A Feasible Approach to an Eco-Drive Environment on Various Road Conditions

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Abstract - **Transportation accounts for ~28% of US greenhouse gas emissions, which play a critical role in global warming and the current climate crisis [1]. As the climate crisis picks up speed and it becomes increasingly evident that action is necessary, any way to mitigate the impact of transportation on the crisis can help countries and businesses reach healthy emission goals. Eco-Drive introduces a way to reduce carbon emissions through "conscious driving", whether it be through automation, or human cognition. Important principles of Eco-Drive include efficient transitions between kinetic and potential energy as inclines change, minimizing sharp acceleration and heavy braking, avoiding unnecessary idling, efficient gear changes, and traffic behavior anticipation. Eco-Drive has been the topic of many experiments finding diverse results based on variables such as location of road (urban, semi-urban, highway), elevation changes and degree of elevation change, traffic flow, and type/size of vehicle. In this project, we will look at how effective Eco-Drive is on different types of roads (many traffic lights, few traffic lights, varying elevation changes) in varying locations (urban, semi-urban, highway). We will model Eco-Drive habits, such as minimizing sharp acceleration, heavy braking, and idle time, in a simulation to collect metrics on energy consumption and travel time. We will also look at the effect of how many cars are driving with Eco-Drive on the total success of all drivers. The end goal will be to determine whether Eco-Drive could be beneficial when implemented on choice DC roadways.**

Index Terms – eco-drive, fuel consumption, emissions, SUMO, PHEMlite

Introduction

In this current day and age, there is a greater interest in the automotive industry now more than ever due to the fact that there exists a wide range of research areas that results in a more environmentally friendly and sustainable society. This interest in an eco-drive environment is important because as more and more people utilize these vehicles, the effect on the environment is directly proportional in that it also results in increased carbon monoxide emissions which in turn negatively affect the atmosphere and environment. As global warming is a very real phenomenon, it is crucial to understand that the automobile industry and services that are used every day by billions of people worldwide is a contributing factor to the constant rise in greenhouse gas emission. In fact, in the US alone, cars and trucks account for approximately one-fifth of all US emission, roughly equally around 24 pounds of carbon dioxide and other global-warming gases for every gallon of gas [3]. These figures can be further broken down into the different areas of the automotive industry ranging from the production process to the usage of these vehicles by the everyday driver. Furthermore, the US transportation sector produces 30% of all US global warming emissions, establishing itself as the sector with the highest percentage. Along with the negative aspect of global warming, there are other areas to consider such as the increased risk of traffic accidents and increased congestion, all resulting in an inefficient road network system. With this knowledge, it is sufficient to say that although these technological innovations and ease of availability to the public has provided many benefits to society, it is crucial to understand that there are negative consequences associated with such constant use.

As more and more companies and entrepreneurs are realizing this industry holds some negative consequences on the environment, the introduction of the term "eco-drive" was presented as a solution that provided not only ecological benefits, but also improvement in driving techniques, road safety, while saving fuel and cost at the same time [4]. The development of a more modernized road network with non-collision intersections and highway and motors have been a great measure taken to improve road safety [5]. Furthermore, driver assistance systems have been deployed in many cars around the globe that provide additional road safety measures along with improved driver comfort and confidence.

This research project focuses on the impact of eco-drive mainly on the environment and such impact will be determined by the fuel consumption and emission rate which are the two common measurements used to determine the effect of vehicle use. The main goal of this research paper is to determine what type of road conditions and what driving behaviors lead to a feasible eco-drive environment. This implies that there may be certain conditions in which introducing an eco-drive plan on certain road conditions is not beneficial and may even be harmful to not only the environment but also to other drivers on a shared road. The results found within this project will prove to be useful to state and federal departments and other countries around the world as a tool to use while determining traffic guidelines and road infrastructure as it can help assess when and where eco-drive can be safely implemented.

GOALS/OBJECTIVE

Because the main purpose of this project is to determine if eco-friendly driving habits can be applied to certain roads, it is important to focus both on factors that are directly affected by driver habits/behavior and from external factors that are outside of the driver's control. Looking at the environment that is outside of the driver's behavior is important because although there are many studies that focus on individual efforts, there is not a lot of research analyzing the effect of fuel consumption and emissions on the traffic flow. Driving behavior of other eco drivers affects other drivers as well- and, in turn, causes an overall effect of the flow of traffic. This project can be broken down into three parts, with each part being the precursor for the next one.

The first objective is to determine which types of roads are suitable for an efficient eco-driving plan integration. This is crucial because there are some instances where incorporating eco-driving habits on certain roads can have an adverse effect and instead of helping the environment, both in the greater ecological sense and the environment as in its surroundings, it can cause negative consequences. An example can be looking at engine fuel cut-off as a method for engaging in eco-driving habits that focuses on driving in neutral and makes the best use of a vehicle's kinetic energy [2]. Although useful in situations where a vehicle can be driven continuously on a certain gear, it can also be extremely difficult and distracting in roads that are situated in the city, turning it into a big safety risk. With that in mind, in order to determine exactly what roads can support an eco-friendly environment, certain different road characteristics will be analyzed such as those with a larger number of traffic lights, roads with elevation changes, road visibility, those that have a heavier flow of traffic due to its location, urban and semi-urban roads and highways.

Next, once these types of roads have been analyzed and deemed safe and efficient to incorporate an eco-friendly habit, determining exactly which kinds of eco-driving habits an individual driver can traffic flow can be used. These habits include such things such as braking distance, adaptive speed control, fuel consumption, emission, waiting times, etc. This also can be affected by the type/size of the vehicles that are driven on these roads as well.

Once a conclusion can be reached for the previous two research goals, a small simulation implementing some eco-driving habits can be done to get a better picture of exactly how the environment and the traffic flow are affected by these changes. Obtaining these metrics from the simulation will further assist in analysis.

Methodology/Simulation

We have used the mobility simulator Sumo for simulating the mobility on the selected road segments. Sumo uses a car following model to simulate mobility. We have focused on the eco friendly driving habit such as moderate acceleration and deceleration, reduced emergency deceleration and driving habit of the driver. We have also considered the road geometry by adding elevations to the Sumo. The default car following model of sumo has been changed to KraussPS which considers the road slope information.

BACKGROUND RESEARCH

As stated above, it is important that proper research is conducted that helps indicate what road conditions need to exist in order to safely and effectively implement an eco-drive environment.

