The Real Cost of Time: An Analysis of Acceleration on Fuel Emissions

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Abstract:
Everyday countless drivers speed aggressively, in hopes of saving their precious time. However, in doing so, they emit immense amounts of harmful greenhouse gases into the environment. My paper analyzes the effects of acceleration on emission, presenting a model for an optimal driving style that can drastically minimize the emissions of a vehicle.

In my research I emphasize how non-aggressive driving is more efficient by illustrating the effects of acceleration on the fuel emissions of a vehicle. Further, I utilize a VT-Meso model, created by Virginia Tech University, to derive a relationship between acceleration and fuel emissions. The model estimates fuel consumption and emission rates using, the average speed, the stops per unit distance, and the average stop duration. Aggressive driving emits approximately 400% more pollutants, in contrast to non-aggressive driving. My research proves that a minor shift in people's driving style can alter the future of the planet.

Introduction

Problem Definition

More likely than not, getting a vehicle from point 'A' to point 'B' involves the combustion of fossil fuels, a process that emits harmful greenhouse gasses like carbon dioxide and nitrogen monoxide into the environment. In December 1970, United States Department of Transportation, reported the total vehicle miles traveled, to be over 89.9 billion - a number that has nearly tripled to over 246.3 trillion as of December 2011. Such a drastic increase in traffic volume begs the question: What kind of impact do vehicles have on our society? And more importantly, how can we help reduce the amount of pollution we emit in the environment? According to the United States Environmental Protection Agency, also known as the EPA, more than half of the air pollution in the nation is caused by transportation, primarily light-duty automobiles (EPA). Automobiles emit many harmful greenhouse gases into the environment, gases that can, not only harm our environment, but also our citizens. For example, nitrogen oxide is a gas that is emitted by many vehicles and is so toxic that it can penetrate deeply into sensitive lung tissue and damage it, causing premature death. Inhalation of such deleterious particles may cause or worsen respiratory diseases such as emphysema and bronchitis. Another harmful gas emitted by vehicles is carbon monoxide, even though it is colorless, odorless and tasteless, it is still highly toxic. There are several other equally harmful and toxic gases that vehicles emit into our atmosphere, therefore it is important for us, as drivers, to decipher a way in which we can reduce these harmful gases from our environment.

In order to deepen our understanding of how acceleration affects the emissions of vehicles, it is important to first decipher the factors that can potentially influence the rate of emission. For example, some of the factors that can drastically affect the fuel emissions of a vehicle are the characteristics of a vehicle, the atmospheric conditions, the weather conditions etc.; however, none of these factors can be altered or monitored even slightly by the driver. Conversely, a factor that drivers have absolute control over is their driving characteristics also known as the driving style, which can be defined in terms of the speed and acceleration of the vehicle.

Recent studies conducted by the EPA have shown that in certain situations the driving style can considerably influence fuel consumption and pollutant emissions between a calm and an aggressive driver. Therefore, one possible resolution to reducing the detrimental environmental impact caused by mobile transportation is by educating drivers to adopt a non-aggressive driving style. Nonetheless, the questions that originate from this particular resolution are: what are the differences between an aggressive and a non-aggressive driving style, if a driver were to adopt a so called non-aggressive driving style, what amount of emissions could be prevented from being released, and most importantly is it worth the time?

Paper Objective

In the attempts to promote an efficient driving style, this paper will prove: drivers with an aggressive driving style, which can be defined as when a person is constantly accelerating and decelerating, emit a greater amount of harmful greenhouse gases into the environment compared to drivers with a non-aggressive driving style, in which the driver maintains a constant speed. According to the EPA an average American drives approximately 12,000 to 15,000 miles a year (EPA), approximately 250 miles a week. In those 250 miles a driver may have many reasons for choosing to drive with an aggressive driving style. The main argument used to justify people’s poor driving choices is time. According to a survey conducted by the EPA, many drivers who choose to drive aggressively tend to believe that they will save a significant amount of time, and thus act completely oblivious to the amount of pollutants they may emit in the environment. In today's society, everyone wants to save 'their' time which equates to saving money, since time is valued as currency. Furthermore, people are able to achieve both of these desires to some extent by driving aggressively, since by doing so they are saving both time and money. However, this absurd reasoning does not take into account the harmful effects that the excessive emissions will have on the environment. Therefore, the main objective of this paper is to quantify that a non-aggressive driving style is less detrimental to our environment than an aggressive driving style. Although an aggressive driving style may save a driver some time, when getting to their destination, it will emit greater amounts of pollutants into the environment.

