What is the most efficient way to drive a car?

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Abstract

Our greenhouse footprint is a topic of high importance lately, and of the biggest contributors to it is transportation. Vehicle manufacturers have already started the production with never seen before efficiency, but how one drives these vehicles also plays a crucial role. We attempted to come up with one, or more, efficient driving patterns for a variety of every day driving scenarios, through the use of a computational model and we optimized our model using a machine learning algorithm. We claim that our machine learning model revealed universally applicable driving patterns, which can lower consumption levels in various every day scenarios. We tested these claims, using a traditional optimization model and computer simulations. What results are a number of suggestions that anyone can apply into their driving and improve upon their performance independent of the type or make of the vehicle they drive.

Contents

1 Introduction

Reports [1] show that CO2 emissions have risen in the past few years all throughout Europe. The expense that accompanies this trend in the form of environmental damage and the shortening, of the already finite, fuel sources (only a very small percentage or vehicles use alternative means of fuel such as electricity) call for an immediate change. The transportation industry contributes, to about 1/5th of the global emissions [2], of which 75.4% comes from road vehicles. Thus, one can understand that even minor changes can make a great impact in the long run.

Vehicle manufacturers have, in recent years, initialized their research towards more sustainable and eco-friendly solutions with many of their products already in mass production. Turbo engines, better compression ratios, electronic fuel injectors, better fuel quality and new crankshaft designs are only some of the innovations that make today's, conventional, engines more and more efficient with each year that goes by. While also, hybrid and electric cars are more and more common [3]. However the lack of sufficient infrastructure to support and maintain the new technologies that car manufacturers have developed, have not yet allowed sustainable vehicles to apply to the masses.

Shifting our focus on the driver, a car's consumption is now an important factor when deciding on the purchase of a new vehicle, with more efficient cars tending to sell more than their counterparts. This study does not focus on making this decision easier but it rather tries to find a driving pattern that can be used independently of the type or make of vehicle.

What makes a driving style efficient, whether on not there is more than one way to achieve an eco-friendly driving and whether or not is safe to drive like this are some of the questions that arise when trying to come up with a definitive answer. Previous attempts have been made on the matter, which mainly included real world case studies on public transportation vehicles [4][5] or algorithms that fed on real world data, for passenger vehicles [6]. In this report, a computer simulation handles the car model while a machine learning algorithm is responsible for the driving optimization.

2 Methodology

2.1 Car and fuel consumption models

As far as manufacturing goes there are 4 main factors that brands focus on when designing the car, that play a major role in its performance. Those are: the aerodynamic design, the engine style, the weight of the car and its transmission. For the purpose of this study all of the above were modelled after the most sold car in the UK for the past few years, the 2020 Ford Fiesta. We also wanted to avoid an automatic transmission since a manual one allows for more control from the driver. Last but not least it should be stated that although the transmission was manual, unlike a real car, the driver did not have to lift his foot off the gas pedal in order to change gears.

A model for the mechanical part of the car had to be built first before looking into optimized driving. In this report we based the focus of the model on the power plant, the engine, of the vehicle since it consumes the majority of the fuel. For simplicity reasons, the assumption was made that the rest of the car's components used up no fuel. The flow chart for it can be found in appendix A.

An internal combustion engine, which is the most widespread kind, operates in a 4-stroke cycle [7] (Figure 1) which forces the pistons to oscillate and hence move the crankshaft which in its turn transfers this movement to the wheels with the use of the gearbox and the wheel axle [8].

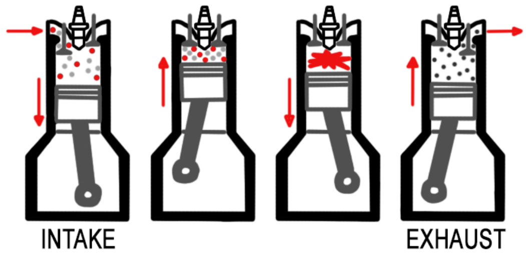


Figure 1: The 4 strokes of a piston's cycle with time moving from left to right. The horizontal arrows mark the direction of air flow while the vertical ones the piston's movement direction.

It is important to understand that fuel is only injected during the first stroke and also that two revolutions of the crankshaft correspond to a single complete 4-stroke cycle, as seen in Figure 1. In engines with multiple pistons, the process of moving the crankshaft is divided between them. Stability, dictates that there should never be two pistons performing the same action at any given moment, so pistons perform one of the four strokes (intake, combustion, expansion and exhaust) in succession. Their lateral movement is translated to rotational movement of the crankshaft which then transfers it to the wheels through the gear box and the wheel axles. The fuel used per revolution of the engine can be expressed as follows:

$$Fuel\,Used = \frac{RPM}{2} * \frac{ED}{Number\ of\ pistons} * \rho_1 * \phi \ \ [g/minute] \tag{1}$$

Here, ED is the engine's displacement -corresponding to the aggregate of the volume of all the piston cylinders in the engine, commonly known as the 'cc' value when looking at a car's specifications- and has units of litres, ρ_1 is the density of air in the engine (in km/m^3) and ϕ is the air to fuel ratio (mass to mass). Here the engine's displacement is divided by the total number of pistons to account for the 4-stroke property described before. Please note that here, we assume that the volume of air equals that of the cylinder and also that the fuel's volume is negligible when compared to it.

2.1.1 The engine loop

During the development of the computational model, a problem surfaced regarding the cycle of how movement is translated from the crankshaft, inside the engine, to the wheels. The two are interconnected with a never ending loop. The RPM meter on every commercial car, shows the driver the revolutions of the engine's crankshaft which are determined from how fast the wheels of the car are turning which in its turn is dictated from how fast the crankshaft is turning. In the real world, the clutch takes care of connecting the two components and keeps the system working flawlessly. Attempting to develop a program that incorporates it however, is a very complicated task that exceeded the scope of this study. To resolve this, initial conditions imposed on the car while also, a new approach of the throttle pedal was developed.

