeamNG**. The following Wikipedia article provides a brief description of the program; this article is cited below as Reference 1. These scenarios were carefully constructed to reflect potential driving scenarios that could occur in real life; there's obviously no sense in conducting trials concerning a topic such as defensive driving that would have no real-world parallel. There are two main forms of scripts that were used: *trajectory scripts* and *state scripts*. The *trajectory scripts* are used to guide the vehicles along a specified path, while the *state scripts* are used to load each tested scenario. In addition to these two types of scripts, the simulation model uses a third type of script to load settings for the tool that logs the state of vehicles in each simulation run; this tool generates CSV files that store the data regarding the simulation run.

Overall, the simulation model gathered data that is consistent with the consensus of many different defensive driving resources. Upon data analysis, it was concluded that a larger following distance is indeed effective at preventing a collision, that a more reasonable vehicle speed can reduce the severity of collisions, and that preventing distractions while driving are imperative to the safety of every involved party. These findings agree with the opinions of the vast majority of authorities regarding defensive driving.

2 Introduction

As stated in the previous section, the simulation model seeks to answer *whether defensive driving techniques are effective at reducing damage and injury in automobile accidents.* No conclusions were drawn regarding an answer to this question until the simulation run data was collected and analyzed.

The project to create this model involved many different steps and has taken up a large amount of time over the course of the past semester. The first phase of development included planning the overall structure of the model. At this stage, specifics weren't specified and the general objectives of the project were laid out in a brief manner. After this, extensive research was undergone regarding both the BeamNG engine (the program utilized to conduct the trials) and defensive driving techniques in general. This research determined which variables were to be studied and tested. UML diagrams were created before implementation to give an idea of what the structure of the simulation model should look like. After this, implementation was undergone and proved to be rather difficult at times. The appropriate scripts were created to be used in conjunction with BeamNG and the model began to take shape. Once the implementation was completed, simulation runs were conducted concerning the variables that were to be tested as per the research conducted in the earlier stages of development. This data was then analyzed and conclusions regarding the efficacy were drawn from this analysis to hopefully provide an answer to the question posed by the project. Once this was completed, analysis of the model itself was conducted. Scenario and sensitivity analysis was undergone to ensure that the scenarios selected were appropriate to the objectives laid out by the project and that the variables tested were both practical and tested with a wide range. Finally, in conjunction with the scenario and sensitivity analysis, verification and validation analysis was conducted to ensure that the simulation model was implemented correctly and appropriately.

The motivation for this topic is a personal one and this paragraph can't help being personal; for this reason, please excuse it if it seems a bit informal. My dad has recently gotten his CDL license and has begun to drive semi trucks all over the eastern United States. Throughout the course of his schooling, he's had to learn many different defensive driving techniques since operating an automobile, especially one as grand as a semi truck, can be easily be a deadly affair. I was curious as to how effective these techniques are at protecting individuals that drive for a living for extended periods of time and was hoping that the findings of my simulation could contribute to my dad's safety on the road.

3 Model Overview

This section will give a more in depth overview of the model itself and all of the parts that contribute to its functioning.

3.1 ScriptAI Editor and Trial Scripts

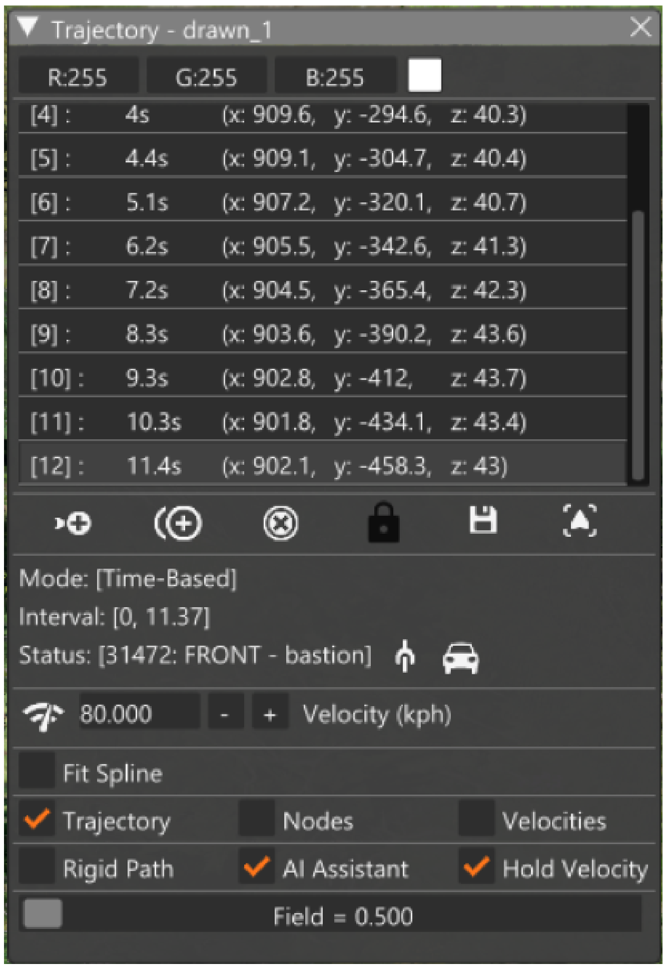
BeamNG includes a tool with its own GUI called the ScriptAI Editor. This tool was used to execute each simulation run and was crucial for modeling each test scenario.

The ScriptAI Editor allows users to create what BeamNG calls *trajectories*. These *trajectories* allow users to place nodes in the in-game world and create a route for the AI drivers to follow. The *trajectories* can either be time-based (the vehicle tries to arrive at each specified node at a particular time interval) or velocity-based (the vehicle moves from node to node while maintaining a specified velocity). The *trajectories* used are time-based; velocity can still be specified (to test the impact of vehicle speed on an accident's outcome) and the time the vehicle is to arrive at each node of the trajectory is altered accordingly. These *trajectories* are saved as JSON files and can be saved and loaded on demand.

This ScriptAI Editor also allows for the creation of *states*. These *states* store information concerning the vehicles involved in each simulation trial and assigns the appropriate *trajectories* to each. These *states* are also saved as JSON files.

Many different scripts were created to execute each tested scenario, each with a difference in the variable being evaluated.

If the reader would like more information regarding BeamNG's ScriptAI editor, the following documentation from the BeamNG website outlines the tool in detail. This documentation is cited in the References section of this report as Reference 2.



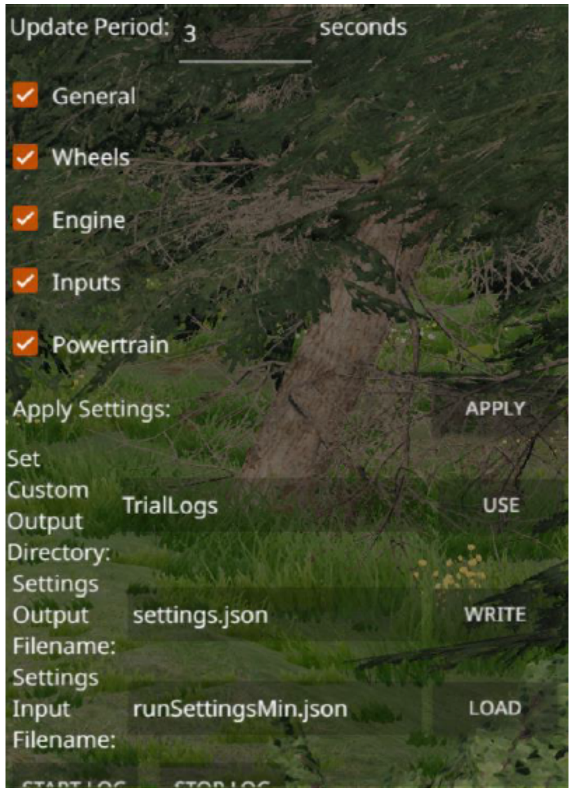
This screenshot, displayed above, shows the GUI for the *trajectories*. It shows the coordinates of each node that the vehicle will travel along and which vehicle it's assigned to. It also allows for the velocity of the trajectory to be adjusted and for the trajectory to be saved to a chosen directory as a JSON file.

The screenshot above shows the GUI that allows for the simulation trial to be executed and allows for the loading and saving of the *states* described previously.

3.2 Data Collection

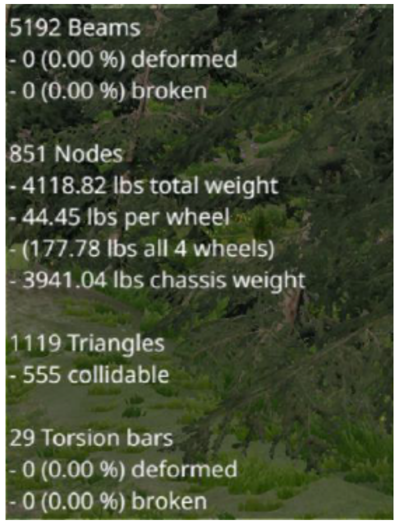
Data was collected in two different ways: through the *Vehicle Stats Logger* included with BeamNG and through the manual recording of the deformation and damage of vehicle "beams" in the simulation run table. The state of these beams are displayed in another tool included in BeamNG called the *Node/Beam Info* HUD. These two data collection methods will be explained in detail in the subsequent paragraphs.