Background

There are many variables that influence a vehicle's energy and emission rates. All these variables can be grouped into six broad categories, which are: weather, travel, roadway, traffic, vehicle and driver related factors. The weather related factors are correlated with temperatures, humidity and wind effects. The travel related factors account for the distance and the number of trips. The vehicle related factors account for various things such as the engine size, the condition of the engine, whether the engine has certain parts like a catalytic converter, whether the vehicle's air conditioner is functioning, as well as the soak time of the vehicle—the duration of time in which a vehicle's engine is at rest prior to being started. The roadway related factors account for the surface of the road on which the vehicle is being driven, the roughness of the road, and the incline and decline of the road. The traffic related factors account for vehicle-to-vehicle or vehicle-to-control interaction. The driver related factors, which account for the differences in driver behavior and aggression, are the main focus of this paper because out of all the factors that impact the fuel consumption of a vehicle, the driver related factors are the ones that can be controlled most easily by the driver. Thus, in this paper, the driver related factors are used to analyze the significance of a non-aggressive driving style.

Model Comparison

Prior to the model being utilized in this paper, California Air Resources Board and EPA created several other emission models to construct a relationship between the driving style and the emissions of a vehicle. For example, the MOBILE6, by the EPA and the EMFAC7F, developed by the California Air Resources Board. The only issue that those models have is that they only take into account travel and weather related factors to compute the vehicle emissions, which is why they are not useful for the purposes of this paper. Also, these models generally fail to take into account roadway related factors and, most importantly, driver related factors on vehicle emissions. Moreover, both models only consider the average speed and the amount of miles traveled by the vehicle to estimate the vehicle's emissions. In contrast, the V-T Meso mode utilizes the driver related factors and the vehicle's instantaneous speed and acceleration levels, to the third exponential degree, in order to estimate a vehicle's fuel emissions. Through the use of this model one can compare the amount of emissions a driver will emit driving with a non-aggressive driving style versus an aggressive driving style.

Model's Background

The Oak Ridge National Laboratory (ORNL) collected the data used to develop the fuel consumption and emission model, V-T Meso model, used in this paper. In order to collect the data, test vehicles were driven in the field to verify their maximum operational boundary. From the test runs, the vehicle fuel consumption and emission rates were measured in a laboratory on a chassis dynamometer. Data sets were created that took into account the vehicles energy consumption and emission rates as a function of the vehicles instantaneous speed and acceleration levels. ORNL collected a large amount of data on the amount of pollutants emitted by several different vehicles. The gathered data included hydrocarbon (HC), oxide of nitrogen (NO_x) and carbon monoxide (CO) emission rates. The vehicles that were utilized to conduct these tests included six light duty automobiles and five light duty trucks, as summarized in Table 1.

Data

The data and the V-T model are from secondary sources. These secondary sources do not include sufficient information to calculate the amount of carbon dioxide emitted into the environment by an aggressive driving style. This is unfortunate because carbon dioxide has a great impact on the concerning issue of global warming. To be able to collect data on carbon dioxide and develop a model from that data would require a large amount of time and resources, both of which are unavailable; therefore, secondary data is used as efficiently as possible and the model developed by Kynoungho Ahnn and colleagues is used to calculate the amount of hydrocarbon emissions of a vehicle. However, carbon dioxide emissions would be proportional to the hydrocarbon emissions because they have similar chemical composition.

Year	Make/Model	Engine	Transmission	Curb Weight (kg)	Rated Power (hp)
Light-Duty Cars					
1988	Chevrolet Corsica	2.8L pushrod V6,PFI	M5	1209	130
1994	Oldsmobile Cutlass Supreme	3.4L DOHC V6, PFI	L4	1492	210
1994	Oldsmobile 88	3.8L pushrod V6, PFI	L4	1523	170
1995	Geo Prizm	1.6L OHC I4, PFI	L4	1116	105
1993	Subaru Legacy	2.2L DOHC flat 4, PFI	L4	1270	130
	ORNL LDV average	2.8L, 5.2 cyl.		1322	149
1995	LDV industry average	2.9L, 5.4 cyl.		1315	
Light-Duty Trucks					
1994	Mercury Villager Van	3.0L pushrod V6, PFI	L4	1823	151
1994	Jeep Grand Cherokee	4.0L pushrod I6, PFI	L4	1732	190
1994	Chevrolet Silverado Pickup	5.7L pushrod V8, TBI	L4	1823	200
	ORNL LDT average	4.2L, 6.7 cyl		1793	180
1995	LDT industry average	4.6L, 6.5 cyl			
	8-vehicle average	**3.3L, 5.8 cyl**		1497	160
1995	**LDV+LDT, industry avg.**	**3.5L, 5.8 cyl**			

Table 1: ORNL Test Vehicle Characteristics

Source: Kyoungho Ahn

Vehicle Selection

The vehicles mentioned in Table 1 were selected in order to produce a model of an average vehicle that is consistent with average vehicle sales in terms of engine displacement, vehicle curb weight, and vehicle type. Specifically, the average engine size was 3.3 liters, the average number of cylinders was 5.8, and the average curb weight was 1497 kg. According to the Journal of Transportation Engineering, “the data collected at ORNL has about 1,300 to 1,600 individual measurements for each vehicle and a Measure of Effectiveness” (MOE). The final model was derived through experimentation with numerous polynomial combinations of speed and acceleration levels; specifically, linear, quadratic, cubic, and quartic terms of speed and acceleration were looked into. The final regression model has linear, quadratic, and cubic speed and acceleration terms because it provides a lower number of terms, and is a good fit to the ORNL data.