All vehicles simulated would start with an initial speed that matched the lower speed limit of the type of road there were on. The throttle was designed so that when it was fully engaged it would deliver the maximum acceleration the car was capable of, which for the purposes of this simulation, was given by:

$$A_{max} = \frac{100km/h}{t_{0-100}} \tag{2}$$

Where A_{max} is the maximum acceleration in m/s^2 and t_{0-100} is the time the car would accelerate from 0 km/h to 100km/h. The latter value was taken from the official specifications given by Ford. The acceleration would then be scaled depending on how much pressure one applied on it, so the acceleration that the car would experience is given by equation (3), where $P_{throttle}$ is the pressure (with a range of 0% - 100%) applied on the pedal.

$$A = A_{max} * P_{throttle} \tag{3}$$

2.1.2 Innovations

As mentioned before, car manufacturers come up with ingenious ways and devices that improve upon their cars' performance. To include and test every single one, is a task that far exceeds the limits of this study, thus it was considered a better idea to only include innovations that are common throughout the whole industry. These are, the electronic fuel injection system and the electronic throttle control (ETC). The latter one is the device that controls the volume of air going into the engine, while the other one ensures that the correct amount of fuel is injected in order to achieve the optimal explosion during the 3rd stroke. An important feature of them is that, for the majority of today's cars, lifting the accelerator pedal corresponds to the ETC cutting the air flow into the engine. When the injection system detects that, it regulates the fuel supply in one of two ways. Either there is no fuel, or very small amounts of it go into the piston chambers. Car manufacturers have also used different techniques, but these are the two most common scenarios for a gasoline engine.

For the purposes of this study, it was assumed that no pressure on the acceleration pedal would result into no fuel being injected. This has the added effect of engine braking. Engine braking is responsible for the sudden deceleration one experiences when lifting off the throttle completely. This is caused, during the first stroke of a cylinder's cycle, when the intake valve is completely closed. The downward movement of the piston effectively creates a vacuum inside its chamber. The piston now needs to waste more energy to move, resulting in its kinetic energy decreasing. This process is repeated thousands of times a minute (depending on the car's RPM) and it has the collective effect of slowing down the crankshaft which ultimately slows down the whole vehicle. In an attempt to simulate this, when the network did not engage the throttle, the deceleration due to drag was doubled.

2.2 Road profile

The road is also an important factor of the driving experience that must be taken into account the model. Cars behave differently depending on the road profile that there are situated and in an attempt for consistency, a series of assumptions were made: All the roads simulated

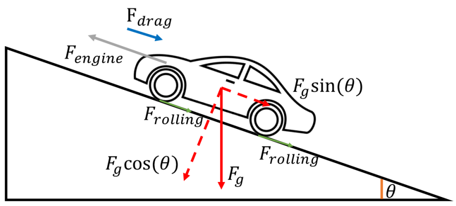


Figure 2: Definitions of vehicle weight F_g, tyre rolling resistance $F_{rolling}$, aerodynamic drag F_{drag} and the force produced by the engine F_{engine}.

followed official speed limit rules, official construction restrictions (incline grades and turning radii) and had a uniform surface.

Dynamically, this meant that the car would constantly have a force opposing its movement in the form of rolling friction, equation (4), while if it was situated on a slope it also experienced a downwards facing force proportional to sine of the angle of slope, equation (5). In addition, the aerodynamic force exerted on the car can been seen in equation (6).

$$F_{rolling} = M_{car} * g * \mu \ \ [N] \tag{4}$$

$$F_{incline} = M_{car} * g * sin(\theta) \ \ [N] \tag{5}$$

$$F_{drag} = 1/2 * \delta * A * v^2 * \rho \ \ [N] \tag{6}$$

Here, M_{car} is the mass of the car, g is the acceleration due to gravity, μ is the tyre friction coefficient and θ the angle of the slope, δ is the car's drag coefficient, A is the cross-sectional drag area of the vehicle, v is th velocity of the car and ρ is the air's density. Figure 2 shows a sketch of all the basic forces applied on the car while its moving up an incline at constant speed.

Last but not least, one of the simulated test cases included the car situated in a turn that span for 1km. Physics dictate that a body moving in a circle would actually have to be below a certain speed limit to continue moving in a circular path. The limit V_{limit} is given by equation (7) where, g is the acceleration due to gravity, μ_{static} is the static friction coefficient for a tire on asphalt and R is the radius of the corner. During the simulations, any driver that exceeded this limit would be eliminated.

$$V_{limit} = \sqrt{\mu * g * R} \ \ [m/s] \tag{7}$$

Us humans are able to estimate this limit based on our experience, however that is not the case for the computer algorithm. Thus, it was decided to give the radius of the turn as one of its inputs.

2.3 Driver

In an attempt to simulate a real driving experience the input of the network was adjusted to the information a human driver would be able to collect: The car's current speed, RPM and gear, the throttle's position, the road's limits and profile were all the inputs the network received at any given time. Additionally, the rate at which the network could act was also changed to match a real driving scenario. The computer was allowed to shift through gears at a minimum of 2 seconds between each shift and it could precisely control the throttle every half a second. Moreover, there was no wheel control involved. With consistency in mind, it was also assumed that the network made no mistakes in its control of the car and it did not exceed the vehicle's limits. Last but not least, the car was able to move unimpeded by obstacles.

2.4 Optimization

The first of the two methods used for optimizing the model was Machine Learning and the NEAT module was the implementation of choice. NEAT stands for NeuroEvolution of Augmenting Topologies and it works using the same principles as natural selection. The model starts with an, initially, simple neural network structure, shown in Figure 3(a), having only an input and an output layer, and progressively evolves using both the connection weight mutation, such as other machine learning models, and the structural mutation processes [9 I.A]. The latter, allows the computer to add new neurons and connections to the network, thus making it more complex as generations go by. The evolution process is dictated by the performance of each individual from each generation. The best performing ones get to breed and thus inherit their characteristics to the next generations to come. Compared to other evolution algorithms NEAT is unique because it keeps track of a gene's (a gene here is a structure that involves a series of neurons and connections) history [Reference 9 II.B]. This makes for a more efficient and faster converging model.

In this case study the network had to drive a car simulated using the model described above, so the individuals of each generation were drivers. Thus, any reference to drivers, or cars or individuals and their performance, correspond to the neural network.