Data collected through the *Vehicle Stats Logger* was collected automatically via a script that ran during each trial. The outputs were recorded to a folder in the repository named TrialLogs; these were later organized for each trial and put into their own folder. These logs are a collection of CSV files, five of them to be exact: Engine, General, Inputs, Powertrain, and Wheels. The Engine CSV stores many different variables related to the state of the vehicle's engine. The General CSV stores general information concerning the vehicle, primarily its location in the BeamNG world at each log and its velocity. The Inputs CSV records the inputs made by the AI in following the trajectory its set to follow in the trial. The Powertrain CSV records information relating to the vehicle's powertrain, including whether it's broken or not. The Wheels CSV stores a LOT of information regarding the wheels of the vehicle, including their velocity and condition. For more information regarding the *Vehicle Stats Logger*, the reader can consult the following documentation from BeamNG; this is referenced below as Reference 3.



The screenshot included above shows the GUI of the *Vehicle Stats Logger*. This GUI allows the output directory of the generated logs to be specified. The data that is logged by the tool is able to be specified by loading a JSON file with the selected parameters.

Nodes, as in many other engines, are used to build the vehicle models that are used in BeamNG and that I use in my simulation trials. "Beams" on the other hand, are rather unique to BeamNG and are in fact where the application gets its name; beams are the connections made between each node of a vehicle model. These beams can be moved and interacted with and are the technology behind how BeamNG handles its collisions. The Beam Node HUD keeps track of every Beam on the vehicle model and collects information regarding whether they're deformed (not in their regular position, indicating some sort of collision), or broken (indicating a more serious collision).

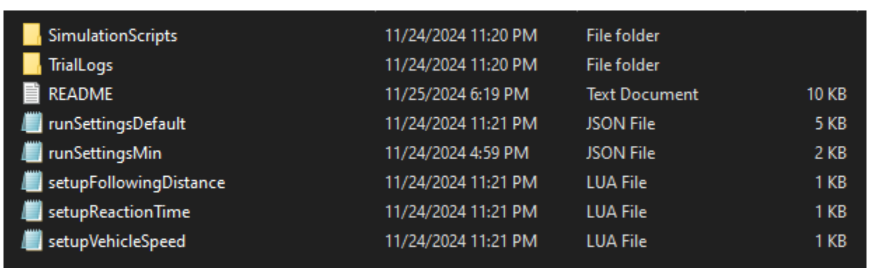


The GUI of the *Node/Beam Info* HUD is shown in the screenshot above. This HUD displays the percentage of deformed or broken beams on the top two lines. These are the percentages that were used to compare the severity of collisions.

By utilizing these two different data collection methods plenty of data was collected for analysis to provide an answer to the model's research question.

3.3 Repository Organization

The repository of the scripts included in the simulation model were stored in a repository with several organized folders.



The image above shows the structure of the repository. The *SimulationScripts* folder contains an organized collection of every script involved in the execution of the simulation runs; there are many more folders within this folder that serve to organize the scripts. The *TrialLogs* folder is the output directory for the CSV files generated by the *Vehicle States Logger* tool utilized in the simulation model. The *README* file provides instructions regarding execution within BeamNG and gives an outline of the structure of the repository itself. The remaining Lua scripts and Json files are used to setup each scenario in BeamNG and load the settings for the *Vehicle Stats Logger*.

The *SimulationScripts* folder deserves a bit more attention. Within this folder, there are three more folders, each named according to the variable it tests: there's a *Following Distance* folder, a *ReactionTime* folder, and a *VehicleSpeed* folder. Within each of these folders, the *trajectory scripts* and the *state scripts* are organized into their own corresponding folder.

4 Simulation Results

The data collected via the two methodologies described in the previous section were organized into an excel spreadsheet. Line graphs were then constructed to show the general trends of the effect each tested variable had on the outcome of each scenario. These results are presented below..

4.1 Results

This section will display the results of the simulation trials in the form of tables and graphs. No discussion or analysis of the results will be included until the next section; this section only intends to display the simulation run results.

The first subsection outlines the simulation run table where data was recorded via the second method outlined in the previous section of this report. The following subsections present the results of each variable's simulation runs in the form of a line graph. The graph shows two different lines that present the damage percentage sustained by each vehicle in relation to the changing, tested variable. These percentages were calculated by finding the average damage reported in all the simulation runs with the specified variable input.

4.1.1 Simulation Run Table

The Simulation Run Table will not be included in this report (for formatting purposes – it's too long and would look awful), but it will be attached with this report if the reader would like to look over the simulation run data in detail. This section will refer to the Run IDs associated with each simulation run and will give a brief overview of the table in its entirety.

The Simulation Run Table gives a brief description of each scenario that was used in the trials. It also describes the parameters of each run. The graphic included below shows the general structure of the table.

Simulation Run Table [Example]	*Modify the table as you see fit.*	Jalen Linville	CS4632, Simulation Trial Table	BeamNG, Defensive Driving Efficacy Project		
Run ID	Objective	Parameters/Configurations	Expected Outcome	Actual Outcome	I'll explain where these percentages come from and what they mean in the	
FOLLOW DISTANCE TESTS	Scenario ->	set distance apart. The front vehicle slams on the brakes after missing a turn. What is the variance in outcome if the following distance of the rear			Front Car Damage	Rear Car Damage
Run 1	Test following distance effect.	Both vehicles travelling at 80KPH with a following distance of 2 meters.	Minor collision due to close following distance.	stop safely; driver would be relatively unharmed.	2.81% deformed; 0.29% broken.	1.44% deformed; 0.00% broken.
Run 2	Test following distance effect.	Both vehicles travelling at 80KPH with a following distance of 2 meters.	Minor collision due to close following distance.	before. Still, the driver would be relatively unharmed.	2.85% deformed; 0.40% broken.	1.56% deformed
Run 3	Test following distance effect.	Both vehicles travelling at 80KPH with a following distance of 2 meters.	Minor collision due to close following distance.	and ran into a tree; major damage to the front of the car.	3.37% deformed; 0.29% broken.	2.00% deformed
Run 4	Test following distance effect.	Both vehicles travelling at 80KPH with a following distance of 6 meters.	Minor collision due to close following distance.	gently bumped into the end of the front car.	3.06% deformed; 0.13% broken.	4.49% deformed
Run 5	Test following distance effect.	Both vehicles travelling at 80KPH with a following distance of 6 meters.	Minor collision due to close following distance.	previous trial; rear car collided with slightly more force.	2.99% deformed; 0.13% broken.	4.37% deformed
Run 6	Test following distance effect.	Both vehicles travelling at 80KPH with a following distance of 6 meters.	Minor collision due to close following distance.	same results as far as damage done to vehicles goes.	3.06% deformed; 0.13% broken.	4.60% deformed; 0.31% broken.

Each run details the objective of the test (in relation to the variable being tested), the parameters, the expected outcome, the actual outcome, and the percentage of damage done to each vehicle involved.

Runs 1 through 24 tested the effect of following distance on the outcome of the scenario. In this scenario, the two vehicles were traveling along a highway when the car in front misses his turn and slams the brakes suddenly. The first half of the simulation runs had each vehicle traveling at 80 KPH and the distance between them was altered. The latter half of these runs had each vehicle traveling at 160 KPH and the distance between them was altered in the same way as before. These runs will be used to analyze the efficacy of leaving a greater distance between you and the vehicle in front of you when driving. I used two different speeds so an analysis could be done of how much more effective a greater following distance is when traveling at a higher speed. The distances tested were 2 meters, 6 meters, 12 meters, and 24 meters; these distances were each tested at least 3 times (same parameters were run 3 times).

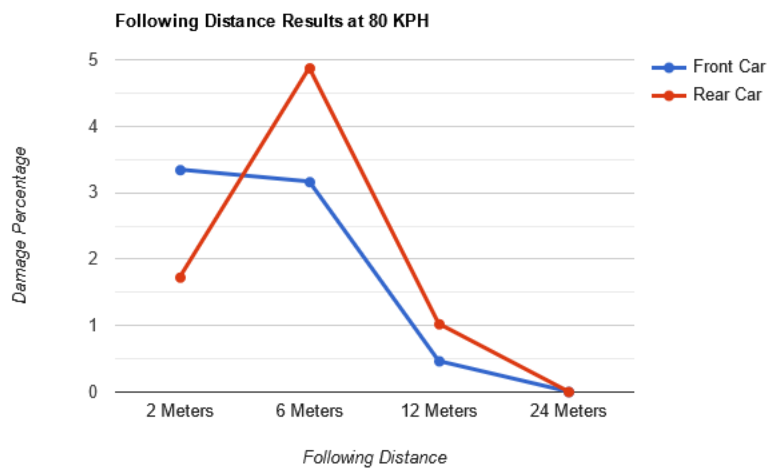
Runs 25 through 44 tested the effect of vehicle speed on the outcome of the scenario. In this scenario, a car merging onto the highway runs a stop sign and pulls out in front of a vehicle traveling along the highway; the only thing that is changed each run is the speed of that highway vehicle. Many different speeds for the highway vehicle were tested: 40 KPH, 60 KPH, 80 KPH, 100 KPH, 120 KPH, and 140 KPH; each of these speeds were tested at least 3 times. The damage done to each vehicle was recorded in the table each time.