The model fits the ORNL data accurately for high speed and acceleration levels, however the model is less accurate at lower speeds and acceleration levels.

$$MOEe = \sum_{i=0}^{3} \sum_{j=0}^{3} \left(K_{i,j}^{e}\ x\ s^{i}\ X\ a^{j}\right)$$

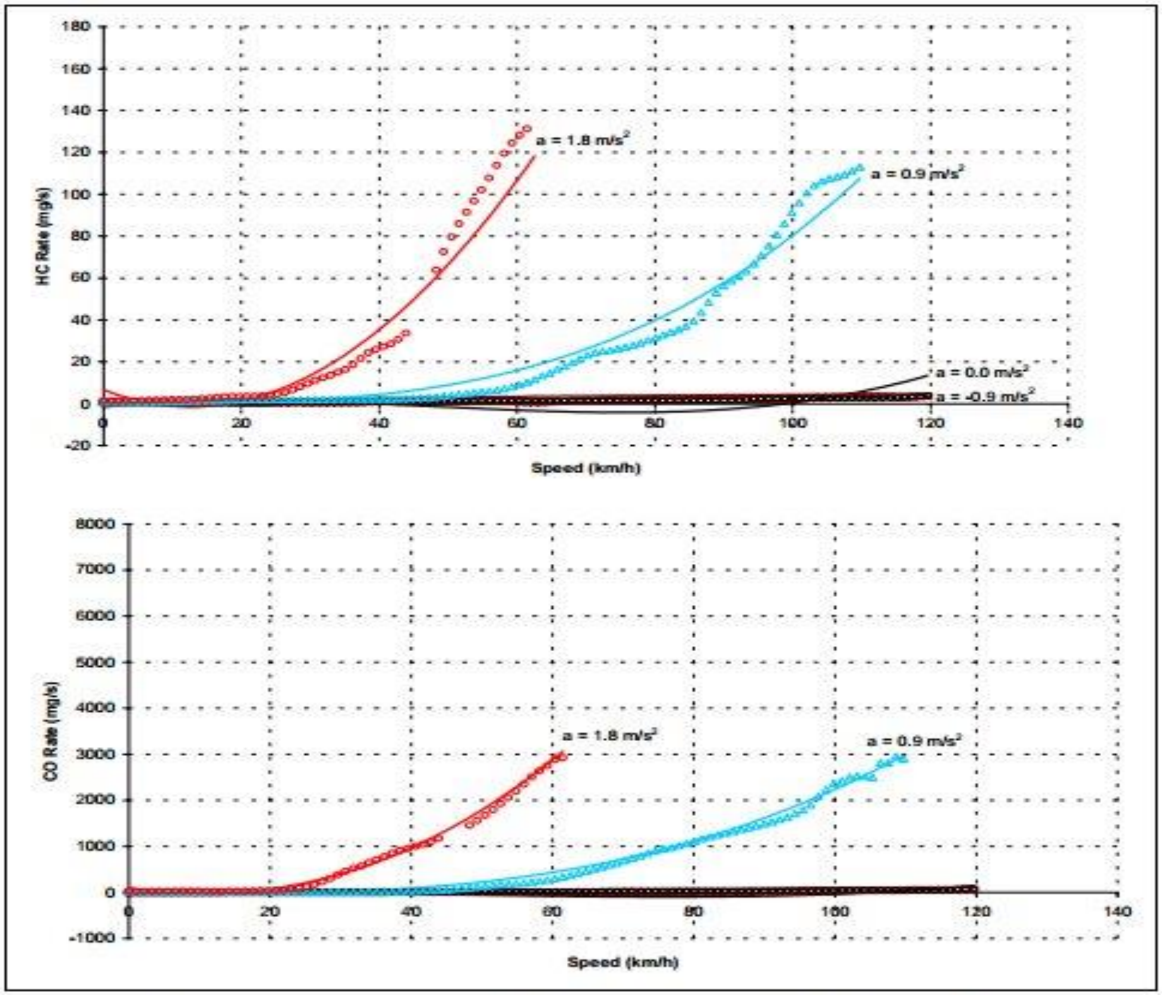

Figure 1: Regression Model Predictions (Composite Vehicle – Polynominal Model)