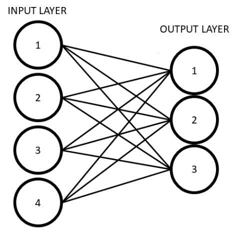
As mentioned above, in a similar manner to other machine learning algorithms, NEAT utilizes weights which act in the connections between the nodes and allows it to make decisions and evolve. Here, we are not going to investigate this process in detail but a more complete approach can be found in K. O. Stanley and R. Miikkulainen "Efficient evolution of neural network topologies," [9].

$$W_{new} = W_{old} - \eta * \frac{\partial L}{\partial w} \tag{8}$$

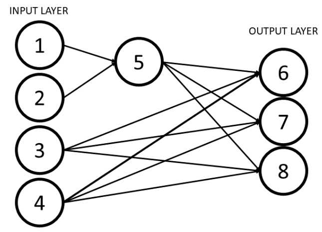
Equation (8) is the weight update formula. W_{new} and W_{old} correspond to the updated and old weights of that connection, while η and the derivative are the learning rate and the loss derivative of that particular weight. The value of η is constant for the model.

Another factor that the decision making process of the network heavily relies on, is its activation function [10]. The input layer supplies the network with information about the current situation, which is then used to produce a value that is fed in the activation function. The output of the function will determine whether or not a specific connection and/or neuron will be activated. The process is then repeated for all connections between all the neurons of the neural network.

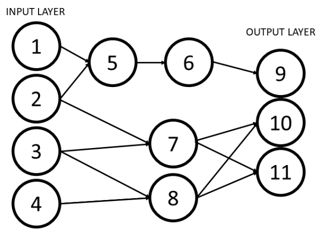
An additional use for the activation function is during the back-propagation process [11]. Back-propagation takes care of the optimization for the neural network, by trying to reduce the difference between the output value of the network and the value we are looking for. Mathematically this is described by equation (8). The process, as its name suggests, starts from the output layer and propagates back through the network updating every connection



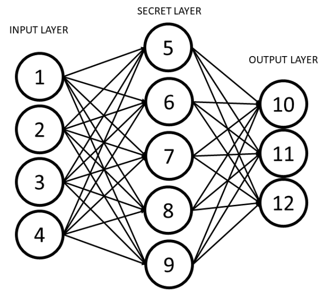
(a) Initial structure



(b) First mutation



(c) Several mutations later



(d) Example of a final structure

Figure 3: Visual representation of the evolution process of a random network's structure.

weight. It is crucial for the evolution process, that the derivative $\frac{\partial L}{\partial w}$ does not approach and does not equal to zero. If that is not the case, the algorithm would not be able to back propagate correctly up to its input layer, thus damaging its evolution process. This symptom is called the 'dead neuron symptom'. The derivative is directly related to the gradient of the activation function, so it is crucial for the user to select an appropriate one.

A different take on the Rectified Linear Unit (ReLU) function, called leaky ReLU is the activation function used in this algorithm. It takes an input value and outputs it back if it is positive or it outputs its product with a fixed value - here we have picked a negative one - if the input is negative.

$$F(x) = max(0, x) \;\; if \;\; x > 0 \;\; or \;\; F(x) = -0.01 * (x) \;\; if \;\; x < 0 \tag{9}$$

This makes for a function with a wide enough range to make for an accurate representation of pressure applied on the throttle. Additionally, leaky ReLU's gradient is non-zero for positive and negative values, which eliminates the dead neuron symptom. Another advantage of this function is that it requires minimum computational power making the algorithm more efficient than other alternatives [10].

Another feature of the algorithm is that, the user has a choice of the fitness threshold and the number of individuals in a generation. The threshold sets the benchmark that the user wants the network to surpass and it also acts as the trigger to stop the evolution process. The higher this value is the better the performance of the network will be at the end. To find an appropriate value, an impossible benchmark was initially used. This caused the fitness of the best performing individuals to converge after a number of generations. The process was

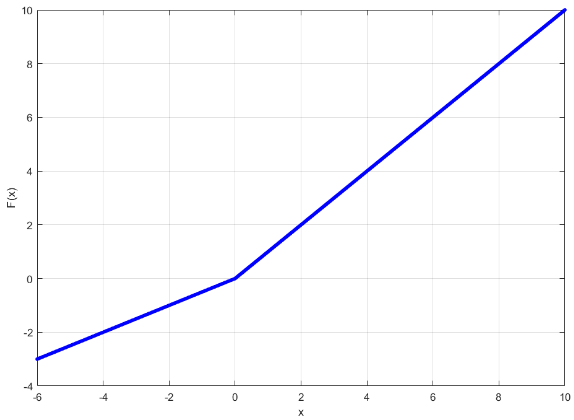


Figure 4: Example plot of a ReLU function

repeated a total of 10 times and the average of the fitness values recorded was the threshold used from that point forward. The same strategy was followed for all the different test cases of this study.

It is also important to mention the reward system used here. The algorithm updated at a rate of 60 times a second. With each update, the individuals were rewarded for staying alive and punished proportionally to their consumption levels. To pursue them to keep moving forward, a checkpoint was also introduced that rewarded the network relative to how far it had travelled. Moreover, if a car drove below or above the speed limits of the road for an extended period of time, it would be eliminated.

2.5 The tests

Table 1, shows the different driving scenarios simulated for the purposes of this study.

Scenario	Lower speed limit (km/h)	Upper speed limit (km/h)
Straight 500m (u)	10	45
Straight 1km (m)	30	96
1km incline (m)	30	96
Varying incline (u)	10	45
Varying incline (m)	30	96
Turn (u)	8	45
Traffic (u)	8	30

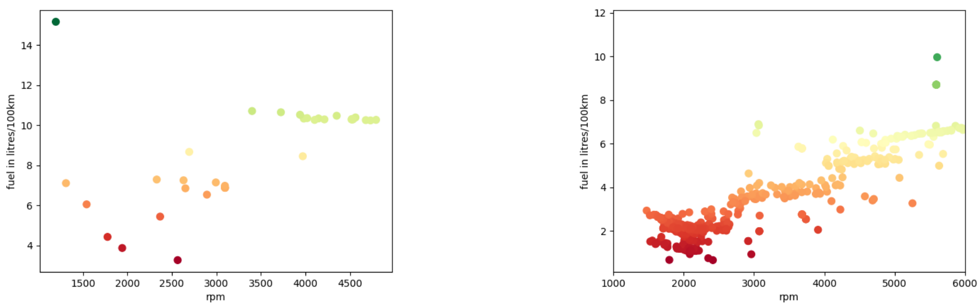
Figure 5: Table 1, the driving test cases

Indices inside the parentheses correspond to the different road types the vehicle was on, which determined the speed limits used for that test case. (u) stands for urban and (m) for motorway roads respectively. The 2km/h decrease seen in the last two scenarios were added after observing that the network struggled to cope with the initial 5km/h reductions, which were introduced in an attempt to, more realistically, simulate these cases. Last but not least, a 20% reduction applied on the upper speed limit of the traffic case.