Various Road Conditions

One of the first things to consider when trying to implement an eco-drive safe environment is to first determine the various road conditions that exist. Some of these road conditions fall into such categories as traffic conditions, intersections, signal phasing timings, rural/urban roadways, city-driving, and different terrains.

Terrains

According to a research study various terrains lead to different results when implementing and not implementing eco-drive measures [6]. This test was done by calculating the fuel consumption on connected automated vehicles and testing to see if introducing an eco-drive environment would actually be beneficial on rolling terrains in particular. Rolling terrains are considered to be road segments that have a multitude of slopes that go above and below the normal road grade. In short, those roadways that have a lot of hills and up and down movement, disturbing the natural vertical/horizontal alignment of a road. It is a known fact that rolling terrains often cause additional fuel waste due to the inefficient transition from kinetic and potential energy [6]. The reason why rolling terrains are considered to cause additional fuel consumption is because of the constant need to break when going downhill and accelerate when going uphill. It is not the acceleration that is the main problem- it is the braking that causes disruption in the kinetic energy and therefore leads to more heat dissipation and fuel consumption.

This study used the Relaxed Pontryagin's Minimum Principle (RPMP) which can be translated well into real-time applications as well as being computationally efficient. The baseline used was the conventional constant speed cruise control. This cruise control was set to the speed limits on the various 7 road segments tested ranging over 47 miles. The eco-drive setting used two different speed controllers. The vehicles are given a preprogrammed ideal speed while a secondary speed controller is utilized in real-time to make any necessary adjustments while in motion. The experiment results determined that there was over twenty percent of savings in fuel consumption (ranging from 2-21%).

A conclusion can be drawn from the study. Cruise control in rolling terrain is not effective and wastes more fuel consumption because of the constant braking needed to be applied when moving downhill in order to maintain the programmed speed limit. More heat dissipation and fuel consumption occurred when the slope was steeper, and the hill length was greater. This suggests that acceleration or speed by itself is not the main measure that determines fuel consumption and emissions waste- it is the braking mechanism that causes that disruption in kinetic energy and therefore, more waste in fuel consumption. It can then be concluded that the use of eco-drive on terrains that have more hills and inclines (i.e., mountainous regions) can be extremely beneficial, saving over 20% in fuel consumption. Conversely, it is important to note that not all instances require the use of eco-drive. For instance, when testing the segment in particular roads that were mostly flat and did not have any bends/curves, the savings from eco-drive mode compared to the baseline usage of cruise control was relatively nonexistent. It can then be concluded that roadways that do not have such varying degrees of incline, either horizontal or vertical, do not necessarily need to have eco-drive implemented. This conclusion is important to note because this then further reinforces the importance of initially determining exactly what road segments actually are feasible to introduce eco-friendly driving on because this now presents a case where there may be instances where eco-drive may actually be detrimental to not only the environment but also other driver safety. Those situations will be discussed later.

Intersections

Other potential road conditions are situations such as traffic intersections. This also closely corresponds with urban roads because there is a proportional relationship between urban roads and traffic intersections, as the more urban the area gets, the higher number of traffic intersections there are. This road condition is important to consider because this results in a stop-and-go driving behavior, introducing new factors such as acceleration and idling time. On takeoff (from a resting position), acceleration generates a high instantaneous emission rate and produces higher levels of pollution [7]. This suggests that there is a higher possibility of fuel consumption at traffic intersections. Applying moderate acceleration in this area may lead to better optimization of fuel consumption.

Traffic/Congestion

Heavily trafficked areas and those with peak hours also result in extra fuel consumption because of the same notion of constantly stopping and going. Eco-drive may not actually be suitable during times like these especially if not every driver is an eco-driver.

Urban/City

Because urban and city roads have more intersections than those compared to more rural arteries, there is expected to be more intersections and various traffic conditions (peak vs nonpeak) and all those same reasons for excess fuel consumption also apply here. Additionally, when also looking at velocity, there is less velocity in city roads (as in acceleration and deceleration) and it is important to note that it is not just the act of velocity that causes the excess fuel consumption, it is the sudden shift in energy and the braking that occurs that is the reason for more dangerous gas emissions [8].

Various Driving Behavior/Events

Now that the different road conditions have been discussed, it is now important to outline different driving behavior/events that drivers exhibit that lead to either an increase/decrease of fuel consumption and emissions which then help determine which behaviors are eco-friendly or not.

Acceleration

Sharp acceleration and deceleration generate more fuel consumption and excess emissions. Smooth acceleration seems to be the key here. Acceleration can be broken down into different driving events such as accelerating sharply, decelerating sharply, and long-time acceleration, all of which contribute to higher fuel consumption [9]. The basic notion is that all these driving events should be avoided, because more energy is consumed when it comes to sharp increases and decreases in the acceleration as well as leaving pressure on the accelerator for too long to build up speed.

Braking

Because of the sudden shift from kinetic energy to potential energy, braking is a great cause of excess fuel consumption. When combined with looking at rolling terrains and those roads that have higher elevations, the constant need to break and accelerate causes more fuel consumption than required. Therefore, although cruise control seems like a good option because it monitors the speed for the driver and they do not need to be as vigilant, when set to just one constant speed and approaching these hills and slopes, there is constant breaking required that then causes unnecessary sharp transitions from kinetic to potential energy. This results in more heat dissipation and excess fuel consumption.

Additionally, according to a research, braking energy is the main energy consumer for drivers when driving at lower velocities (acceleration/deceleration). Another thing to consider for braking is the reason for the braking to occur. Is it because of a traffic light, another vehicle jumped into the lane, or did the driver forget to lock her front door when leaving the house in the morning? If it is the latter, that instance is near impossible to measure as it is a personal issue rather than something that could be addressed via road infrastructure (traffic lights) or driver assistance systems (how to change lane successfully/without causing disruption to the flow of traffic).

Idling

Idling is also a driving behavior that causes fuel consumption, and it occurs around 15% of the time in urban areas [8]. Idling could potentially be reduced through the development of better road infrastructure or less congestion.

Headway

Headway distance is also very important to look at, as it determines braking distance and how sudden a driver may have to press on the brakes. Minimum headway is the shortest distance that a driver/vehicle may have with another driver/vehicle without the need to reduce the speed of the vehicles or the traffic flow. This is important to look at because the less headway the driver has, the more likely sharp braking is going to occur if there is a reduction of speed ahead such as a traffic light or a sharp turn or bend in the road which then causes the disruption of kinetic energy, leading to more heat dissipation and excess fuel consumption

Driving style

Driving style is also a very interesting aspect to look at when trying to determine what sort of driving behaviors result in eco-friendly driving. According to research conducted in China (and in fact much research conducted in Europe) aggressive driving raises the fuel consumption and emissions by 12-40% and 20-50% respectively [9]. This may seem surprising; however, it aligns well with other research because aggressive driving usually involves such parameters such as speed and acceleration/deceleration, factors that greatly affect fuel consumption.