The model that fit the ORNL data well is as follows:

$$MOEe = \sum_{i=0}^{3} \sum_{j=0}^{3} \left(L_{i,j}^{e}\ x\ s^{i}\ X\ a^{j}\right) \qquad a \geq 0$$

$$MOEe = \sum_{i=0}^{3} \sum_{j=0}^{3} \left(M_{i,j}^{e}\ x\ s^{i}\ X\ a^{j}\right) \qquad a < 0$$

Where:

MOE_e = Instantaneous fuel consumption or emission rate (l/s or mg/s)

Kei,j = Model regression coefficient for MOE "e" at speed power "i" and acceleration power "j"

Lei,j = Model regression coefficient for MOE "e" at speed power "i" and acceleration power "j" for positive accelerations

Mei,j = Model regression coefficient for MOE "e" at speed power "i" and acceleration power "j" for negative accelerations

s =Instantaneous Speed (km/h)

a = Instantaneous acceleration (m/s2)

Coefficients	Constant	Speed	Speed^2	Speed^3
Positive acceleration				
Constant	−0.87605	0.03627	−0.00045	2.55E−06
Acceleration	0.081221	0.009246	−0.00046	4.00E−06
Acceleration^2	0.037039	−0.00618	2.96E−04	−1.86E−06
Acceleration^3	−0.00255	0.000468	−1.79E−05	3.86E−08
Negative acceleration				
Constant	−0.75584	0.021283	−0.00013	7.39E−07
Acceleration	−0.00921	0.011364	−0.0002	8.45E−07
Acceleration^2	0.036223	0.000226	4.03E−08	−3.5E−08
Acceleration^3	0.003968	−9E−05	2.42E−06	−1.6E−08

Note: Speed: km/h; acceleration: km/h/s; HC emission rate: mg/s.

Table 2: Sample Coefficients of Hybrid Regression Model (HC Emissions for Composite Vehicle

Table 2 illustrates the coefficients that are used in the model proposed by Kyoungho Ahn. The model is based on the collection of the ORNL data for vehicle fuel consumption and emissions, in terms of the vehicles acceleration level and instantaneous speed. These coefficients are used to make the model fit well with the data provide results to a higher accuracy.

Coefficients of Determination

In statistics, the coefficient of determination (not to be confused with coefficients of variation) is denoted R^2 and pronounced R squared. It shows how well data points fit a line or curve. Therefore, the coefficients of determination can tell whether or not the function fits to the data being used. It is a statistic, used for statistical models, whose main purpose is either to predict future outcomes or the test hypotheses, on the basis of other related information. It also provides information on how well observed outcomes are replicated by the model, as well as the proportion of total variation of outcomes explained by the model. The most general definition of the coefficient of determination is:

$$R^2 \equiv 1 - \frac{SS_{\rm res}}{SS_{\rm tot}}.$$

Where:

SS_{reg} - variance of the model's predictions

SS_{tot} - total variance of the dependent variable

R^2 does not indicate whether:

The independent variables are a cause of the changes in the dependent variable;

Omitted-variable bias exists;

The correct regression was used;

The most appropriate set of independent variables has been chosen;

There is co-linearity present in the data on the explanatory variables;

The model might be improved by using transformed versions of the existing set of independent variables.

Analysis

The V-T Meso model is used to determine

Whether accelerating and decelerating is more detrimental to the environment than driving at a constant speed.

How much more emissions does a driver pollute and how much time does he or she save, when aggressively trying to pass a car?

Comparisons and contrasts of traveling at a higher constant speed vs. traveling at a lower constant speed, in terms of time saved and emissions produces.

Through this analysis one can judge whether driving with an aggressive manner is worthwhile, considering time and emissions.

I. Is accelerating and decelerating more injurious to the environment than driving at a constant speed?

Accelerating and Decelerating

Scenario:

A driver traveling on the freeway speeds up to 80 km/hr, he or she chooses to accelerate to 120km/hr, which takes him or her approximately 10 seconds, the driver then decides to return to his original speed, by decelerating to 80km/hr, which takes him or her approximately 20 seconds. Assuming that the driver did not apply any braking force to decelerate and anticipating that he or she is traveling on a relatively level freeway (slope approximately close to 0). How much pollution would the driver emit into the environment? In this scenario, there are many variables that are being taken into account to calculate the emissions rate using the model developed by the ORNL data, which focuses on only acceleration levels and instantaneous speed.