The rest of the simulation runs, runs 45 through 80, tested the effect of distractions on the outcome of the scenario. In this scenario, a car is stopped around the corner on the highway. The approaching vehicle was tested with a delay in reaction time. Many different delays in reaction time were tested: 0ms (natural reaction time), 400ms, 800ms, 1600ms, 2400ms, and 3200ms. These reaction times were each tested 3 different times, with 2 different speeds: 80 KPH and 120 KPH. Again, as in the previous runs, the damage done to each vehicle was recorded in the table as a percentage given by BeamNG.

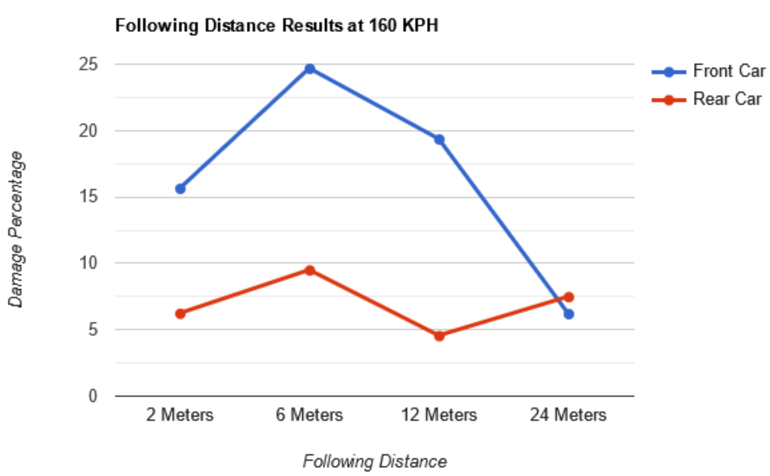
This is just a brief overview of the different runs conducted; the reader is encouraged to look over the attached table if more details are desired.

4.1.2 Following Distance Graphs

The following graphs display the results of the simulation runs concerning variation in following distance.



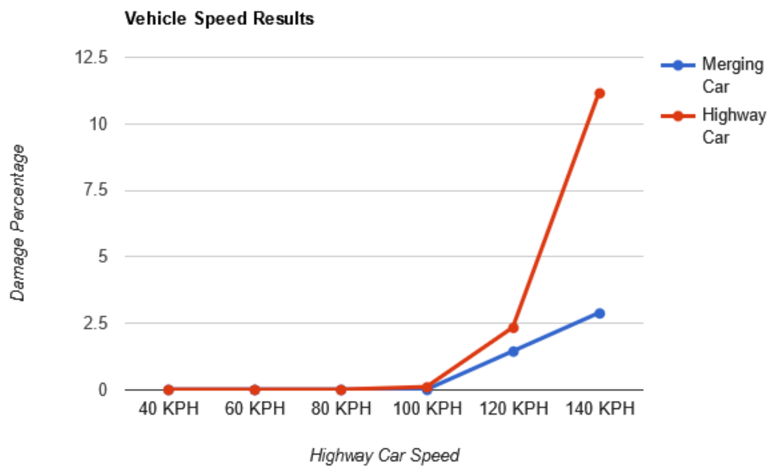
The above graph shows the average damage percentage reported by BeamNG for each of the tested values for the following distance variable with the cars both traveling at 80 KPH.



The graph shown above shows the average damage percentage reported by BeamNG for each of the tested values for the following distance variable with the cars both traveling at 160 KPH. Notice there was still a collision at 24 meters.

4.1.3 Vehicle Speed Graphs

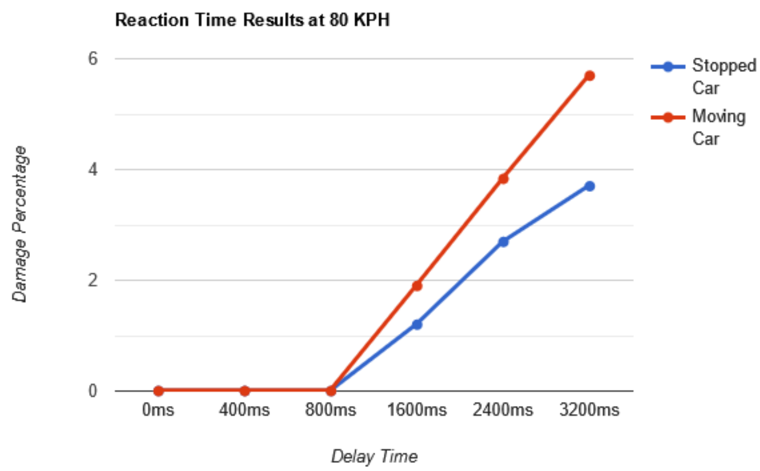
The following graph displays the results of the simulation runs concerning variation in vehicle speed.



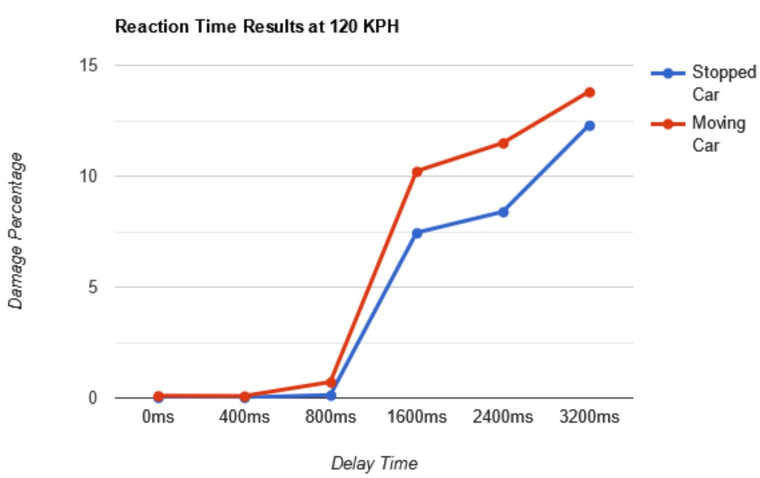
The graph shows the average damage percentage reported by BeamNG for each of the tested values for the vehicle speed variable. Notice the highway car traveling at the varied speeds sustained more damage every time there was a collision.

4.1.4 Reaction Time Graphs

The following graphs display the results of the simulation runs concerning variation in reaction time.



The graph above shows the average damage percentage reported by BeamNG for each of the tested values for the reaction time variable with the moving vehicle traveling at 80 KPH.



The graph shown above displays the average damage percentage reported by BeamNG for each of the tested values for the reaction time variable with the moving vehicle traveling at 120 KPH. Notice the moving car always sustained more damage when a collision occurred.

4.2 Analysis

This section will analyze the results of the simulation runs and discuss the implications these results have as regards the simulation model's research question.

4.2.1 Analysis Approach

In analyzing the data, an approach was taken that helps to provide an answer to the question posed by the model; that is "*Are defensive driving techniques effective at preventing damage and injury in automobile accidents?*" The approach sought to discover a correlation between the changes in the tested variables and the damage done to each vehicle in the trials conducted. If a higher following distance seemed to cause less damage to each vehicle for example, it would seem to suggest that leaving more distance between vehicles, a defensive driving technique, is efficacious. This is a sort of regression analysis: what is the effect each tested variable has (the independent variables) on the damage sustained by the involved parties (the dependent variables).

The number of variables under consideration during analysis was minimized by only changing the tested variables; the trajectories followed by each car for example stayed consistent in each trial. For example, in the vehicle speed tests, the vehicles followed the same paths; only the velocity of the highway vehicle changed. Nearly all of the data analyzed is quantitative. Qualitative aspects may show up, such as the appearance of the vehicles after the incident, but the graphs presented in this report will only include quantitative data.

4.2.2 Discussion

In this section, the results presented in the previous section will be discussed according to the approach considered above.

First, the following distance tests.

The general trend in these tests was that the larger the following distance, the less catastrophic the automobile incident. This would seem to suggest that leaving more space between your vehicle and the next (i.e., a larger following distance) is indeed an effective defensive driving technique. This seems to be especially true at higher speeds. If we compare the tests conducted at 80 KPH to the 160 KPH tests, the reported damage percentages are MUCH higher. At a lower speed, such as 80 KPH (about 50 MPH), a large following distance seems to be effective at preventing a collision altogether; note the 0% damage reported by BOTH the front car and the rear car. This is not the case at the higher speed of 160 KPH (about 100 MPH), though the sustained damage does seem to be reduced. The only odd trend in any of the following distance trial graphs is the rear car, traveling at 160 KPH. For some reason, the larger following distance proved to be more detrimental.