3 Results

3.1 Efficiency levels and RPM

Figure 6 shows fuel consumption in litres per 100km for the straight road scenarios for both an urban and a motorway environment, as a function of the average RPM. Each dot represents a different driver that made it to the end or the route. Results clearly agree with the intuitive idea that more revolutions equal to a greater consumption levels. Additionally, the two plots reveal that below a certain RPM, efficiency drops down again. It can be clearly seen that in both graphs, when the RPM drop below 2000 there is a noticeable increase in fuel consumption levels. This is caused due to the fact that driving a car at such low RPM would correspond to it travelling at a very slow speed, thus taking longer to complete a route and consume more fuel while doing so.



(a) 500m straight, urban (b) 1km, motorway

Figure 6: Consumption levels of drivers that completed their course, on a straight road in an urban and in a motorway scenario, for 500m and 1000m respectively. A single dot represents one car that made all the way to the end, while the colouring of them depends on the consumption levels recorded by each of them.

The spread of the data, is a glaring indication that although fuel consumption and RPM are related with each other, the driving behaviour of the driver plays the most crucial role. It was observed that drivers who followed more efficient strategies were able to achieve similar consumption levels to drivers that averaged 2000 less revolutions.

Moving on, table 2 shows a pattern in the driving of the most efficient drivers, for all scenarios tested. What is immediately obvious is that all of them drove their car in the 2000 - 2500 RPM range and that there is a clear distinction between the urban and the motorway scenarios. Motorway efficiency always outperforms the city one during testing from car manufacturers [12], a trend that is also noticeable here. The 3 motorway scenarios correspond to the 3 lowest consumption levels recorded while, the lowest consumption between urban scenarios is 30% larger than the least efficient motorway test case.

Moreover, Table 2 shows that although when travelling on the motorway drivers strive to travel near the lower speed limit that does not hold true for the urban test cases. The speeds recorded for all urban scenarios were on average 15km/h above the speed limit, 3 times more than the 5km/h average for the motorway scenarios, indicating that when one is forced to drive at slow speeds the most efficient strategy is to remain in between the two limits of the road.

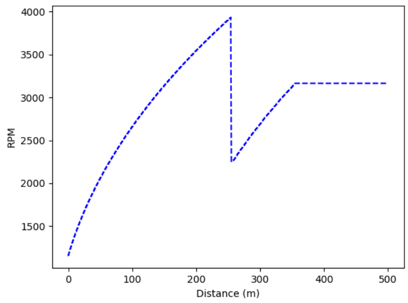
Scenario	Avg. RPM	Avg. Speed (km/h)	Gear	Fuel in l/100km
Straight 500m (u)	2565	37	2nd	3.3
Straight 1km (m)	2416	51	3rd	0.7
1km incline (m)	2434	83	4th	2.01
Varying incline (u)	2342	38	2nd	5.77
Varying incline (m)	2422	62	3rd	2.09
Turn (u)	2485	21	1st	3.8
Traffic (u)	1962	30	2nd	5.49

Figure 7: Table 2, showing the data of the best performing individuals recorded for all the different scenarios tested. The cars were limited to the top speed of the road there were in and the drivers did not have the ability to select the neutral setting of the gearbox. Indices inside the parentheses correspond to the type of road the car was in. (u) used for the urban case and (m) for the motorway one, with the top speeds being 45km/h and 96km/h respectively. The gear corresponds to the average gear used by the drivers, and not the only gear they used, and it was rounded to the nearest integer.

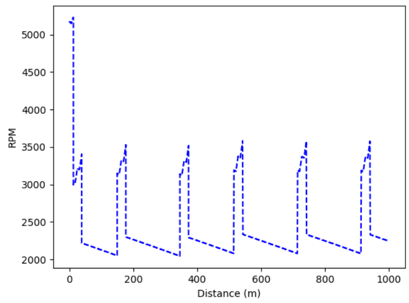
The best efficiency was recorded during the 1km straight road test case with a consumption as low as 0.7 litres/100km, while the most efficient urban test case was the 500m straight road case with 3.3 litres/100km. What is interesting is that there is not a direct relation between how fast a car was travelling and how much fuel it consumed. The fastest speed recorded at 83km/h corresponded to the second lowest consumption seen with 2.01 litres/100km while the least efficient scenario was the second slowest one, the urban varying incline with an average speed of 38km/h and 5.77 litres/100km.

A look into the exact driving patterns followed by the network helps up reach another important conclusion. Fuel efficiency is directly proportional to the acceleration of the car. Figure 8 shows the driving styles, in terns of RPM as a function of distance, used by the network to achieve the consumption levels stated in the table above, for the straight road scenarios. The 500m straight road, the continuous 1km long turn, the urban varying incline and the traffic are the least efficient scenarios, and also the test cases that the cars would accelerate the most.

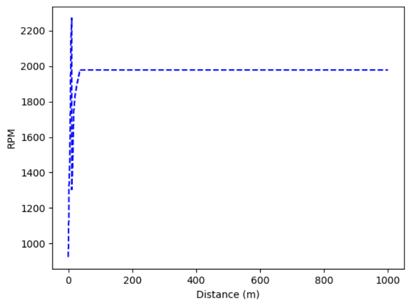
3.2 Driving behaviours



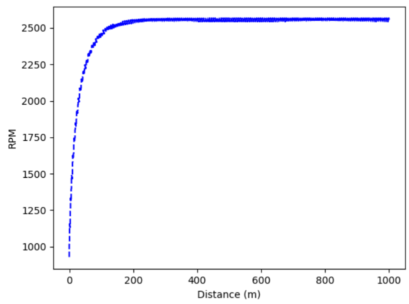
(a) Straight 500m



(b) Straight 1km



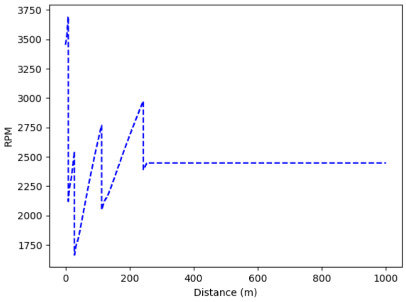
(c) Traffic



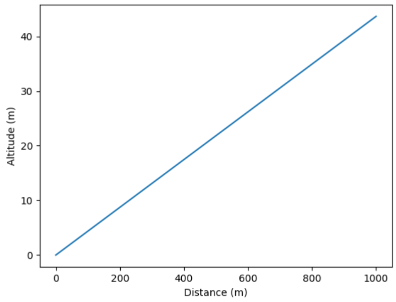
(d) Turn for 1km

Figure 8: RPM as a function of distance plots for the efficiencies recorded for the straight road scenarios in Table 2.