SP_1 = 80 km/hr

$\Delta a = \Delta SP / \Delta T = 4$ km/hr^2 acceleration

$\Delta a = \Delta SP / \Delta T = 2$ km/hr^2 deceleration

T_1= 0 seconds

T_2= 30 seconds

SP_2= 120 km/hr

$\Delta T = T_2 - T_1 = 10$ seconds

$\Delta SP = SP2 - SP1 = 20$ km/hr

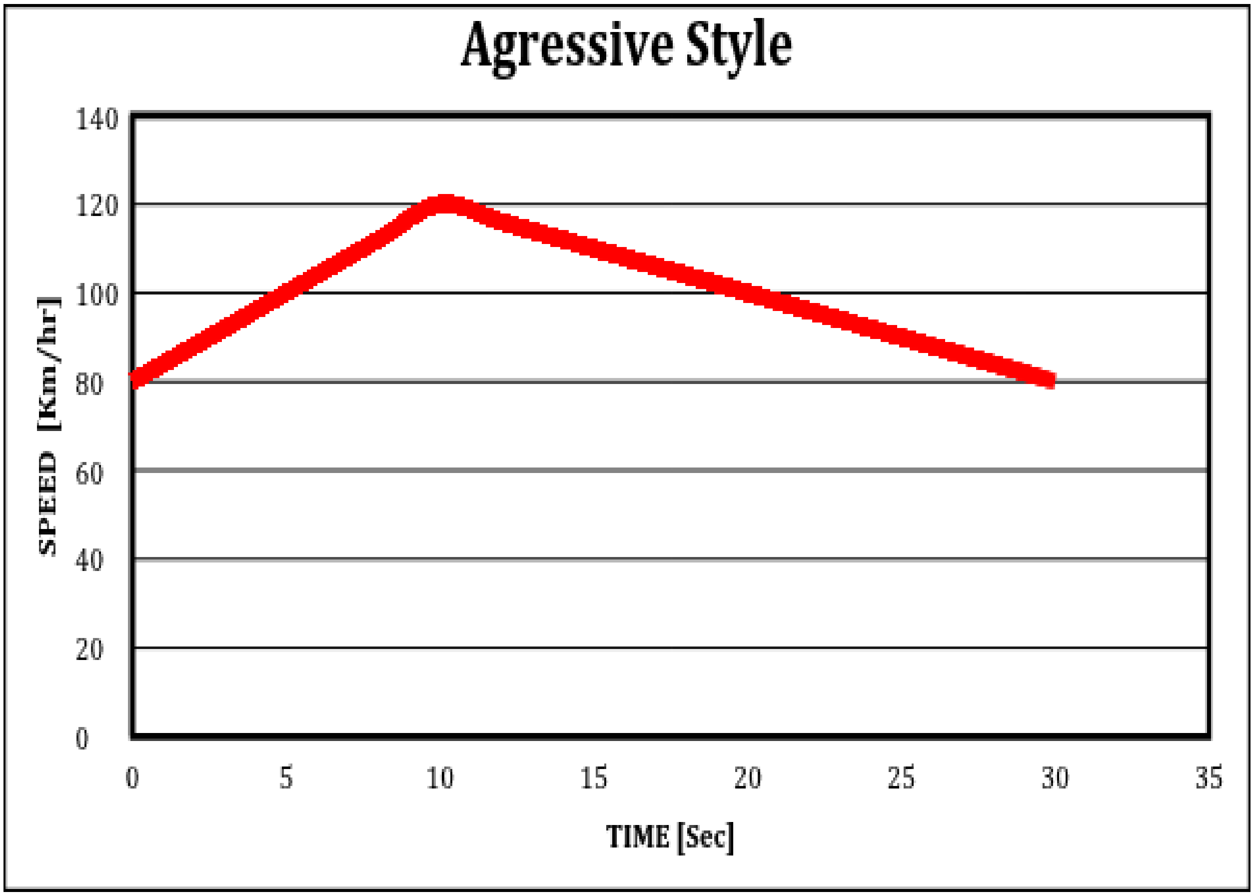

Figure 2: Agressive Style

In the time interval of 30 seconds the driver accelerated to 120 km/hr and then decelerated to 100 km/hr, emitted approximately 168 mg of hydrocarbons in 30 seconds.

Constant speed (Non-aggressive driving)

Scenario:

A driver traveling on the freeway speeds up to 100 km/hr. He or she chooses not to accelerate and maintain a constant speed. How much pollution would the driver emit in the environment?

SP_1 = 80 km/hr Δa=0 km/hr^2 (assuming constant speed is maintained)