Note that there is an interesting trend, where the 2-meter tests result in less sustained damage than the 6-meter tests. It's possible this is due to human error when creating the tests, but I would like to point out that the collision went rather differently when the cars were closer together and that this could indicate the difference. In the 2-meter test, the rear car bumped the front car each time and sort of drafted behind it like race cars do when they both were coming to a stop. In the 6-meter test however, there was enough space between them for the collision to be a direct collision; the speed of the two vehicles was much more different when colliding in the 6-meter test as compared to the 2-meter test. Hopefully this sheds some light on why the graphs of the following distance tests look the way they do.

Another interesting fact presented by the data is that at higher speeds, the front vehicle sustains much more damage than the rear car. At 80 KPH the damage sustained by each vehicle involved was rather similar. At 160 KPH however, the front car underwent much more damage, especially concerning the 6 meter test.

In short, leaving a greater following distance when driving seems to be effective at reducing fatal outcomes in scenarios where automobile accidents are possible.

Next, the vehicle speed tests.

At lower speeds, a collision was able to be prevented altogether. Once the highway vehicle began to move at higher speeds though, there was a collision. This is what leads to the drastic uptick in damage reported, both to the merging car AND the highway car. One interesting thing to note is that the damage sustained by the highway car is MUCH higher than the merging car. Even though, in this scenario, the accident may be the fault of the merging driver that ignored the stop sign, driving at a lower speed could save the life of the driver that isn't at fault. When the highway driver was driving at 140 KPH, attempting to hit the brakes at all ended up leading to a catastrophic result.

Notice that neither vehicle really sustained damage until the highway vehicle was traveling at around 100 KPH (about 62 MPH). This seems to be the speed at which the driver is unable to prevent some sort of collision, even if it is a minor one. When traveling at 140 KPH, the outcome was much more catastrophic for the highway car; the highway driver suffered nearly 4 times as much damage to their vehicle, suggesting the driver would be in a far worse condition than the driver of the merging vehicle.

In conclusion, reducing vehicle speed seems to be effective at preventing a terrible outcome in situations where an automobile accident is possible.

Finally, the results of the reaction time tests.

At both speeds, whether the moving car was traveling at 80 KPH or 120 KPH, the driver was able to prevent a collision when not distracted. In the 0ms trials, the driver simply hits the brakes at approximately the natural reaction time of a human. These parameters assume the driver is watching the road the entire time. This is a logical outcome and would be assumed; clearly the driver should be paying attention to the road the entire time.

In the next two trials, a delay is added to the reaction time of the driver, albeit a delay of less than a second in both cases. The 400ms delay didn't prevent the driver from stopping in time at either speed. However, with an 800ms delay in response time, something interesting occurs. In the trials where the driver is traveling at 80 KPH he is still able to brake in time to avoid a collision; when traveling at 120 KPH however, that 800ms delay is enough to cause a collision. This seems to suggest that driving without distraction is even more important at higher speeds.

At both speeds, however, a collision occurred with a delay in reaction of 1.6 seconds. The damage sustained by both parties was much more severe when traveling at 120 KPH as opposed to 80 KPH. This seems to correlate with the vehicle speed tests, though the point of the different speeds here was to notice changes between how important eliminating distractions was at a lower speed as compared to a higher speed.

With the 2.4 second and 3.2 second delay, a moderate collision occurred when the highway vehicle was traveling at 80 KPH. The moving car sustained a bit more damage than the stopped car, but it was at least comparable. At 80 KPH, the delay didn't prevent the driver from being able to brake for at least a short time before colliding. In the 120 KPH scenario however, with these longer delays in reaction time, the driver hardly got a chance to brake. For example, in the 3.2 second delay scenario, with the highway vehicle traveling at 120 KPH, the driver basically only got the chance to tap the brakes. The collision that occurred was very nearly full speed, hence the much higher damage percentages.

To sum up the results of the reaction time tests, it seems that preventing distractions while driving is a very effective way of preventing automobile accidents. It also seems that the higher the travel speed, the more effective it will be at preventing a catastrophic outcome.

5 Scenario and Sensitivity Analysis

5.1 Scenario Analysis

In analyzing the scenarios of the simulation model, this section will first establish why the tested scenarios were chosen in the first place and how they correspond to real-world situations pertinent to satisfying the goals of the simulation model. The simulation model contained three different scenarios - one for each tested variable - and each were structured to be practical; the variables were then varied in each scenario to measure the effect of each variable. After justifying the tested scenarios, an optimistic scenario and a pessimistic scenario based on the original scenarios will be outlined and the effects on the dependent variables gathered in my simulation model (the percentage of damage to vehicles involved and the output logs of each vehicle) will be presented.

5.1.1 Following Distance Scenario and Alternatives

First, the original following distance scenario will be outlined and justified as to why it was used to test the effect of the following distance variable.

The scenario involves two vehicles traveling on the highway in one of the maps provided with BeamNG. In this scenario, the only thing that changes is the distance between the two vehicles; this is why this is the scenario used to test the effect of follow distance. While the two cars are traveling, the front car, upon arriving at an intersection, realizes they've missed their turn and slams on the brakes in an effort to make the turn. The rear car then slams on the brakes. The outcome is determined by how much distance there was between the two vehicles. Will the rear car be able to stop in time to prevent a collision? Clearly, this scenario could be applicable to real life. I didn't want my simulation to provide data that was so abstract it couldn't be applied to real-world driving simulations. It isn't hard to imagine something similar occurring in someone's daily commute.

The first alternative scenario will be the "optimistic" one and will involve the front car actually managing to make the turn.

The second scenario will be the "pessimistic" one and will involve the rear car not even attempting to stop for the front car.

The results of these two scenarios will be compared with the original in the results section below.

5.1.2 Vehicle Speed Scenario and Alternatives

Before discussing the alternative scenarios that were tested, the original scenario will be outlined and justified.

In the vehicle speed scenario, one vehicle is traveling down the highway towards an intersection. Another vehicle, at the same time, is making its way from a different direction to that same intersection. The intersection has a stop sign that the second car should stop at before attempting to merge onto the highway. In this scenario, the merging vehicle doesn't stop at the stop sign and tries to merge onto the highway immediately. The only thing that changes in this scenario is the speed of the highway vehicle. If the highway vehicle is traveling at a high speed, does the driver have enough time to prevent a collision with the merging vehicle? The scenario could easily occur in the real-world; people ignore stop signs often enough.

The first alternative scenario will be the "optimistic" one and will involve the merging car actually making a stop at the stop sign.

The second scenario will be the "pessimistic" one and will involve the rear car not even attempting to stop for the merging car.

The results of these two scenarios will be compared with the original in the corresponding results section below.

5.1.3 Reaction Time Scenario and Alternatives

As with the other two scenarios, the original reaction time scenario will be explained and justified before moving to the alternative scenarios.

The reaction time scenario consists of two vehicles. One is stopped around a corner on a highway. The other vehicle is approaching at a set speed and doesn't hit the brakes until the driver would actually spot the stopped vehicle in the real world. An artificial delay is added to the time the driver hits the brakes and this is the only parameter that changes for the scenario. This was used to determine the effect a distraction of whatever specified time has on the outcome of an automobile accident. It isn't hard to imagine that a driver could be distracted from looking at the road for a period of time; I see it daily. The actual reason for the distraction in this scenario doesn't really matter; the time the driver brakes is just delayed. Perhaps the driver is looking at his phone, texting, messing with the glove box, etc. It doesn't really matter WHY the distraction is happening; only the practical effects of it, the delay in response time, is what effects the outcome.

The reaction time scenario consists of two vehicles. One is stopped around a corner on a highway. The other vehicle is approaching at a set speed and doesn't hit the brakes until the driver would actually spot the stopped vehicle in the real world. An artificial delay is added to the time the driver hits the brakes and this is the only parameter that changes for the scenario. This was used to determine the effect a distraction of whatever specified time has on the outcome of an automobile accident. It isn't hard to imagine that a driver could be distracted from looking at the road for a period of time; I see it daily. The actual reason for the distraction in this scenario doesn't really matter; the time the driver brakes is just delayed. Perhaps the driver is looking at his phone, texting, messing with the glove box, etc. It doesn't really matter WHY the distraction is happening; only the practical effects of it, the delay in response time, is what effects the outcome.

The first alternative scenario will be the "optimistic" one and will involve the stopped car attempting to move out of the way of the oncoming car.

The second scenario will be the "pessimistic" one and will involve the moving car not even attempting to stop for the stopped car.

The effect of these two scenarios on the tested variable will be compared with the original below.