Percentage of Eco-Drivers on the Road

It is interesting to note that the percentage of eco-drivers in any given situation can have different effects on the overall traffic flow and the environment. In the study mentioned above, it was found that if the percentage of eco drivers on the road was 25% or above, there were positive environmental benefits all around when compared to normal driving [9]. However, if there were below 25% of eco-drivers on the road, there was a negative impact as the eco-drivers would impede the normal drivers on the road and disrupt the smooth driving pattern which then led to excess fuel consumption and emissions and increased travel time by eco-drivers. It is safe to conclude from that study then that the optimal driving environment needs to be homogeneous in nature with many drivers behaving in the same manner, whether using eco-drive or not.

Eco-Drive Environment

After the research above some conclusions can be made about a feasible eco-drive environment. One of the main factors of fuel consumption and emissions is the acceleration/deceleration parameter. And this is affected by different terrains with more elevation changes, more bends/curves in the road and at intersections. It can be concluded that in situations where there is constant energy shifting from acceleration to deceleration is where eco-drive can be implemented in order to benefit the environment and the flow of traffic. With that being said, looking at roads such as rolling terrains and intersections prove to be a good test-case scenario to use as that causes a lot of acceleration changes.

Conditions Where Eco Drive May Not be Needed

It is natural to assume that incorporating eco-drive in all types of environment would be beneficial and prove to be effective; however, that is not the case. Certain roads that do not have bends, do not have intersections, are relatively smooth with almost no elevation changes really do not require eco-mode to be initiated because there is no true disruption in the flow of traffic.

With all the research done, it is said to assume that eco-drive is mainly needed on roads that have some sort of defining road characteristic such as bends/curves, elevation changes, traffic lights, etc. that cause some sort of change to the kinetic energy in the vehicle and disruption in motion. This change in motion requires the need to adjust the vehicle's speed and acceleration and that adjustment is the reason why there is excess fuel consumption and emission. Because of that reason, the focus on the following simulation conducted in this paper was to test the different acceleration speeds because that is one the greater indications of whether eco-drive can be effective. Additionally, as noted, if there are less eco-drivers on the road, that can create a dangerous situation so that is another area to be tested.

Experimental Setup

To simulate ecofriendly driving the default maximum acceleration of the vehicles has been changed from 2.6 m/s^2 to 1.6 m/s^2 and deceleration has been changed from 4.5 to 4 m/s^2 which prevented sharp acceleration and deceleration. To simulate ideal driving imperfection was changed from 0.5 to 0.2.

To calculate the effect of ecofriendly driving emission for each vehicle running in the simulation has been calculated using PHEMlite emission model's freely available PKW_G_EU4 class which calculates the emission of gasoline powered passenger vehicles. Vehicle's fuel consumption, CO2, NOx and PMx were calculated using the emission model. Also, average travel time, waiting time, travel duration, speed were calculated to see the effect of ecofriendly driving on mobility.

The simulation has been done under heavy and light traffic using Eco-Drive, No-Eco-Drive and Mixed (50%Eco-Drive, 50 % No-Eco-Drive) for two roads and all the metrics have been calculated for these scenarios to understand the effects.

In order to test the findings of the research conducted, there were two road segments that were tested to see whether an eco-drive environment can be implemented. The first road segment was Georgetown Pike in Virginia, near the Great Falls area as this road segment provides a rolling terrain with a lot of elevation changes and bends/curves in the artery.
The other road segment used was Braddock Rd starting from the intersection of Twinbrook Rd and Braddock Rd and ending with Hemming Ave and Braddock Rd. This road segment was chosen because it is centered more in an urban/city environment with lots of intersections and allows to test for eco-drive feasibility.

Both environments have been tested on high traffic and low traffic volumes to see exactly what sort of effect eco-drive has in those conditions. This simulation will help determine if certain roads are better to use eco-drive depending on time of day or traffic conditions.

Experimental Results/Analysis

The following parameters were looked at: speed, duration, and waiting time.

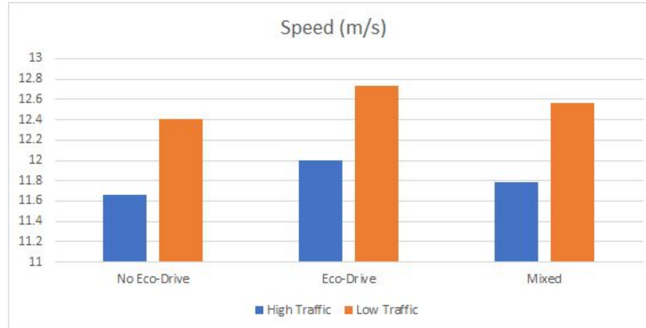
Speed is the average speed the vehicles were driving in their designated routes. Duration is the average time it took the vehicle to reach the destination or travel on the designated route. Waiting time can also be interpreted as idling time as this is the average number of seconds the vehicle had to travel less than 0.1 m/s and scheduled stops do not count here so this is a great indication.

Georgetown Pike

Below are the results for Georgetown Pike in high volume and low volume. In the high volume, there were 10,744 vehicles. In the low volume simulation, there were 2167 vehicles.