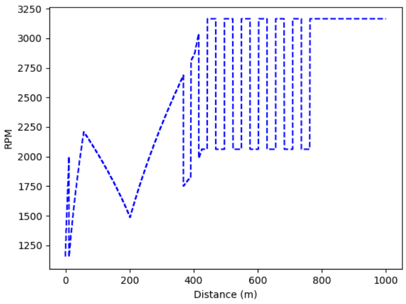
Figure 9 shows RPM as a function of distance for the incline scenarios along with the road profile for each of them.



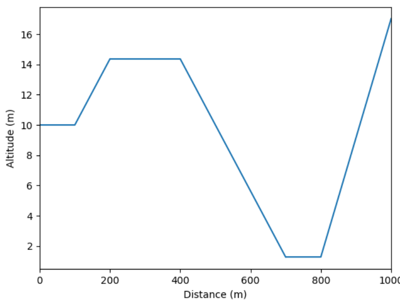
(a) Continuous incline for 1km



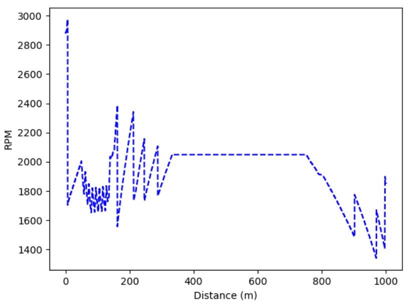
(b) Continuous incline for 1km, road profile



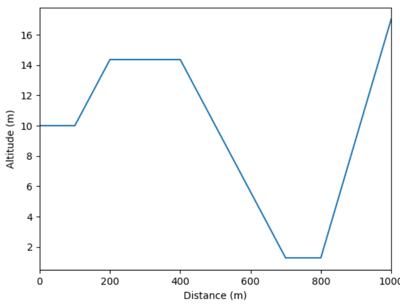
(c) Varying incline, urban



(d) Varying incline, urban road profile



(e) Varying incline, motorway

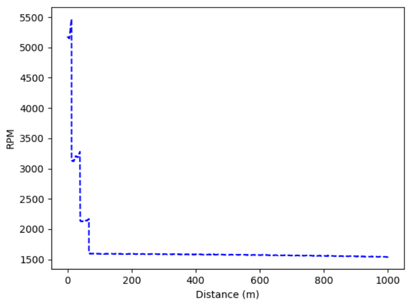


(f) Varying incline, motorway road profile

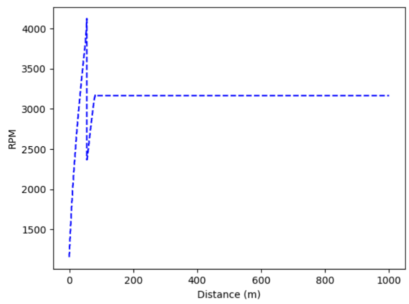
Figure 9: RPM as a function of distance plots for the most efficient drivers in the incline scenarios and the corresponding road profiles.

The best efficiency levels for the straight road for 1km and the varying incline scenarios all came from strategies with rapid changes in the revolutions of the car, which are capable of making one's vehicle unstable and dangerous to drive. Thus, Figure 9 includes alternative methods for these scenarios along with their consumption levels, showing that great efficiency levels are also feasible with more regulated driving styles.

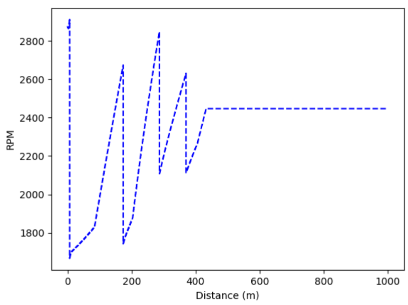
Table 3, compares throttle position for some of the best and some of the worst performing drivers at a similar revolution range. The results clearly indicate that the use of the pedal also plays a crucial role in efficiency.



(a) 1km motorway, 1.72 l/100km



(b) Varying incline urban, 6.95 l/100km

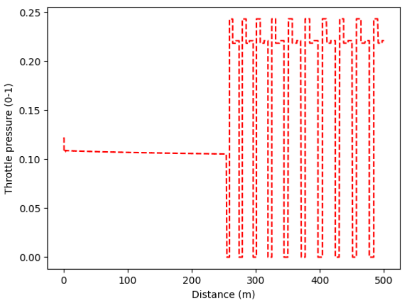


(c) Varying incline motorway, 2.67 l/100km

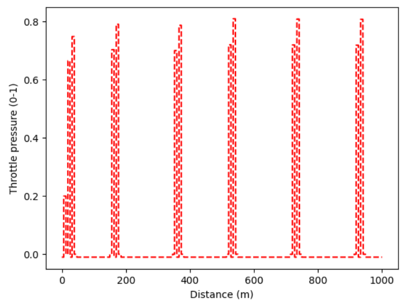
Figure 10: Alternative feasible strategies to the 1km on the motorway and the varying incline scenarios, along with their consumption values.