5.1.4 Following Distance Scenario Results and Discussion

Following Distance Scenarios

SCENARIO	Original Output	Optimistic Output	Pessimistic Output
Run 1	1.64	0.00	9.53
Run 2	1.60	0.00	9.72
Run 3	1.47	0.00	9.78
Run 4	1.64	0.00	9.47
Run 5	1.57	0.00	9.42

This table compares the outputs of the two alternative scenarios to the original one used in testing.

The optimistic scenario in this case prevented a collision every time. The car made its turn and there was enough distance between it and the rear car to prevent an accident.

The pessimistic scenario was rather catastrophic each time however and despite the lower speed used in this scenario, a direct collision resulted each time.

In testing the different following distance scenarios, the original scenario performed as it did when conducting the original simulation runs. Damage outputs were rather consistent and suggest that a higher following distance contributes to less damage reported.

The optimistic scenario, as per the table provided, prevented a collision in every case. The front car managed to make the turn and no collision occurred, whether the following distance was 2 meters, 6 meters, 12 meters, or 24 meters.

The pessimistic scenario had a much higher damage output however, since the rear vehicle collided with the front at near full speed.

The original scenario does a better job of testing how much impact following distance has on the outcome of an automobile accident but the two alternative scenarios were good to test simply because they could easily occur in real life.

5.1.5 Vehicle Speed Scenario Results and Discussion

Vehicle Speed Scenarios

SCENARIO	Original Output	Optimistic Output	Pessimistic Output
Run 1	4.47	0.00	13.37
Run 2	3.78	0.00	12.64
Run 3	4.32	0.00	12.94
Run 4	4.51	0.00	14.03
Run 5	3.92	0.00	13.46

This table compares the outputs of the two alternative scenarios to the original one used in testing.

The optimistic scenario in this case prevented a collision every time. The merging car stopped and let the highway car pass.

The pessimistic scenario resulted in much more damage to both vehicles however. The highway car collided with the merging car at practically full speed.

The results of the different vehicle speed scenarios were similar to the following distance scenarios.

In the case of the original scenario, the damage outputs were consistent with that of the original simulation runs. There was some variance so a few trials were conducted but they all returned numbers within a practical range.

The optimistic scenario prevented a collision each time. This scenario could easily occur in real life, as most of the time, vehicles come to a stop before merging onto a highway. The damage outputs were the same every time the scenario was executed.

As in the case of the following distance pessimistic scenario, the pessimistic vehicle speed scenario contributed to a much higher damage percentage reported. This scenario also helps to display the importance of reducing vehicle speed when it comes to reducing the damage displayed in automobile accidents. If the vehicle speed was lowered, there would be less damage reported even if the driver didn't apply the brakes, as in this scenario.

5.1.6 Reaction Time Scenario Results and Discussion

Reaction Time Scenarios

SCENARIO	Original Output	Optimistic Output	Pessimistic Output
Run 1	17.74	5.31	22.31
Run 2	16.39	6.54	21.42
Run 3	17.56	5.92	21.89
Run 4	17.24	5.39	21.66
Run 5	16.91	5.77	22.04

This table compares the outputs of the two alternative scenarios to the original one used in testing.

The optimistic scenario in this case still resulted in a collision but due to the stopped car trying to make an effort to get out of the path of the moving car, the damage output was considerably less. This is definitely a good alternative scenario as it's likely the driver of the stopped car would attempt to do such a thing in real life.

The pessimistic scenario resulted in a higher damage output, as would be expected. This outcome could be the case if the driver of the moving car was distracted and not even watching the road upon coming around the corner.

The reaction time alternative scenarios were different compared with the rest, since there was a collision in every single outcome.

The original scenario performed near exactly as it did when conducting the original simulation runs. The damage outputs were similar when the total damage of both vehicles is accounted for.

The optimistic scenario, unlike the optimistic scenarios for the following distance and vehicle speed variables, did not completely prevent a collision. However, due to the effort of the stopped vehicle's driver, the damage output was considerably less. In a real world situation, the action on the part of the stopped vehicle's driver could easily have saved both drivers lives. This alternative scenario was a fantastic one simply because it is highly likely the stopped car would undergo such a maneuver to prevent an accident.

The pessimistic scenario performed similarly to the other pessimistic alternative scenarios; the damage output was much higher due to the highway car's lack of a response to the stopped vehicle.

The optimistic scenario is especially important in regards to reaction time, since the reaction time of the stopped car's driver in moving out of the way could be taken into account. This scenario tested in conjunction with the original scenario could provide a more definitive answer as to whether minimizing distractions is truly an effective defensive driving technique.

5.2 Sensitivity Analysis

The tested variables that were analyzed: following distance, vehicle speed, and reaction time. These are the variables that were tested in the simulation model. This section will outline the extent to which changes in these variables affect the dependent variable (the percentage of damage sustained by vehicles in the simulation).

All the variables were measured in comparison to the outcome variable; in the case of my simulation model, this is the damage percentages supplied by the *Node/Beam Info* display. They were also compared by the amount of time elapsed; that is, the amount of time it took to complete the simulation trial. For vehicle speed this was especially prevalent.

My method of analysis only tested one parameter at a time; that is, a local sensitivity analysis was conducted. In the case of the following distance sensitivity tests, only following distance was altered. In the case of the vehicle speed sensitivity tests, only the vehicle speed was altered. In the case of the reaction time sensitivity tests, only the reaction time was altered. This helped ensure the differences in results were actually based on the desired parameter.

5.2.1 Following Distance

The first tests conducted to determine the effects of altering the following distance consisted of testing the extremes.

First, a following distance of 0 was tested; that is, no space at all between the vehicles. Second, a negative following distance was tested; that is, the vehicles started in the same exact spot. Third, an absurdly high following distance was tested; that is, something far above the maximum 24 meters that was tested during the original simulation runs. These were done by altering the starting position of the rear car in the following distance scenario.

After these extreme tests, tests were conducted that slightly vary the following distance based on some baseline. A baseline of 10 meters was selected; the variable was then tested when altered 10% and 20% in either direction.

5.2.2 Vehicle Speed

The first tests conducted concerning the vehicle speed involved the extremes, as with the following distance.

First, a velocity of 0 KPH was tested. Second, an absurdly low velocity, 10 KPH, was tested. Third, an absurdly high velocity was tested. These were done by altering the velocity of the trajectory within BeamNG in the vehicle speed scenario.

After these extreme cases were tested, tests were conducted that varied the vehicle speed as compared to some base line value. A base line of 120 KPH was used; this was altered 10% and 20% in either direction.

5.2.3 Reaction Time

Like the previous two variables, the first tests conducted concerning reaction time dealt with the extremes.

First, an inhuman reaction time was tested; the driver reacted before even seeing the stopped vehicle. Second, an absurdly long reaction time, 30 seconds, was tested. These were conducted by altering when the moving car uses its brakes within BeamNG in the reaction time scenario.

After these two extreme cases were tested, a base line value was selected and then altered 10% and 20% in either direction. The base time reaction was 1.6 seconds.

5.2.4 Following Distance Sensitivity Results

Following Distance Sensitivity

Original Output	Output	Time
-20%	1.95	11.93sec
-10%	1.78	12.02sec
0%	1.62	12.14sec
+10%	1.31	12.21sec
+20%	1.16	12.31sec

This table shows the trend of the effect of following distance on the percentage damage output of both vehicles and the impact on the time the simulation trial took to run.

All of the outputs are within the same range and the effect on the time of the trial is minimal.

In the case of the tested extremes, the 0 meter test's output was similar to the 2 meter test's output that was originally conducted. The absurdly large following distance had the obvious results; the two vehicles didn't even come close to colliding and there wasn't any damage to any vehicle involved. The negative follow distance broke BeamNG; the two vehicles clipped inside one another and the trial couldn't complete.

As can be seen in the table provided, there is a clear trend towards increased damage to both vehicles if the follow distance decreases. The time it takes to complete the trial also reduces a bit since the vehicles start a bit closer together. In the opposite direction, there is a related correlation; as the follow distance increases, there is a trend towards less damage to each vehicle. The time also trends in the opposite direction as before, with the trial taking a bit longer since the rear car has a bit more ground to cover.

When compared with the other tested variables, the following distance variable is much less sensitive. Vehicle speed changed the damage output much more than following distance, especially since the following distance was only changed by a minimal amount in either direction.

5.2.5 Vehicle Speed Sensitivity Results

Vehicle Speed Sensitivity

Parameter Variation	Output	Time
-20%	0.21	10.84sec
-10%	1.79	9.90sec
0%	3.97	9.11sec
+10%	8.35	8.45sec
+20%	9.04	7.88sec

This table shows the trend of the effect of vehicle speed on the percentage damage output of both vehicles and the impact on the time the simulation trial took to run.

The outputs here vary widely and decreasing the vehicle speed increases the time the trial takes by a fair margin, while increasing the vehicle speed decreases the time the trial takes by a moderate amount.