Speed

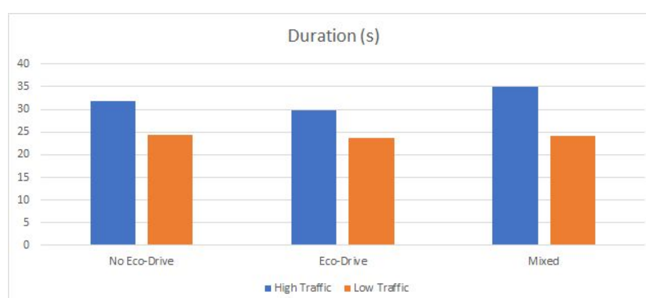
Environment	High Traffic	Low Traffic
No Eco-Drive	11.66(m/s)	12.41(m/s)
Eco-Drive	12(m/s)	12.73(m/s)
Mixed	11.78(m/s)	12.56(m/s)



In low volume, using an eco-drive environment, drivers were able to travel more distance compared to a non-eco-drive environment. There was a 2.5% increase of speed from eco-drive and non-eco drive drivers. Even in the mixed environment, there was still a 1.2% increase in speed. These numbers may seem small, but this was just a small sample used in the simulation. When using real-time numbers, the differences would be greater and beneficial. It is also interesting to note that even in high volume, having an eco-drive environment still was advantageous in this parameter by an increase of 3%. So, although drivers were not able to travel as much of a distance when compared to low traffic (which makes sense because more cars = less room for travel), there was a greater benefit of using an eco-drive environment than a non-eco drive environment

Duration

Environment	High Traffic	Low Traffic
No Eco-Drive	31.85(s)	24.35(s)
Eco-Drive	29.86(s)	23.72(s)
Mixed	34.93(s)	24.08(s)



The results in this parameter were quite interesting. In high traffic and an eco-drive environment, the average time it took the vehicle was 29.86 seconds. The average time it took for non-eco drivers was 31.85 seconds, so eco drive resulted in a 6% decrease. However, a mixed environment greatly increased the duration when compared to a non-eco drive environment by an increase of 9.7%. This is interesting as this shows that either a fully eco-drive environment is beneficial or non-eco drive environment. The mix may cause longer travel time because the flow of traffic is not homogenous and causes disruptions. This aligns well with the previous study that stated if there are a mix of eco-drivers on the road, it could cause increased travel time and a disruption in traffic flow. In low traffic, there was not a great deal of variation between the different modes which also indicates that eco-drive is more beneficial when dealing with periods of higher volumes rather than low volume traffic as that requires less braking and acceleration.

Waiting Time

Environment	High Traffic	Low Traffic
No Eco-Drive	7.01(s)	2.74(s)
Eco-Drive	6.28(s)	2.82(s)
Mixed	9.88(s)	2.78(s)

In general, there was more idling time in periods of high traffic and low traffic. Eco-drive-in high traffic exhibited the least amount of waiting time in comparison to a non eco drive environment with a percentage decrease of 10%. Again in a mixed environment, there was actually a percentage increase of 40%. This again showcases that not all environments are conducive to eco-drive if it is not fully incorporated by each driver.

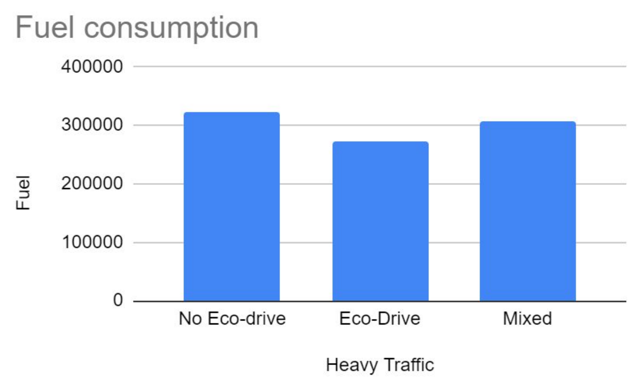
In a rolling terrain environment, the results indicated by the parameters measured show that a fully eco-drive environment is beneficial when it comes to the actual journey the vehicle takes as it can travel more distance in less amount of time, with less idling time and shorter travel time. It is now necessary to look at the effects on the environment in terms of fuel consumption and emissions

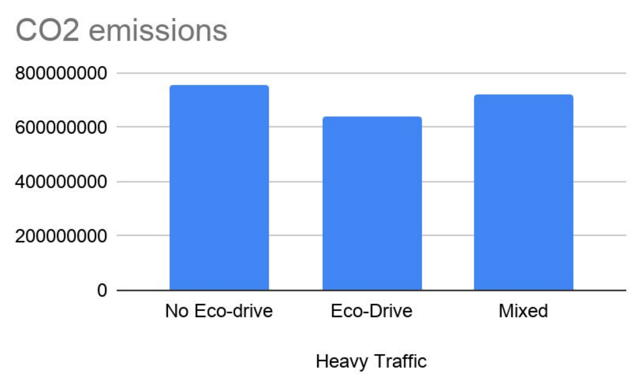
Fuel Consumption and Emissions

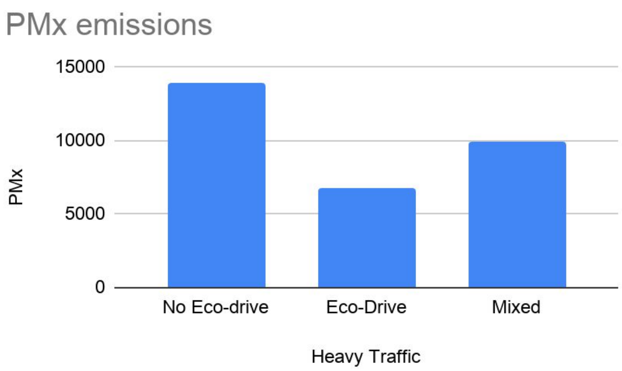
Georgetown Pike

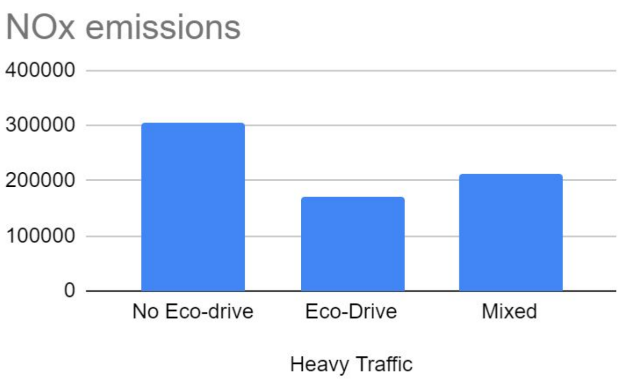
The following graphs depict the comparison of fuel consumption and various emissions when the driver uses no eco-drive, eco-drive and mixed driving patterns during heavy and light traffic.