Scenario	RPM	Throttle (%)	Fuel	RPM	Throttle (%)	Fuel
Straight 500m (u)	2631	22.6	7.29	2565	16.7	3.3
Straight 1km (m)	2393	13.9	3.00	2416	5.6	0.7
1km incline (m)	2425	96.2	3.07	2434	68.9	2.01
Varying incline (u)	2583	18	7.02	2342	11.7	5.77
Varying incline (m)	2527	0.249	3.60	2422	0.241	2.09
Turn (u)	2561	5.5	5.48	2485	4.6	3.8
Traffic (u)	2146	6	8.72	1962	13.1	5.49

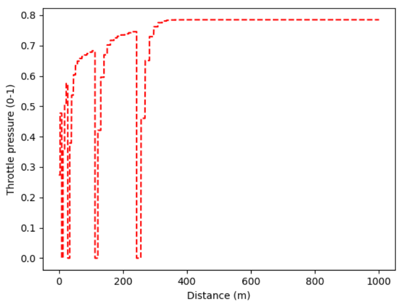
Figure 11: Table showing the pressure applied on the throttle pedal by the best and worst performing drivers in a similar range of revolutions for all 7 test cases. The indexes inside the brackets are used in the same way as the previous table. RPM are the average revolutions for the course. Throttle pressure is measured as a percentage with 100% being utilizing its whole motion and 0% not using it at all. Moreover, this percentage corresponds to the average pressure applied for the whole duration of the run. Fuel is measured in litres per 100km traveled.



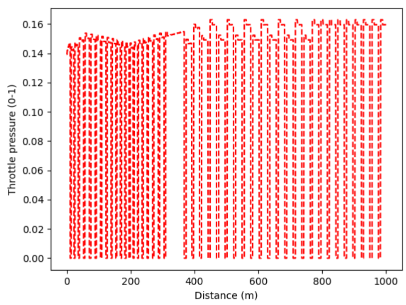
(a) Continuous incline for 1km



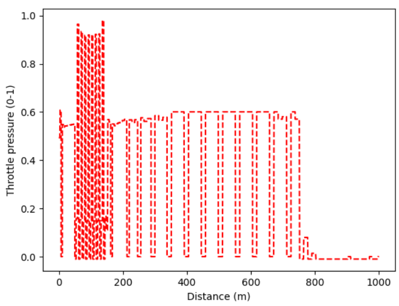
(b) Continuous incline for 1km, road profile



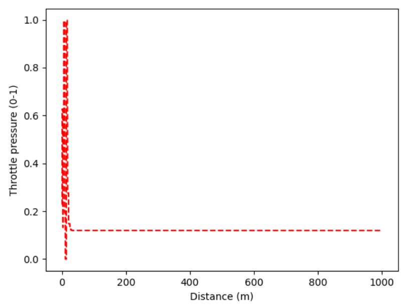
(c) Varying incline, urban



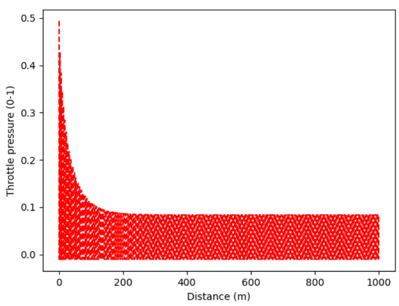
(d) Varying incline, urban road profile



(e) Varying incline, motorway



(f) Varying incline, motorway road profile



(g) Varying incline, motorway road profile

Figure 12: Throttle position plots against distance covered that show the 'chaotic' nature of the network's driving styles. The range 0-1 corresponds to the throttle not being pressed at all and being fully pressed, respectively.

Plots in figures 8, 9, 10, 12 and the table 3 all point to the fact that consumption is decreased when the throttle pedal is least used, with the only test case that opposes this rule being the traffic case recording a 37.5% increase in efficiency with an increase in the use of the throttle.

The very rapid changes in RPM, as seen in figure 8.(b) and figure 9.(c), show that the network opted to not use the throttle, at all, during some parts of their routes. This is also clearly indicated in figure 11, with all graphs having showing a similar pattern of on-and-off use of the throttle. Moreover the efficiencies recorded, especially for the straight 1km case with a consumption level as low as 0.7 l/100km, also strongly points to the fact that minimizing throttle engagement is crucial for decreasing consumption levels.

Another common feature of the graphs shown above, is that in all test cases the RPM tends to average around a specific range, with deviations not exceeding 1000 RPM. This indicates, that the network opted to use driving patterns that had, on average, minimum to non change in their speed. Although the urban varying incline and 500m urban cases are the two that appear not to follow this rule, they both still show large parts in their courses during which their RPM average out around a specific range.

4 Discussion of Results

4.1 Driving styles

RPM vs distance plots give us an insight into the behaviour of the network during these attempts. The turn case is the only graph that does not feature the distinct sharp edges recorded in all other cases, which correspond to shift changes performed, The less sudden changes are caused through the use of the throttle, which is actually the most revealing part of the network's driving.

Figures 7 and 8 both show some abnormal driving styles. The 1km straight and the urban varying incline cases both are characterized by rapid revolutions changes, also visible in the motorway varying incline scenario. Figure 12, gives a clear picture of why this is happening. The network is rapidly changing between engaging the throttle, with varying intensity, and not engaging it at all. This allowed for the vehicle to gain sufficient speed and momentum to continue moving forward while at the same time using no fuel during the process, since the intake of the engine was closed during the time when the throttle pedal was not used. This strategy the most popular one used by the most efficient drivers seen during testing. Despite its great efficiency though, anyone with driving experience can understand that this would make for an unstable and dangerous drive.

However, there are a few cases where one may benefit from this finding during every day driving. Suppose one finds themselves driving down a slope. Findings show that although the driver in the motorway varying incline followed this strange throttle pattern, the RPM and thus the speed of the vehicle remained the same throughout for the whole span of the downwards facing slope. Thus suggesting that in cases where the vehicle has gained sufficient momentum to keep it moving forward, lifting off the throttle feasible and safe.

One may also find that the network's short bursts of acceleration can be useful in these cases since they will keep the car moving at a minimum fuel cost. The limitation here comes down to the performance of the driver. Not handling these bursts in a regulated manner can have a big impact on how a car will drive, thus this technique should only be used when a driver feels comfortable with their vehicle and driving abilities.

The obscure behaviour observed can also be credited to a limitation of the model. That is, the fact that the drivers did not have the ability to use the brakes to decelerate. This especially affected the varying incline and turning scenarios. Drivers would often be eliminated from gaining too much speed, either by pressing to hard on the throttle and/or from acceleration due to gravity in downward slopes, but not being able to slow down the car fast enough. This was found to significantly affect both simulation times - 2 to 4 hours for 25 runs when it would typically take 1 to 2 hours for all other cases - and the performance of the network in these test cases.