In the case of the tested extremes, a speed of 0 KPH caused the vehicles to just sit there, as would be expected; no collision occurred of course. The test with a vehicle speed of 10 KPH took much longer to complete and didn't result in any collision, as to be expected; the driver had plenty of time to come to a stop and avoid a collision. A speed of 200 KPH was actually rather similar to the highest speed tested previously, 140 KPH, because the vehicle only had so much time to accelerate. It couldn't reach a speed of 200 KPH before colliding with the merging vehicle.

The table provided above displays the average outputs of several different runs concerning variation in the vehicle speed variable.

This variable is clearly very sensitive. Just slight changes in either direction made a heavy impact on both the damage output given by BeamNG and the time it took for the trial to conclude.

The conclusions to be drawn from this are extremely practical; reducing your driving speed could save your life. Driving at a high speed could make it much harder to prevent an accident in a real driving scenario.

5.2.6 Reaction Time Sensitivity Results

Reaction Time Sensitivity

Parameter Variation	Output	Time
-20%	15.73	5.93sec
-10%	17.49	6.67sec
0%	18.35	7.40sec
+10%	19.53	8.14sec
+20%	20.96	8.88sec

This table shows the trend of the effect of reaction time on the percentage damage output of both vehicles and the impact on the time the simulation trial took to run.

The damage outputs here are pretty similar in either direction. Not nearly as much variance as compared to the vehicle speed variable.

In the case of the extremes, the negative reaction time caused there to be no collision; it wasn't even close. The extremely high reaction time, 30 seconds, was surprisingly similar to the 3.2 second delay tested previously because the driver didn't even get a chance to really use the brakes in both; there was a bit more damage to each vehicle with the 30 second delay.

The table included above displays the average outputs for many different runs dealing with variation in reaction time.

This variable is more sensitive to changes than the following distance but not nearly as sensitive as the vehicle speed. Nonetheless, the trend suggests that reducing distractions, thereby mitigating reaction delays while driving, would contribute to less damage to vehicles and persons involved.

The time variable tracked in this case is the time it took for the highway vehicle in the reaction time scenario to apply the brakes. The reaction time has a direct impact on this. If the reaction time is shorter, there is less damage reported and the time is shorter. Vice versa, if the reaction time is longer, there is more damage reported and the time is longer.

6 Verification and Validation Analysis

6.1 Verification

The verification process was undergone to ensure that the simulation model was implemented correctly. This involved checking for coding errors and logical errors present in the simulation model.

There are several different methods of verification but not all of them were relevant to the simulation model. This section will briefly outline which common methods of verification were utilized and which were not.

Unit Testing is a means of verification that was **not** utilized. This is because in the simulation model, none of the individual Lua scripts and JSON files are even intended to work in isolation. They must all be used within BeamNG and with tools provided by the BeamNG engine; testing to see whether they run outside of BeamNG would've been nonsensical.

Integration Testing involves testing how well the various integrated components of the simulation work together. This form of verification was utilized. The tests checked to make sure the trajectory JSON files worked with the state JSON files to correctly load each scenario.

Regression Testing is a method that ensures that recent changes to the simulation model's implementation haven't interfered with any of the existing functionalities. The conducted tests checked to make sure that newly added Lua scripts and JSON files didn't interfere with the function of the older scripts and files.

Edge Case Testing involves testing the simulation model with extreme parameter conditions to check for any unexpected results. Each simulation trial was run with extreme values, either very low or very high, to ensure that the simulation model functioned as expected.

Code Review involves conducting a review of the code that makes up the simulation model to check for syntax errors and logical flaws. This was conducted and documented.

Finally, a review of version control best practices was **not** necessary as no version control was used to manage the repository.

6.1.1 Integration Testing

The integration tests made sure that each JSON file containing simulation states (these are loaded to conduct each different trial) used the correct trajectory scripts. Each state file was loaded in BeamNG and the trajectories were checked to confirm whether they were the correct scripts or not. The tables for these tests are provided below.

First, the following distance state JSON files were tested.

Test Case ID	IT01
Description	Determine whether following distance trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "80K_2M-SEDANS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT02
Description	Determine whether following distance trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "80K_6M-SEDANS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT03
Description	Determine whether following distance trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "80K_12M-SEDANS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT04
Description	Determine whether following distance trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "80K_24M-SEDANS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Next, the vehicle speed state JSON files were tested.

Test Case ID	IT05
Description	Determine whether vehicle speed trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "40K-SEDANS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT06
Description	Determine whether vehicle speed trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "60K-SEDANS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT07
Description	Determine whether vehicle speed trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "80K-SEDANS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT08
Description	Determine whether vehicle speed trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "100K-SEDANS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT09
Description	Determine whether vehicle speed trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "120K-SEDANS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT10
Description	Determine whether vehicle speed trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "140K-SEDANS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT11
Description	Determine whether vehicle speed trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "160K-SEDANS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Finally, the reaction time state JSON files were tested.

Test Case ID	IT12
Description	Determine whether reaction time trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "80K_0MS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT13
Description	Determine whether reaction time trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "80K_400MS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT14
Description	Determine whether reaction time trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "80K_800MS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT15
Description	Determine whether reaction time trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "80K_1600MS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT16
Description	Determine whether reaction time trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "80K_2400MS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT17
Description	Determine whether reaction time trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "80K_3200MS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT18
Description	Determine whether reaction time trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "120K_0MS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT19
Description	Determine whether reaction time trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "120K_400MS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT20
Description	Determine whether reaction time trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "120K_800MS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT21
Description	Determine whether reaction time trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "120K_1600MS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT22
Description	Determine whether reaction time trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "120K_2400MS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

Test Case ID	IT23
Description	Determine whether reaction time trial "state" scripts are properly integrated with the appropriate "trajectory" scripts
Input	Load "120K_3200MS" JSON file from repository.
Expected Result	BeamNG should load the corresponding trajectories to the ScriptAI editor.
Actual Result	The correct trajectories were loaded.
Status	PASS

As is evident by the provided test tables, the state files are properly integrated with the trajectory files. The trials function as intended.

6.1.2 Regression Testing

The following distance scripts were among the first scripts created for the project. Regression testing consisted of running new scripts and conducting tests and then making sure that the older scripts - the following distance trial scripts - still function as expected.

1. The reaction time trial with a speed of 80 KPH and a delay of 1600ms was run. Then, after this, the following distance trial with a speed of 80 KPH and a following distance of 2 meters was loaded. The scripts were loaded correctly and the trial went as expected.

2. The reaction time trial with a speed of 160 KPH and a delay of 2400ms was run. Then, after this, the following distance trial with a speed of 80 KPH and a following distance of 6 meters was loaded. The scripts were loaded correctly and the trial went as expected.

3. The vehicle speed trial with a speed of 120 KPH was run. Then, after this, the following distance trial with a speed of 80 KPH and a following distance of 12 meters was loaded. The scripts were loaded correctly and the trial went as expected.

4. The vehicle speed trial with a speed of 40 KPH was run. Then, after this, the following distance trial with a speed of 80 KPH and a following distance of 24 meters was loaded. The scripts were loaded correctly and the trial went as expected.

The earliest created trials still performed correctly despite there being many more scripts in the repository.

6.1.3 Edge Case Testing

Each variable that was intended to be tested by the simulation model underwent edge case testing. This included **following distance**, **vehicle speed**, and **reaction time**. Concerning these tests, an error margin of 10% was acceptable (as compared to the expected result); this is comparable to the variance of the damage outputs in the trials that were conducted initially. A 10% difference in the total damage output meant a similar outcome occurred in the simulation trial. This is simply due to the nature of the BeamNG engine.

Following Distance The following distance edge case tests tested the extreme cases regarding the following distance variable. There were two tests conducted: one with a following distance of 0 meters, and another with a following distance of 200 meters. The tables for the tests are supplied below.

The extreme minimum was tested multiple times to ensure reliability. There was some variance in total damage output allowed here; even if the total damage percentage was a bit different, the trial played out very similarly each time.

Test Case ID	EC01
Description	Test extreme minimum for the follow distance parameter.
Input	Following distance of 0 meters.
Expected Result	Similar output to the 2 meter trials performed previously. Expected total damage output (both vehicles) of around 4.5%.
Actual Result	Vehicles spawned very close to one another. Collision occurred in trial. Total damage output of 4.39%.
Status	PASS

Test Case ID	EC02
Description	Test extreme minimum for the follow distance parameter.
Input	Following distance of 0 meters.
Expected Result	Similar output to the 2 meter trials performed previously. Expected total damage output (both vehicles) of around 4.5%.
Actual Result	Vehicles spawned very close to one another. Collision occurred in trial. Total damage output of 4.63%.
Status	PASS

Test Case ID	EC03
Description	Test extreme minimum for the follow distance parameter.
Input	Following distance of 0 meters.
Expected Result	Similar output to the 2 meter trials performed previously. Expected total damage output (both vehicles) of around 4.5%.
Actual Result	Vehicles spawned very close to one another. Collision occurred in trial. Total damage output of 4.57%.
Status	PASS

The extreme maximum was only tested once. There was no way the rear car would ever come near to a collision due to the large space between the vehicles.