Heavy Traffic	CO2(mg/s)	PMx(mg/s)	NOx(mg/s)	Fuel(ml/s)
No Eco-drive	752229456.9	13895.98	305574.73	323458.02
Eco-Drive	639620546.8	6789.95	171948.07	273214.72
Mixed	717994796.2	9868.18	210886.34	307287.18





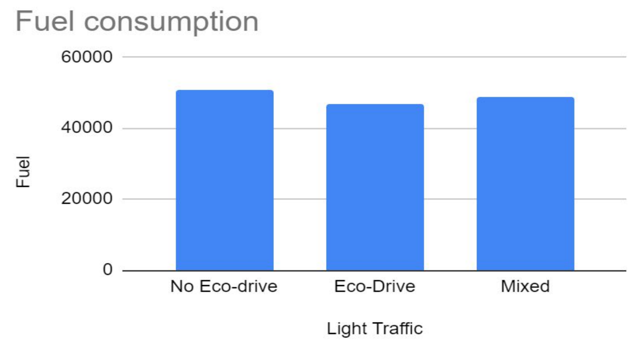


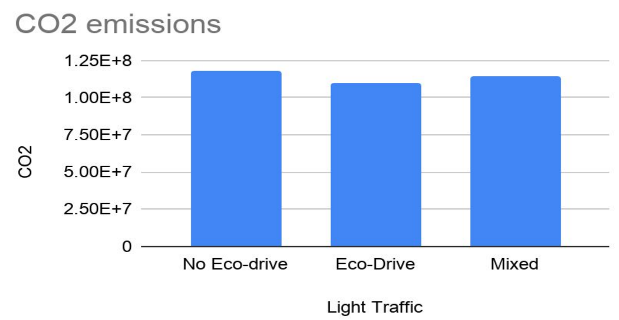


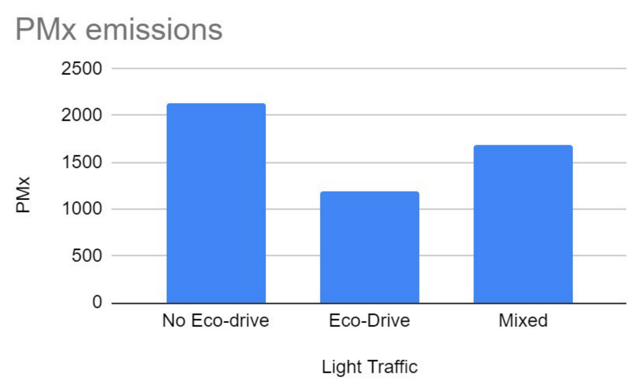
During heavy traffic, there is a 15.53% decrease in fuel consumption while using eco-drive and 4.99% decrease while using mixed driving patterns when compared to not using eco-drive at all.

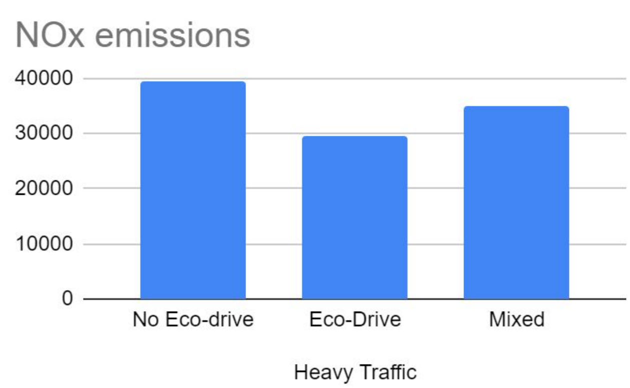
There is a considerable amount of difference in the emissions of carbon dioxide, nitrogen oxides and various particle matters. While using eco-drive, CO_2 emissions have decreased by 14.97%, NOx by 43.73%, PMx by 51.13% and during mixed driving, it can be seen that CO_2 emissions have decreased by 14.97%, NOx by 30.99% and PMx by 28.98% in comparison to not using eco-drive.

Light Traffic	**CO2(mg/s)**	**PMx(mg/s)**	**NOx(mg/s)**	**Fuel(ml/s)**
No Eco-drive	117983206.4	2136.33	39456.48	50684.62
Eco-Drive	109590529.7	1188.11	29420.14	46829.09
Mixed	114276215.7	1686.29	34957.24	48964.23









During light traffic, there is a 7.61% decrease in fuel consumption while using eco-drive and 3.39% decrease while using mixed driving patterns when compared to not using eco-drive at all. There is a considerable amount of difference in the emissions of carbon dioxide, nitrogen oxides and various particle matters. While using eco-drive, CO_2 emissions have decreased by 7.11%, NOx by 25.43%, PMx by 44.38% and during mixed driving, it can be seen that CO_2 emissions have decreased by 3.14%, NOx by 11.40% and PMx by 21.06% in comparison to not using eco-drive.

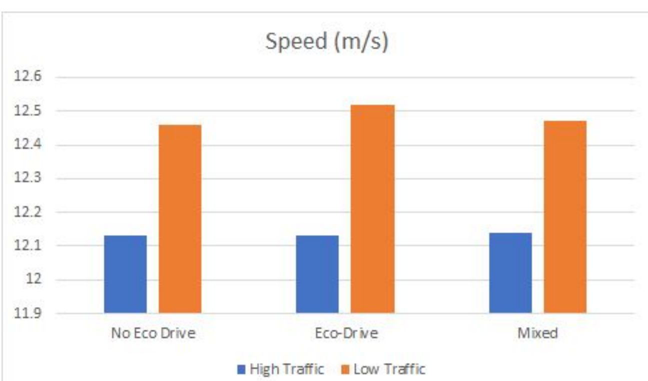
From the above data, it can be concluded that using eco-driving methods not only saves fuel but helps in decreasing the amount of greenhouse gas emissions. Also, switching between eco-drive and non-eco-drive methods is more beneficial in terms of curbing both fuel consumption and emissions rather than driving the vehicle normally during both heavy and light traffic.

Braddock Road

Below are the results for the road segment for Braddock Road. The same parameters were initially used as above: speed, duration and waiting time. These values measure how beneficial eco-drive is to an environment when it comes to driver journey.

Speed

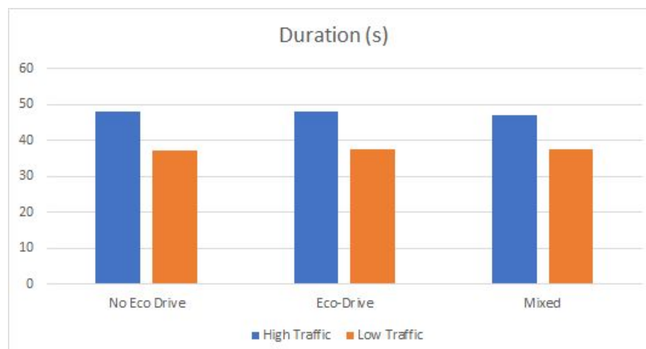
Environment	High Traffic	Low Traffic
No Eco Drive	12.13 (m/s)	12.46(m/s)
Eco-Drive	12.13(m/s)	12.52(m/s)
Mixed	12.14(m/s)	12.47(m/s)



Naturally, the speed parameter will be higher in a low traffic environment as there are less vehicles on the road, so the average vehicle is able to travel a larger distance in a shorter period. Now looking individually at a higher traffic, there is not a significant difference when it comes to the speed profile if there is an eco-drive environment or not. However, in a low traffic environment, there is a difference to be seen. In a fully eco-drive environment, there is a small increase of .48% of speed when compared to a non eco drive environment. When taken out to the real-world environment, this percentage will most likely increase.