4.2 Average speed on various cases

As shown in Table 2, surprisingly travelling at low speeds is not always the most efficient way to drive. To understand this we need to consider the timing. Although driving slowly on the motorway will save you fuel, the same cannot be said for driving inside the city. Since different speed limits hold for each case, a slow speed inside the city will waste a lot more time compared to the motorway. It is this extra time spent on the road makes for the decrease in efficiency over extended distances.

Moreover, on the topic of speed, figure 9 shows that it is more favourable for one to use a higher RPM, when situated on an incline, to counteract the deceleration caused by gravity. One may argue that table shows that incline scenarios recorded average RPM that lie in part with the other test cases. Remember however, that these are average values and thus the data in figure 9 is a more reliable source when it comes to this fact. To add to this, figure 10 (b) shows that the most efficient driver, who followed a reasonable driving style, averaged more than 3000 RPM.

4.3 Rest of the results

In both fuel consumption - distance plots there can been seen a wide spread in the data. The reason for this, as mentioned before, is that each dot on the graph represents every driver that completed the course, independent of their performance.

The next distinct characteristic of the two is the difference between the number of data points in each. This can be directly related to the difference in difficulty to complete each of the two test cases. The higher speed limit of the motorway case made for a much broader range of techniques working since, for example, a driver would be able to fully engage the throttle in 2nd gear and still finish the course, which would have cause elimination if used in the urban test case.

Another explanation for this difference, is the threshold set for the two tests. The lower value used for the 500m case, meant that it would take less generations of evolution for the model to produce capable enough individuals. Raising this threshold would for one make the simulation run for a longer time but it would also increase the number of drivers finishing their course.

One more feature that the two plots in Figure 6 share is the linear relation between the consumption levels of drivers that used similar strategies but averaged different RPM. During testing, it was observed that the best performing individuals in each RPM range, shared some distinctive driving patterns between them and that this feature would scale along with the effectiveness of these patterns. Meaning that the worst performing individuals of each RPM range, also showed similar driving behaviours.

4.4 Engine and fuel model

The simulation and optimization model used for this study were able to produce results that agree with car manufacturers claims while also gives an insight into the best driving patterns one can apply into their driving to achieve the highest efficiency possible. Consumption levels stated in this report exceed even the most efficient, on paper, cars available on the market today [12]. It should be stated however, that these results are not realistic for a few reasons.

First and foremost. Modelling a perfect engine with no losses throughout its whole operation and also having it be the only vehicle component that uses fuel to operate is an idealized version of reality. It is however, the most objective one. Faulty or wear down car components, small abnormalities in the engine's 4-stroke cycle, energy lost due to heat - and other such factors that affect a vehicle's performance - are all subjective to each vehicle's case and, perhaps more importantly, are not up to the driver to control. The study aims to come up with a solution that could be utilized by anyone, independent of type or make of vehicle one drives. The particular simulation used here allows for this, since it provides us with findings that can be applied by everyone. Of course, one would have to expect different consumption levels for his/hers case but those will be a scaled version of the findings stated in this study.

Moving on, the mathematical model of the throttle and the acceleration of the car must be discussed. It was decided to follow this approach since the 0-100km/h benchmark can provide one with enough information on what the vehicle is capable of, when driver at its limits. However, realistically a vehicle's maximum acceleration is dependent on the maximum torque the vehicle is able to output, along with its horsepower and mass. To develop this, requires extensive knowledge of the car's torque and horsepower curves which are not widely available for most passenger cars. A better approach would be the use of a universally accepted formula that relates the torque of the engine with its horsepower but once again this is not realistic, since gasoline cars, unlike electric vehicles, do not output their maximum torque and/or horsepower at any given moment.

Last but not least, it should be mentioned that the engine braking model here is not realistic. The deceleration one would experience with engine braking is dependent on the revolutions of the engine, the gear ratio in the gear box and the behaviour of the intake. A proper model if this would require extensive knowledge of the conditions inside the engine which on one hand, differ from case to case, and on the other, are not widely available. Hence it was decided to use the approach of doubling the effect of drag on the car, as an alternative. Although this method can be effective for large speeds, it does not work that well for slow speeds due to the square dependence on the velocity.

4.5 Uncertainties

One more sticking feature of the results stated in this report, is that they do not have an associated uncertainty with them. The reasons for this are: the number of assumptions made for the model and the fact that the numerical values of these results are irrelevant to the aims of this report.

The approximations made for the engine and the acceleration mathematical models make for a systematic error that affects all of the numerical results presented here. Calculating this value, is a task that exceeds the limits of this study and requires extensive engineering knowledge. The main focus here, is not to produce precise results, but to give an accurate representation of how drivers should behave and control their vehicles to be more efficient.

4.6 Comparing results with a traditionally optimized model

The above claims are further supported from findings stated in a report written by my project partner, Affan Rashid. The optimization approach he used, allowed for a more complicated vehicle model to be developed and tested. Although his consumption levels are larger than the ones stated here, the conclusions he reached when it comes to which is the most efficient way to drive agree with the statements made here. The throttle and, hence, the acceleration the the vehicle are the most important inputs when it comes to fuel efficiency.

Findings on the driving patterns that best fit certain test cases also agree between the two studies. In both simulations, the most efficient drivers would strive to travel slowly when situated on a straight road and moderately accelerate when going uphill. Moreover, they would also lift off the throttle for as long as possible whenever the circumstances allowed to.

5 Conclusions

Efficient driving is a topic which concerns the majority of today's vehicle users and manufacturers. The machine learning algorithm and car model used in this study show that is possible to produce expected results and, more importantly, came up with patterns that anyone can incorporate in their daily driving experience, without the use of real world data. The two main outcomes of this study are that, throttle and acceleration are the two most important inputs when it comes to fuel consumption. Efficient drivers may strive to lift off the throttle when on a downhill, minimize its use on fast straight roads and use it in moderation when driving inside a city. Moreover, findings suggest that, the 2000-2500 RPM range is the optimal one when it comes to fuel efficiency, independent of the driving scenario one finds themselves in. Last but not least, a higher RPM is more favourable when going up on an incline while drivers should strive for the 2000 RPM range in traffic and long corners.