Test Case ID	EC04
Description	Test extreme maximum for the follow distance parameter.
Input	Following distance of 200 meters.
Expected Result	No collision will occur in trial. The rear vehicle won't even come close to the front. Total damage output of 0.00%.
Actual Result	No collision; the rear car had PLENTY of space between it and the front car. Total damage output of 0.00%.
Status	PASS

Vehicle Speed The vehicle speed edge case tests tested the extreme cases regarding the vehicle speed variable. There were three tests conducted: one with a vehicle speed of 0 KPH, one with an absurdly slow vehicle speed, and a third with an extremely high vehicle speed. The tables for these tests are supplied below.

The vehicle speed of 0 KPH was only tested once; it was clear that the result would be the same every time the trial was conducted with a speed of 0 KPH.

Test Case ID	EC05
Description	Test velocity of 0 in vehicle speed scenario.
Input	Vehicle speed (velocity) of 0 KPH.
Expected Result	The vehicles in the simulation will just sit there. Nothing will happen.
Actual Result	Exactly as expected. If the given speed is 0 KPH, nothing happens. The trajectory files are still loaded, but the cars can't move along them.
Status	PASS

A test with an extreme minimum of 0.1 KPH was conducted. As it says in the "Actual Result" section of the table below, I ended the trial and tested with a new, *less extreme*, extreme minimum.

Test Case ID	EC06
Description	Text extreme minimum for the vehicle speed parameter.
Input	Vehicle speed (velocity) of 0.1 KPH.
Expected Result	The simulation will take an absurdly long amount of time to execute. There won't be a collision since it'll be easy for the rear car to brake.
Actual Result	The length of the trial was estimated to be 10914.3 seconds by the BeamNG ScriptAI Editor; ended the trial early (because I didn't want to wait 3 hours) and decided to try a less extreme minimum.
Status	FAIL?

Another extreme minimum test was conducted, this time using 10 KPH (about 6.2 MPH).

Test Case ID	EC07
Description	Text extreme minimum for the vehicle speed parameter.
Input	Vehicle speed (velocity) of 10 KPH (about 6.2 MPH).
Expected Result	The simulation will take a long amount of time to execute. There won't be a collision since it'll be easy for the highway car to brake.
Actual Result	It took 93.77 seconds for the trial to finish executing due to the low vehicle speed. There wasn't a collision of course. Total damage output of 0.00%.
Status	PASS

Three extreme maximum tests were conducted, all with a vehicle speed of 200 KPH.

Test Case ID	EC08
Description	Text extreme maximum for the vehicle speed parameter.
Input	Vehicle speed (velocity) of 200 KPH.
Expected Result	Total damage output exceeding that of the previously conducted trials with a vehicle speed of 140 KPH (average total damage output of around 14.50%.
Actual Result	Severe collision. Total damage output of 20.46%.
Status	PASS

Test Case ID	EC09
Description	Text extreme maximum for the vehicle speed parameter.
Input	Vehicle speed (velocity) of 200 KPH.
Expected Result	Total damage output exceeding that of the previously conducted trials with a vehicle speed of 140 KPH (average total damage output of around 14.50%.
Actual Result	Severe collision. Total damage output of 21.79%.
Status	PASS

Test Case ID	EC10
Description	Text extreme maximum for the vehicle speed parameter.
Input	Vehicle speed (velocity) of 200 KPH.
Expected Result	Total damage output exceeding that of the previously conducted trials with a vehicle speed of 140 KPH (average total damage output of around 14.50%.
Actual Result	Severe collision. Total damage output of 22.19%.
Status	PASS

Reaction Time The reaction time edge case tests consisted of two different tests: one with a negative reaction time of -800ms (the driver reacted before even seeing the vehicle) and one with an absurdly high reaction time of 30 seconds. The tables for these tests are provided below.

The negative reaction time was only tested once. The moving vehicle stopped before a driver in real life would even see the stopped vehicle. There was no way a collision would ever occur; one test was enough.

Test Case ID	EC11
Description	Test negative value for reaction time parameter.
Input	Reaction time of -800ms.
Expected Result	No collision; total damage output of 0.00%.
Actual Result	Total damage output of 0.00%.
Status	PASS

The extreme maximum of 30000ms (30 seconds) was only tested once.

Test Case ID	EC12
Description	Test extreme maximum for the reaction time parameter.
Input	Reaction time of 30000ms.
Expected Result	Severe collision. Total damage output similar to that of the 3200ms trials (around 26%).
Actual Result	Severe collision. Total damage output of 27.18%.
Status	PASS

6.1.4 Code Review

The scripts were loaded into an IDE to check that there are no syntax errors. After this, they were reviewed to check for logical errors.

The Lua scripts included in the repository were loaded into VSCode to check for syntax errors. If any were found, they were resolved. These scripts were looked over to check for logical errors. None were found; the logic is very straight forward, since each script just depends on calling functions included within BeamNG.

The trajectory JSON files were scanned over to make sure they were formatted correctly. Due to the integration testing, it has already been confirmed they function as intended. They consist of a collection of coordinates so checking for logical errors is not applicable.

6.2 Validation

The validation process ensured that the model accurately reflected a real-world system. The importance of this is obvious; if the simulation model did not reflect driving scenarios that could occur in the real world, then the data collected from it and the conclusions drawn from that data would be irrelevant to answering the research question posed by the simulation model.

Conducting research online looking for similar simulation models, determined the simulation model to be rather unique. No examples could be found of other people using BeamNG for similar purposes. Because of this, *cross-model validation* was not practical and perhaps not even possible. Additionally, *historical data validation* was also not practical; automobiles have changed a lot in the recent decades and research concerning defensive driving techniques is rather novel. Additionally, comparing my data to real-world data would prove to be difficult simply because no real-world study would provide damage percentages reported by BeamNG. To counter this, information was instead cited that details how well BeamNG itself reflects real-world outcomes in similar scenarios.

Because of the problems outlined in the previous paragraph, *parameter validation* and *face validation* were conducted. The parameter ranges were compared to data found online concerning defensive driving studies. Parameter ranges were also thought through pragmatically by reflecting on common speeds drivers drive at in real-world scenarios. In regards to the *face validation*, conclusions made by the data collected from the simulation model were compared with expert opinions related to the efficacy of various defensive driving techniques.

In short, the tested parameters were tested and justified, conclusions drawn from the simulation model's data were corroborated with expert opinions, and BeamNG's accurate physics engine capabilities were shown using various sources.

6.2.1 Parameter Validation

Several sources regarding defensive drive data were consulted to determine whether the parameters tested were within reasonable ranges.

Following Distance: Tests were conducted for 2 meters (about 6.6 feet) of following distance, up to 24 meters (about 78.7 feet).

In validating the parameter ranges for the following distance variable, a few different articles found after research online were consulted. Most of these articles presented following distance in seconds, rather than a distance, and specified how many seconds it should take for you to pass some landmark on the side of the road after the car in front of you has passed it.

Reference 4 cited below is an article from a website featuring advice for safe driving. This website recommends leaving 3 seconds between you and the car in front of you. When traveling at 80 KPH (50 MPH), the speed the following distance tests were conducted at, this translates to 220 feet. Reference 5 cited below is another article from the Nationwide Insurance Agency's website regarding safe driving. This article also recommends leaving 3 seconds between you and the vehicle in front of you; this translates to 220 feet at 50 MPH.

Based on these articles, the maximum following distance that was tested was well below the minimum recommended following distance. However, the purpose of these tests was to determine whether an increased following distance contributed to less damage in a collision and could possibly even prevent a collision. The results of the parameter range used answered this with a resounding "yes".

Vehicle Speed: The parameter range that was tested regarding vehicle speed was 40 KPH (about 25 MPH) to 160 KPH (about 100 MPH). The most trials were conducted around 120 KPH (about 75 MPH).

In validating whether this range was reflective of reality, a few different sources were consulted.

The first source that was consulted is reference 6, cited below. This document is from a study conducted by the *National Highway Traffic Safety Commission*. The study gathered information related to the mean and median speeds vehicles travel at on interstates throughout the country. Table 7 on page 35 of the study displays the mean and median speeds on several different types of interstate roads. The table is included below.