SP_2= 80 km/hr T_1= 0 seconds T_2= 30 seconds

ΔSP=SP2-SP1=0 km/hr Δ T = T_2-T_1= 30 seconds

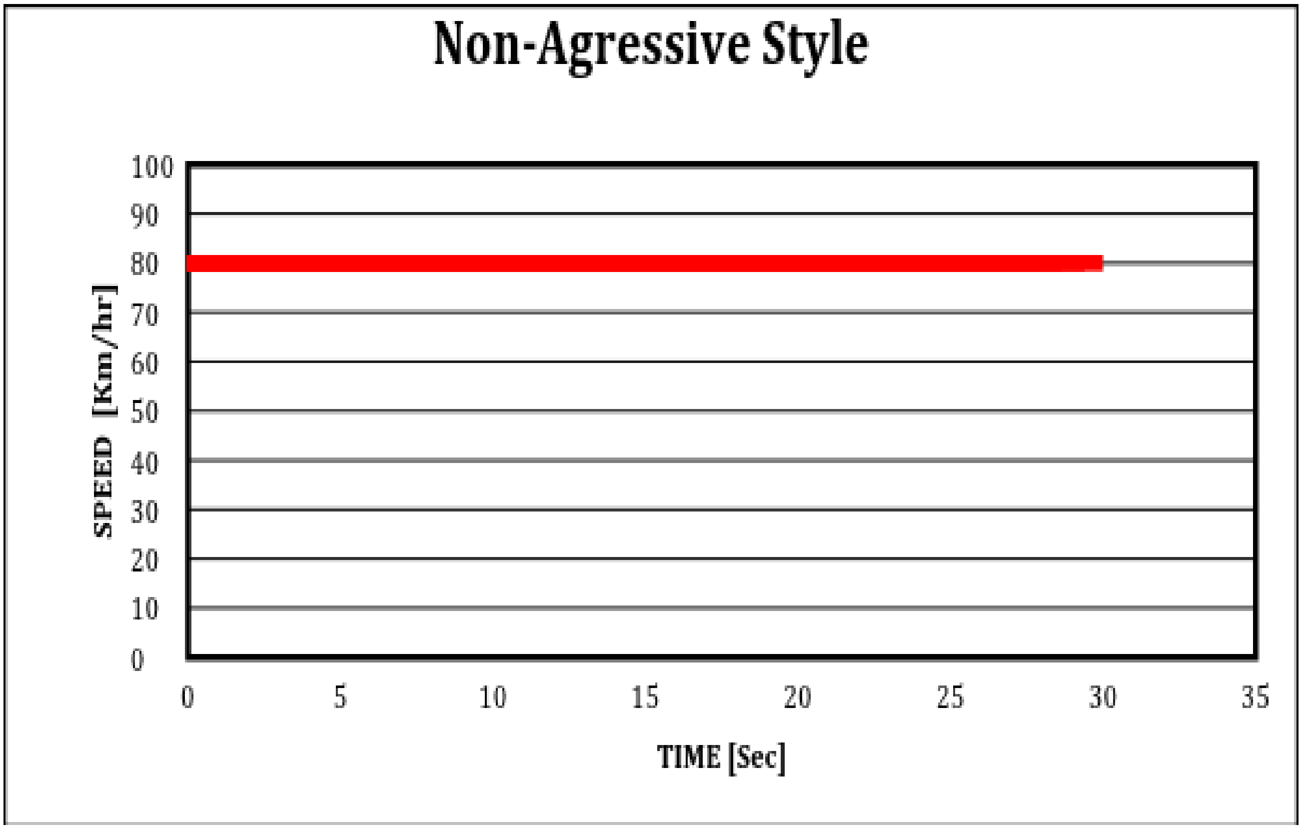

Figure 3: Non-Agressive Style

In the time interval of 20 seconds the driver, maintained a constant speed of 100 km/hr, emitted approximately 13.5 mg of hydrocarbons in 30 seconds.

Conclusion for I

The driver with an aggressive driving style, who chooses to accelerate and decelerate when it was not necessary, emitted 168.5 mg of hydrocarbons in the environment; whereas, the driver who maintained a constant speed throughout only emitted about 13.5mg of hydrocarbons in the environment. According to the calculations, the aggressive driver emitted 1350% more emissions than the driver that drove with a non aggressive driving style, therefore accelerating and decelerating is exceedingly harmful for the environment, because it releases a larger amount of harmful pollutant into the environment, when compared to driving at a constant speed which releases a smaller amount of pollutants into the environment.

II. How much more emissions does a driver put into the environment when he or she is aggressively trying to pass a car.

Purposely passing a car

Frequently, there are those drivers who are always in a rush when driving, regardless of how long their commute is. The most popular cause behind this behavior is time. Drivers think that by driving faster they will save a lot of time so, in order to save time they try to pass a car and speed as much as possible (EPA). In this case, how much time does a driver really save doing this and how much more pollutants does he or she emit in doing so.

A driver traveling on the freeway speeds up to about 100 km/hr, he chooses to accelerate to about 120km/hr, to pass a car in front of him, which takes him about 10 seconds, and then he decides to slow down because the car in front of him is traveling at a lower speed than him, therefore he decelerates to 100km/hr, which also takes him 20 seconds. Then he travels at a constant speed of about a 100 km/hr for about 100 seconds. Assuming that he did not apply any brakes to decelerate and anticipating that he is traveling on a relatively level freeway (slope approximately close to 0), what is the amount of pollutants that he emitted traveling approximately 3.8 km? Also, what is the amount of time that he saves compared to a driver who travels the same amount of distance, but at a constant speed of 100 km/hr?