5.1 Taking things further

The approach followed in this study, showed that it is possible to produce expected results and come up with usable solutions using a computational model. The algorithm used here may be extended to include features like, brakes, engine braking, a clutch and /or a handbrake that would allow for a greater level of input for the network.

We can also study the effects of other components of the car on efficiency, such as engines that utilize different kinds of fuel or alternative energy resources as a whole. Electric and hybrid vehicles in particular can be further studied since they introduce new technologies that allow them to record exceptional results [13]

Following on the machine learning approach, expanding from the evolution method used here, one can introduce real world data into the model to train it. For one, this would make for more realistic results while it would also be possible to come up with more realistic driving from the computer. Taking this further, it opens up the realms of self driving and automatic vehicles since the computers inside them can be trained to not only drive safely but also efficiently.

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Appendices

A

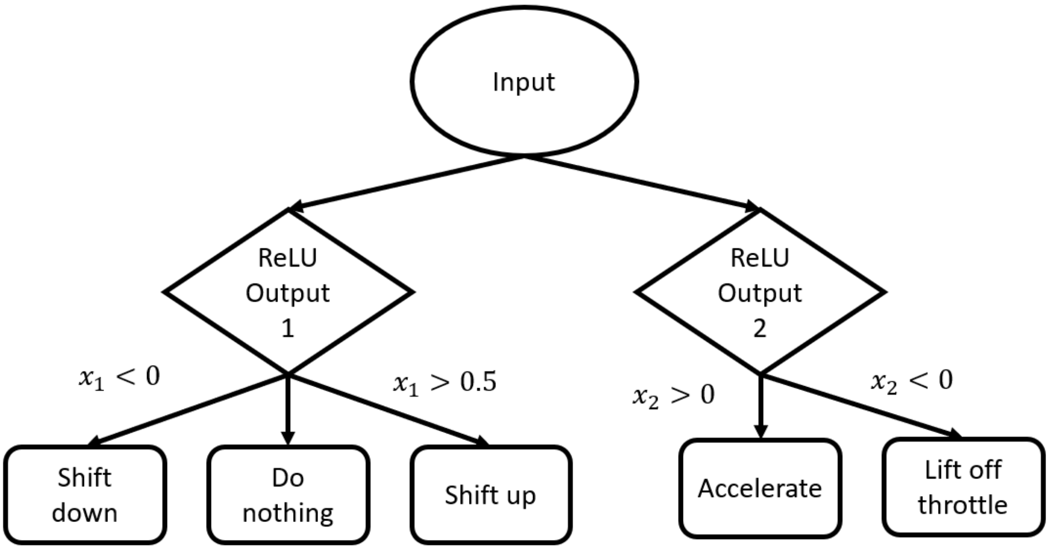

Figure 13: Activation Function flow chart

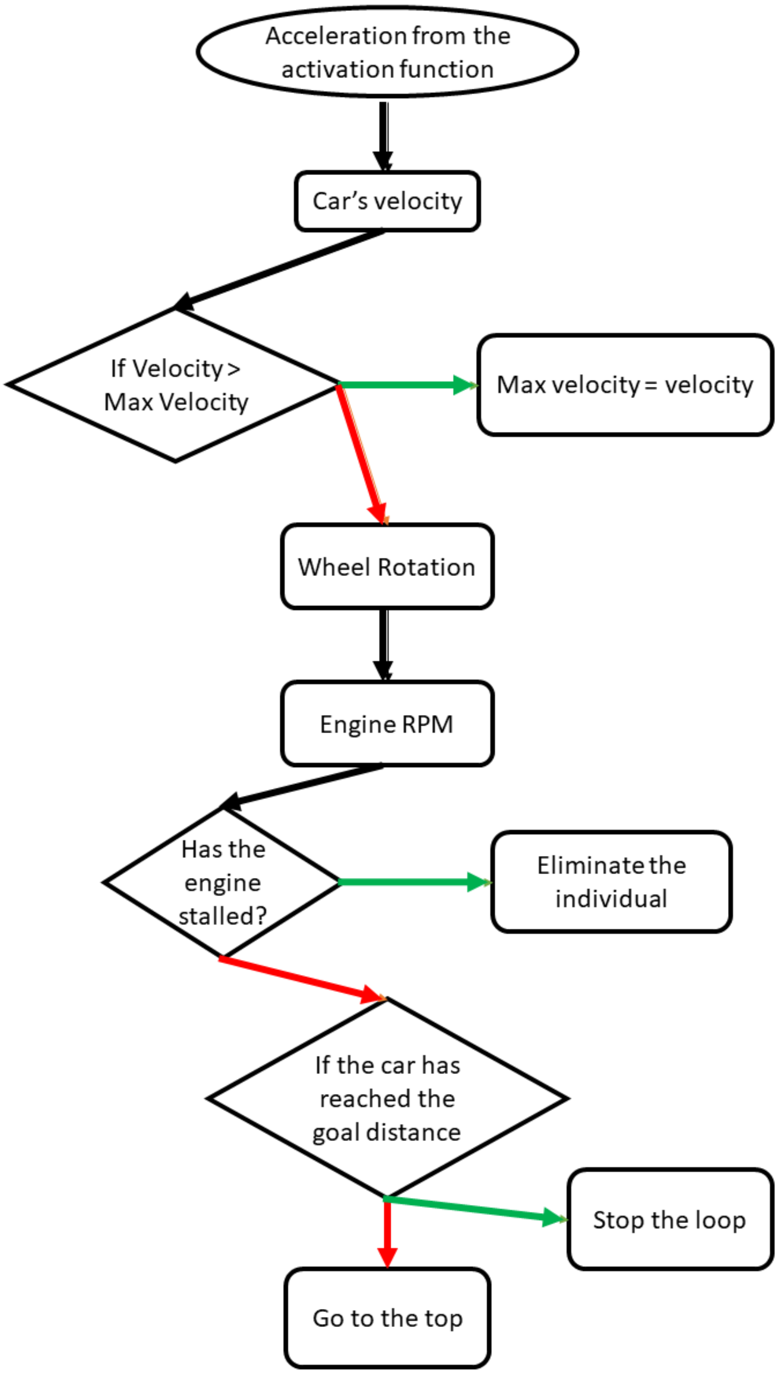

Figure 14: Vehicle calculations flow chart