Table 7. Overall Speeds by Road Class (All Traffic)

	FCC ROAD CLASS							
	1 Limited access		2 Major arterial		3 Minor arterial/collector		Total	
	Speed Estimate		Speed Estimate		Speed Estimate		Speed Estimate	
	2015	Change	2015	Change	2015	Change	2015	Change
	Est. (SE)	Est. (SE)	Est. (SE)	Est. (SE)	Est. (SE)	Est. (SE)	Est. (SE)	Est. (SE)
Mean	69.0 (1.0)	-0.1 (1.5)	54.9 (1.6)	3.0 (2.0)	48.8 (2.0)	2.3 (2.1)	62.9 (1.3)	5.7 (1.7)
Median	69.8 (1.0)	-0.1 (2.2)	55.9 (2.2)	3.9 (2.6)	47.8 (2.6)	2.2 (2.7)	65.7 (1.1)	7.7 (2.1)
Quantile (0.85)	77.3 (0.6)	-0.2 (1.2)	68.3 (1.2)	5.8 (1.7)	62.1 (2.3)	5.1 (2.5)	75.8 (0.7)	2.3 (2.1)
Quantile (0.95)	81.3 (0.6)	0.4 (1.0)	75.2 (0.8)	6.3 (1.5)	71.2 (2.7)	6.5 (2.7)	80.4 (0.6)	1.4 (1.7)

As can be seen from the table, the average speed on all kind of interstate roads is 62.9 MPH. This speed was heavily accounted for when conducting simulation trials.

The second source that was consulted for vehicle speed parameter validation was concerning the minimum tested speed. This document (reference 7, cited below) from a study conducted by MIT provides the residential speed limits of several different U.S. states. As can be seen by this source, the common speed limit is 25 to 30 MPH. This speed was repeatedly tested in my simulation trials.

In short, the parameter range tested in the simulation model very closely represents realistic driving speeds.

Reaction Time: The parameter range that was tested concerning reaction time was 0ms (no distraction) to 3200ms.

Similar to how the previous parameters were validated, I conducted research to find sources online that detailed common values for such a variable. Unfortunately, most sources I could find recorded data such as the number of deaths that distracted driving caused. It was difficult to find a source that described how long each of these distractions were and what length of time constituted a fatal distraction.

To remedy this problem, I consulted my own anecdotal evidence. Most distractions when driving are brief ones. Most often, when drivers are using their phone they look at the device for around a second or so and then glance back at the road. When this is done several times, it can contribute to a long "distraction period" but each individual distraction is only a few seconds at the most.

My parameter range accounts for realistic distraction times. Most often, drivers glance back at the road often, even when driving distracted. Each distraction only occupies a few seconds at the most.

6.2.2 Face Validation

To perform face validation, the conclusions drawn from the data collected from my simulation model were compared with expert opinions regarding similar subjects.

Data analysis concluded that a larger following distance can reduce damage and loss of life in automobile accidents. Research online was performed to find sources that passed judgment on this topic. Several were found and two have already been cited: reference 5 and reference 6. Both of these articles support the conclusion that in the real world, a larger following distance between vehicles will make automobile incidents less catastrophic.

In regards to vehicle speed, my simulation model displayed an obvious correlation between vehicle speed and the severity of an accident. I found several different articles online that supported these conclusions. This suggests that my simulation model behaves similar to vehicles in the real world. Reference 8, cited below, is an article from a website dedicated to providing information regarding defensive driving techniques. This article concludes that controlling vehicle speed helps prevent an automobile accident.

Reference 8 also states that distractions should be prevented while driving, as they can contribute to accidents. The simulation trials conducted to test the efficacy of a faster reaction time support the same conclusion. In the simulation model, a distracted driver caused a worse accident in every case.

6.2.3 BeamNG's Physics Engine

The reason BeamNG was chosen for the simulation model in the first place was that it presents a realistic driving simulation. The results of the trials ought to have closely reflect reality and there honestly wasn't a better physics engine to use (in regards to simulating vehicles). This section of the report will be dedicating to attempting to prove that BeamNG is in fact, a reliable vehicle and physics simulation.

Research was conducted online before even completing the project proposal and found several articles describing how good of a simulation environment BeamNG is.

This article from expertbeacon.com, cited below as reference 9, describes how realistic the BeamNG engine is in regards to its physics simulation. Because of how vehicle models are rendered in the engine, the collisions are very accurate and closely reflect what would happen in a similar scenario in the real world. Due to this, it's reasonable to assume that the outcome of a simulation trial conducted in BeamNG is rather close to the outcome that would occur in real life with similar conditions.

Another article from a car magazine (cited below as reference 10) outlines the accuracy with which collision occur in the BeamNG engine. The only downside the article discusses in reference to BeamNG is it's quite intensive computational requirements; the physics simulation itself is superb.

In short, the vehicle physics simulation present in BeamNG is among the best available. The outcome that occurs in the BeamNG engine is quite accurate to what would occur in a similar real-world scenario.

7 Overall Analysis and Discussion

This section serves to establish that the simulation model did, in fact, fulfill the objectives that it set out to satisfy. The research question posed by the project - *whether defensive driving techniques are effective at reducing damage and injury in automobile accidents* - was provided with a direct answer. The project did not assume the answer, it merely set out to provide one.

The section concerning the simulation results and the analysis of the provided data has already elaborated on this topic a bit, but a brief summary of the conclusions made by the project will be given. The simulation model certainly proved that defensive driving techniques are effective at reducing the damage and injury sustained by vehicles and persons in automobile accidents. A larger following speed greatly contributes to a driver's ability to prevent a collision or at least mitigate the severity of one. A reasonable vehicle speed seems to do the same; in every simulation run where the speeds were increased, the damage sustained by the involved parties increased. Lastly, preventing distractions in order to minimize the time it takes for a driver to react in a driving scenario reduces the severity of a collision and can even sometimes prevent one altogether.

These results are presented via tables and graphs in the corresponding section, "Simulation Results". The reader is encouraged to refer to this section for further details.

One surprising outcome was the severity of the following distance trials with a distance of 6 meters between the vehicles. It was expected that the accident would be less severe than the 2 meter tests but this was consistently not the case. This doesn't mean that the simulation model failed in any regard, considering it only wanted an answer to the question; it just means that the answer provided didn't exactly correlate with what was expected.

The scenario and sensitivity analysis that was conducted showed that the simulation model's scenarios were correctly implemented and showed that the tested variables had a clear impact on the results of each simulation run. Vehicle speed proved to be the most sensitive variable; this is hardly surprising and all the sources that were consulted concerning defensive driving supported the idea that a higher vehicle speed can have a devastating impact on the outcome of an automobile incident.

The verification and validation process proved that the simulation model reflect a real-world system relevant to the objectives laid out by the project and that the simulation model was implemented correctly. Several tests were undergone to ensure that the simulation model was constructed correctly and many different sources from various sites online were consulted to ensure that the simulation model reflected a real-world system and tested appropriate parameters.

For more specifics regarding scenario and sensitivity analysis and the verification and validation process, the reader is encouraged to refer to the corresponding sections.

8 Conclusion

From the onset, the simulation model sought to answer *whether defensive driving techniques are effective at reducing damage and injury in automobile accidents*; all the work undergone throughout the course of the project was aimed towards providing an answer (supported by data) to this question. The data collected from the simulation model and the analysis of that data provided a clear answer: **"Yes, defensive driving techniques are certainly effective at reducing damage and injury in automobile accidents."**

The tested variables - following distance, vehicle speed, and reaction time - all proved to have a direct impact on the outcome of each tested scenario. The primary takeaways concerning each variable will be expanded upon.

The following distance, or the distance between two traveling vehicles, has a clear correlation with the severity of an automobile accident. If the following distance between two vehicles increases, the damage done to involved parties decreases. This conclusion drawn from analysis of the simulation model's data is supported by the opinion of many different experts concerning defensive driving. Several of these articles are cited below.

The speed of a vehicle has a profound impact on how severe an accident will be. If a vehicle is traveling at a higher speed, there will be a higher amount of damage done to the involved parties. As with the conclusions drawn concerning the following distance variable, this is supported by many different sources regarding defensive driving.

The reaction time of a driver has a clear impact on the severity of a automobile collision as well. The severity of the collisions in each tested scenario got progressively higher when the reaction time was higher; if the driver was delayed in their response, the result of the scenario was far more catastrophic. Again, as with the other two tested variables, this conclusion is corroborated with many different references that were found on the web.

While the simulation model is certainly complete, work could be done in the future to make the scripts more accessible to someone unfamiliar with BeamNG. Utilizing the scripts requires a bit of knowledge regarding the inner workings of BeamNG. While this could never be entirely avoided, it could at least be mitigated.

In short, the simulation model confirms the efficacy of defensive driving techniques. **The next time you find yourself behind the wheel of a vehicle, be it a sedan, truck, or any other, leave plenty of space between you and next vehicle, drive at a reasonable speed, and don't participate in any distractions. These principles could easily save your life in the case of an automobile accident.**

9 References

1. wikipedia.org article that gives a brief description of BeamNG.

2. Documentation from BeamNG concerning the ScriptAI Editor.

3. Documentation from BeamNG detailing the Vehicle Stats Logger.

4. drive-safely.net article detailing safe following distances.

5. nationwide.com article detailing safe following distances.

6. NHTSA study concerning national traffic speeds.

7. MIT study regarding minimum residential speed limits in several different U.S. states.

8. defensivedriving.org article outlining several different defensive driving techniques.

9. expertbeacon.com article describing the realism of the BeamNG simulation engine.

10. motortrend.com article that describes the accuracy of BeamNG collision simulation.