Duration

Environment	High Traffic	Low Traffic
No Eco Drive	47.97(s)	37.33(s)
Eco-Drive	48.03(s)	37.51(s)
Mixed	46.91(s)	37.5(s)



In a low traffic environment, it is interesting to note that both in an eco-drive environment and mixed environment, there was an increase of duration time from the non eco drive environment, by .48% and .45% respectively.
In a high traffic environment, travel time is decreased the most in a mixed eco environment when compared to the baseline of non eco, with travel time decreased by 2.2%. There was an increase of travel time in an eco-drive environment by .12%

Waiting Time

Environment	High Traffic	Low Traffic
No Eco Drive	25.4(s)	15.47(s)

Eco-Drive	25.3(s)	15.4(s)
Mixed	24.21(s)	15.49(s)

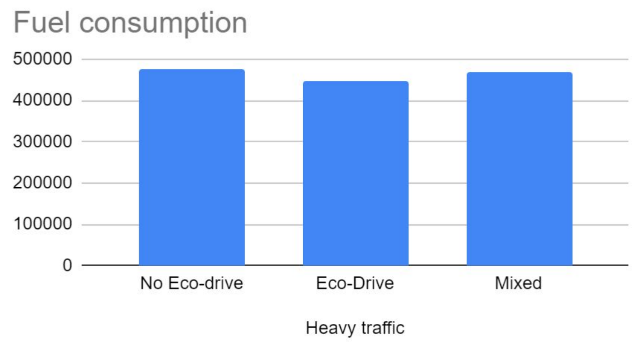
Idling time in a low traffic environment does not differentiate too much between all three environments. There is slightly more of a difference in idling time during high traffic volume. Interestingly enough, idling time in a mixed environment decreased from the baseline of a non-eco drive environment by 4.7%.

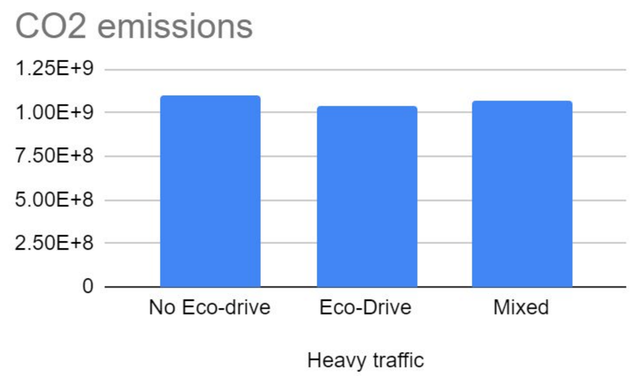
After conducting analysis on this road segment, it is safe to say that incorporating an eco-drive environment from the perspective of travel journey parameters does not seem to be greatly affected if in an eco-drive environment or not. When put in a real-time situation, some of these percentages are expected to increase in difference because of higher volume of traffic; however not greatly so.

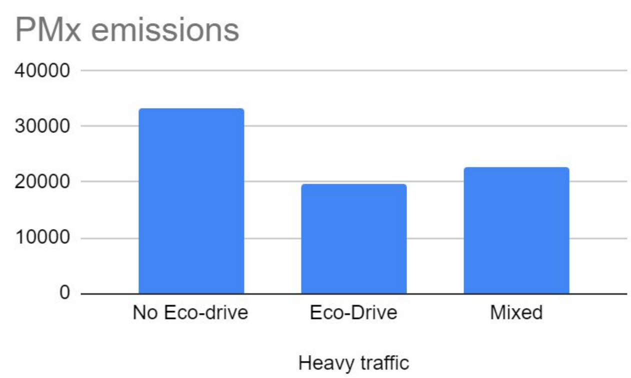
Fuel Consumption and Emissions

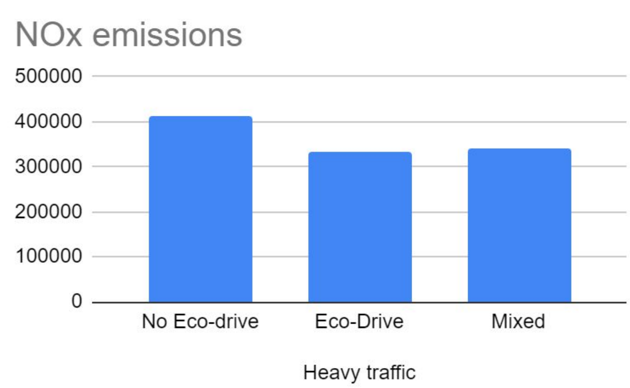
Braddock Road

Heavy Traffic	CO2(mg/s)	PMx(mg/s)	NOx(mg/s)	Fuel(ml/s)
No Eco-drive	1099264757	33282.8	411025.25	476781.81
Eco-Drive	1039299197	19837.06	332877.93	445674.53
Mixed	1068545585	22587.57	339777.85	468786.87