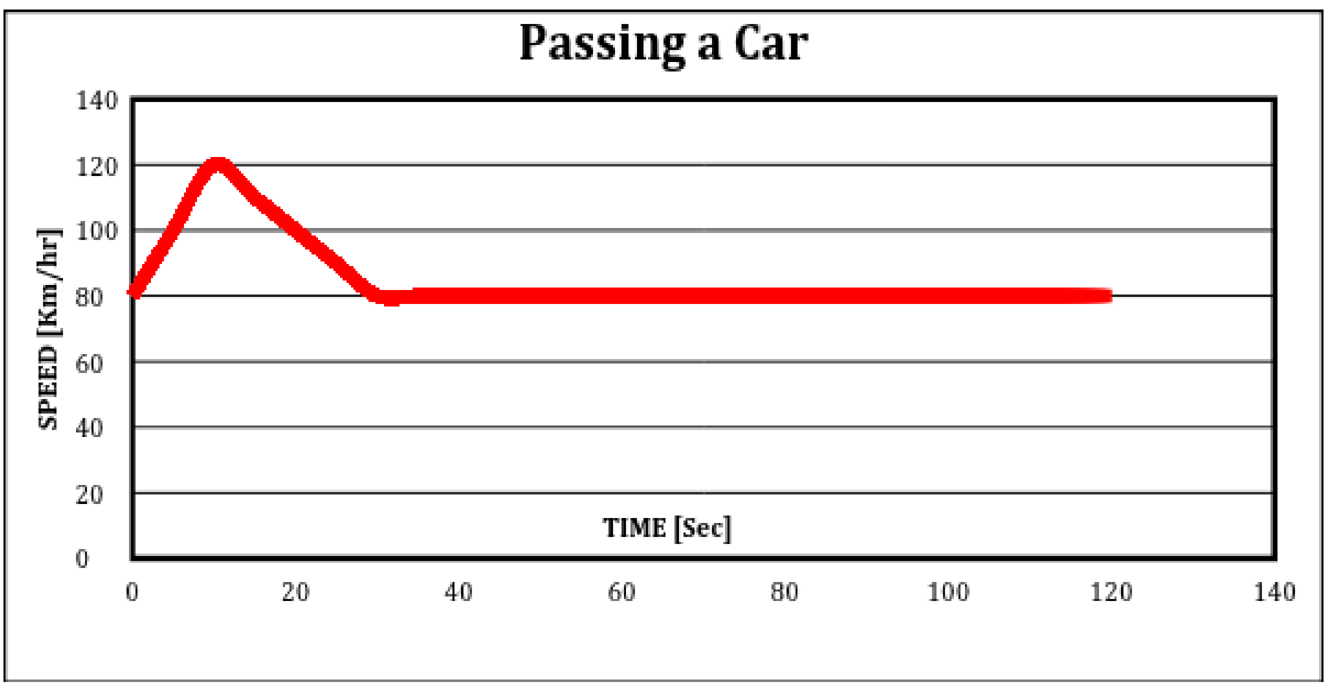

Figure 4: Passing a Car

Versus:

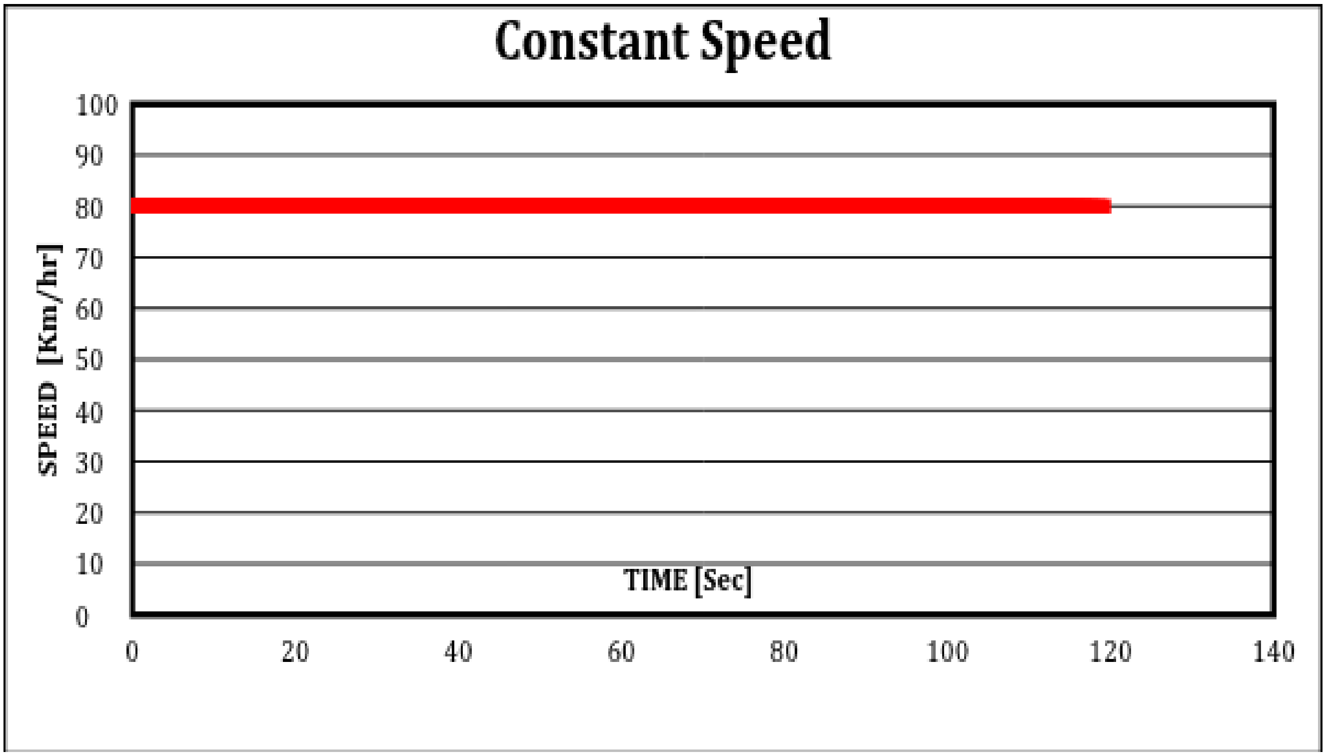

Figure 5: Constant Speed

Conclusion for II

The driver, who intentionally drove in an aggressive manner, by passing cars, emitted 208 mg of hydrocarbons in the environment and only saved about 2 seconds doing so, whereas the driver who drove with a non-aggressive driving style only emitted 57.5 mg of hydrocarbons in the environment and lost 2 seconds. The aggressive driver emitted 4 times more pollutants into the environment just so he could save two seconds. Clearly, the cost, four times the amount of pollutants, is not worth the additional benefits, 2 seconds.

One driver, in the span of 2 minutes, created 363% more emissions. The numbers would be on even more disconcerting if the driver were to pass more cars, which is highly likely, and also if the driver were to travel more than 3.8 km with the same driving style. There are countless drivers who choose to drive this way, even though it is completely unnecessary. Imagine the amount of pollution they create everyday just by choosing to pass a car.

III. Compare and contrast traveling on a higher constant speed vs. traveling on a lower constant speed, into terms of time savings and emissions released in the environment. Would it be better to travel at a higher constant speed versus a lower constant speed?

Higher constant speed vs. Lower constant speed

In terms of time, if a driver were to travel at a constant speed of a 100 km/hr for a distance of about 3.389 km. It would take him/her about 122 seconds or 2 minutes and 2 seconds. The amount of emissions that the driver would release would only be 97.72 mg of hydrocarbons. However, if the same driver were to travel the same distance at 105 km/hr, it would only take him about 116 seconds or 1 minutes and 56 seconds. Therefore, he/she will save approximately six seconds of time in that particular commute, but will emit 107.2 mg of hydrocarbons in the environment. By driving at 105 km/hr rather than 100 km/hr there was a time saving of about 4.8% with a 9.7% increase in emissions. Hence, driving a bit faster only to save six seconds does have some consequences when it comes to polluting the environment. However, to determine whether it is worth it to drive a bit faster and pollute the environment, only to save a few seconds, is a decision that the driver will have to make.

Conclusion for IIII

Every day countless drivers release excessive amounts of harmful pollutants into the environment, in order to save a few seconds of their time. They are completely oblivious to the harmful effects of their actions. A simple yet effective solution to this issue is the utilization of a non-aggressive driving style. A driver can easily manipulate the way he or she drives and, with the use of an optimal driving style, a substantial change can be seen in the amount of emissions generated by a vehicle. As shown, a non-aggressive driving style is much more efficient than an aggressive style in terms of the amount of pollutants emitted by a vehicle. The V-T Meso model used in this paper helps to prove that by driving at a constant speed a driver can emit almost 4 times less pollutants than driving with an aggressive style. The paper only provides the data in hydrocarbons because of the unavailability of data for other gases such as carbon dioxide, however those ratios are proportional to the ratio of the hydrocarbons. In addition, the paper also proves that though an aggressive style driver can save a couple of seconds in a small commute, the driver will emit a superfluous amount of lethal hydrocarbons into the environment. Thus we can conclude that by not driving aggressively, not only will the driver emit less harmful pollutants, but he or she will also have a less stressful commute, therefore decreasing the chances of getting into to a collision and jeopardizing their life along with the lives of other drivers. Because of these reasons, it is important that drivers incorporate a non-aggressive driving style into their own driving habits, thereby decreasing the chances of being involved in an accident and making a difference one trip at a time.

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