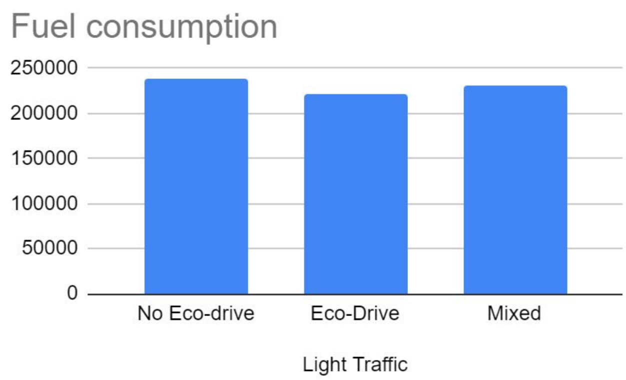


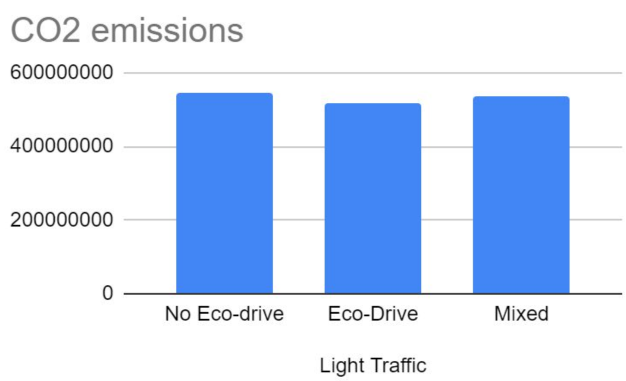


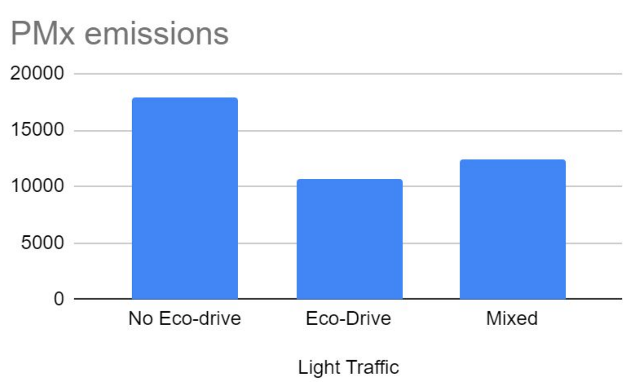
During heavy traffic, there is a 6.52% decrease in fuel consumption while using eco-drive and 6.52% decrease while using mixed driving patterns when compared to not using eco-drive at all.

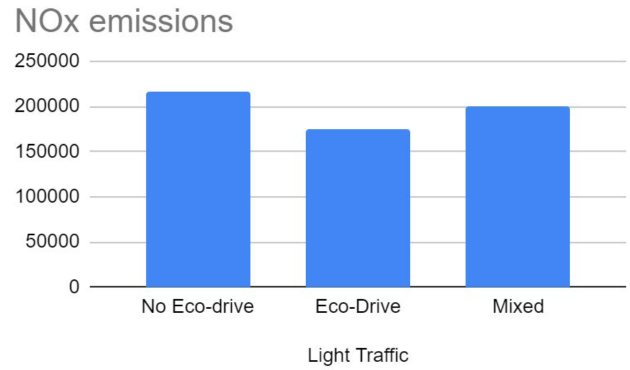
There is a considerable amount of difference in the emissions of carbon dioxide, nitrogen oxides and various particle matters. While using eco-drive, CO_2 emissions have decreased by 5.45%, NOx by 19.01%, PMx by 40.39% and during mixed driving, it can be seen that CO_2 emissions have decreased by 5.45%, NOx by 17.33% and PMx by 32.13% in comparison to not using eco-drive.

Light Traffic	**CO2(mg/s)**	**PMx(mg/s)**	**NOx(mg/s)**	**Fuel(ml/s)**
No Eco-drive	547650406.9	17912.42	217038.42	238009
Eco-Drive	515834651.5	10684.94	174620.52	221444.48
Mixed	535408871.7	12454.34	200891.97	231580.6









During light traffic, there is a 6.95% decrease in fuel consumption while using eco-drive and 2.70% decrease while using mixed driving patterns when compared to not using eco-drive at all. It can be seen that there is a considerable amount of difference in the emissions of carbon dioxide, nitrogen oxides and various particle matters. While using eco-drive, CO_2 emissions have decreased by 5.80%, NOx by 19.54%, PMx by 40.35% and during mixed driving , it can be seen that CO_2 emissions have decreased by 2.23%, NOx by 7.44% and PMx by 30.47% in comparison to not using eco-drive.

From the above data, it can be concluded that using eco-driving methods not only saves fuel but helps in decreasing the amount of greenhouse gas emissions. Also, switching between eco-drive and non-eco-drive methods is more beneficial in terms of curbing both fuel consumption and emissions rather than driving the vehicle normally during both heavy and light traffic.

Final Analysis

After performing analysis on both road segments, there is a greater difference and improvement on performance when incorporating an eco-drive environment in a rolling terrain segment such as Georgetown Pike. This aligns with the previous research done because the elevation changes are the reason why there is excess fuel consumption and emissions due to extra heat dissipation as well. The constant transition of energy due to acceleration/deceleration causes waste of energy and incorporating eco-drive friendly habits such as smooth acceleration has helped reduce emissions.

Now, when it comes to the Braddock Road intersection, there is not as vast of a difference when trying to compare between a non-eco-drive environment and an eco-drive environment. This again aligns with previous research because intersections generally speaking involve a lot more aspects and driving behavior as there is more stop and go driving patterns in the traffic flow as compared to a highway area like Georgetown Pike. There was still a reduction in fuel consumption and emissions, but the general savings did not differ greatly during high and low traffic volume, as it did in the Georgetown Pike road segment. This can also allude to the possibility that if there is even heavier traffic, introduction of eco-friendly driving behavior may not be greatly beneficial as it could affect flow of traffic more. It is important to keep in mind that although eco-drive focuses heavily on creating a safer environment ecologically, it also tries to create an efficient traffic flow pattern without increasing travel time. Finding the balance between the two is key here.

Further Research

The majority of the research in this particular project was centered around the different types of roads and road situations that drivers are in that are outside of their control such as rolling terrains, intersections etc., when trying to determine exactly what sort of impact, positive or negative, occurs when incorporating an eco-drive environment. It is sufficient to say that there are a lot of other factors that determine whether eco-friendly driving behaviors can be implemented on certain roads such as looking at different types of vehicles that are not just limited to passenger vehicles. Commercial trucks and public transportation vehicles require different measures in order to incorporate eco-friendly driving behaviors as they have more vigorous engines and require greater braking distance and headway, all of which are factors that determine how much fuel consumption is being used.

Additionally, it would be interesting to look at locations that offer a robust public transportation system that involves buses operating on a timed bus schedule and see if certain eco-drive habits can happen here. One of the big contributing factors to excess emissions is the stop-and-go process that drivers face so it would be very interesting to see at what rate should buses approach their designated stops when picking up/dropping off passengers and the effect of other cars that are behind the bus. Factors such as advance warning for drivers behind the bus would allow for drivers to either safely and efficiently change lanes to avoid any major change of speed or determining the correct headway and braking distance needed that helps to avoid sudden deceleration and braking that causes a chain reaction effect to all other drivers on the road. School buses would also fall under this category as both these situations do cause a major disruption to the flow of traffic and therefore, fuel consumption and emissions.

Another beneficial area to look at when trying to accommodate for an eco-drive environment is looking deeper into driving behavior in terms of personal driving style. There was a research conducted on such a topic that tried to determine the effects of aggressive driving behavior on fuel consumption and emissions [10]

Combining all these different characteristics can bring about different results and those roads deemed feasible for eco-driving could no longer be considered as other factors put on the road can cause changes. Such factors could also be difficult driving situations due to weather. Drives change their driving patterns when it is typically any weather condition other than sunny/overcast with no precipitation. Precipitation generally tends to increase traffic as the average driver adjusts speeds to go a bit slower and braking distance also increases due to the road conditions. Additionally, certain conditions such as fog near a road that is mountainous and has rolling terrains can also cause variations and it would be interesting to see if eco-drive could still be implemented safely and efficiently in those conditions.

Furthermore, in the rolling terrain study mentioned earlier, it would be greatly beneficial to perform that study when there is a lot more traffic [6]. The reason why is because the initial study was done without traffic and if there was traffic, then the tests were rerun. This also suggests that eco-drive mode may not necessarily be useful in more congested, traffic settings say during peak hours because it relies on the use of more eco-drivers versus less eco drivers

Having proper vehicle inspections and ensuring that the vehicle has all parts operating in the correct way is also important and can be another area to study. Effective car maintenance is important as that ensures that all parts are working appropriately and getting emissions testing is also important.

Another area for further research is to test how effective eco-drive training is. There was a study done that showed that eco-driving classroom training resulted in carbon dioxide emissions by 12.23% [10]. This can be quite an ideal situation to begin with because a twelve percent reduction in such dangerous gas emissions is remarkable without having to address the need to develop new road infrastructure or have a car that is equipped with the latest eco-drive technology as virtually any driver can exhibit some sort of eco-drive behavior as long as they are conscious of it.

Conclusion

This paper attempted to determine which road conditions allow for a safe integration of eco-friendly driving behavior. One of the main reasons for this research was the fact that not every situation calls for an eco-drive environment as that can cause potential harm to not only the ecological environment but also damage to other drivers in the surrounding location. This paper first delineated certain road conditions that may or may positively be impacted by eco-drive and then displayed those conditions in a simulation using SUMO. In the end, the findings discovered through the simulation hold true against the research that was conducted prior to the virtual environment. Fuel consumption and emissions are a great problem that the world is currently facing and with the great advancements in technology, it has now made it a possibility to address the real issue of global warming and the increased pollution caused by the transportation industry.

As discovered in this research and through demonstration through the simulation, there are many factors that determine what causes excess fuel consumption and emissions that can be avoided if certain road conditions, infrastructure, and driving behavior were catered to. One of the biggest reasons why fuel consumption rates are high is because of acceleration/deceleration. Smooth driving has proven to be extremely beneficial as it reduces the consumption rate**.** Further research is warranted in this study as there are various other factors that need to be looked at and addressed.

Team Member Contributions

All team members contributed to the final project and all of this was possible because of a good teamwork environment. All team members contributed to the final analysis of the paper (such as calculating the results, etc for each road segment etc) Everyone's input was needed. Additionally, Kat, Palash, and Sarah focused on the simulation aspect of the paper as well as conducting the background research required in order to create the simulation and present the topic. Charan and Kanav worked creating additional code to extract the results obtained by the simulation and parsing that data into a readable form for conducting the analysis. Alka worked on the analysis of the results of the paper and creating the graphs and tables for a better format to read. Every individual contributed to the write-up on the final report as well.

References

[1] Carbon Pollution from Transportation. (2020, June 25). Retrieved October 30, 2020, from https://www.epa.gov/transportation-air-pollution-and-climate-change/carbon-pollution-transportation.

[2] The Golden Rules of Eco driving. (n.d.). Retrieved October 30, 2020, from https://www.ecodrive.org/en/what_is_ecodriving/the_golden_rules_of_ecodriving/.

[3] Car Emissions and Global Warming. (2014, July 18). Retrieved from https://www.ucsusa.org/resources/car-emissions-global-warming

[4] What is Eco-Driving? (n.d.). Retrieved from http://www.ecodrive.org/en/what_is_ecodriving/

[5] Caban, Jacek & Vrábel, Ján & Šarkan, Branislav & Ignaciuk, Piotr. (2019). About eco-driving, genesis, challenges and benefits, application possibilities. Transportation Research Procedia. 40. 1281-1288. 10.1016/j.trpro.2019.07.178.Dweck, Carol S. "Messages That Motivate: How Praise Molds Students' Beliefs, Motivation, and Performance (In Surprising Ways)." In Aronson, Joshua (ed.), 2006, *Improving Academic Achievement: Impact of Psychological Factors on Education*. New York: Elsevier Science, pp. 37 – 60.

[6] Ma, Jiaqi & Hu, Jia & Leslie, Ed & Zhou, Fang & Huang, Peter & Bared, Joe. (2019). An Eco-Drive Experiment on Rolling Terrains for Fuel Consumption Optimization with Connected Automated Vehicles. Transportation Research Part C Emerging Technologies. 100. 10.1016/j.trc.2019.01.010.

[7] Chen, Chen & Zhao, Xiaohua & Yao, Ying & Zhang, Yunlong & Rong, Jian & Liu, Xiaoming. (2018). Driver's Eco-Driving Behavior Evaluation Modeling Based on Driving Events. Journal of Advanced Transportation. 2018. 1-12. 10.1155/2018/9530470.

[8] Heijne, V., Ligterink, N., & Stelwagen, U. (2017). Potential of eco-driving. UDRIVE Deliverable 45.1. EU FP7 Project UDRIVE Consortium. https://doi.org/10.26323/UDRIVE_D45.1

[9] Chen, Chen & Zhao, Xiaohua & Yao, Ying & Zhang, Yunlong & Rong, Jian & Liu, Xiaoming. (2018). Driver's Eco-Driving Behavior Evaluation Modeling Based on Driving Events. Journal of Advanced Transportation. 2018. 1-12. 10.1155/2018/9530470.

[10] Adamidis, F. K., Mantouka, E. G., & Vlahogianni, E. I. (2020). Effects of controlling aggressive driving behavior on network-wide traffic flow and emissions. *International Journal of Transportation Science and Technology, 9*(3), 263-276. doi:10.1016/j.ijtst.2020.05.003.