INTELLIGENT TRAFFIC LIGHTS TO REDUCE VEHICLE EMISSIONS

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ABSTRACT

Cars with petrol-driven internal combustion engines are sources of air pollution. Until alternative car engines will replace petrol-driven engines, road transportation is a major source for emissions of carbon monoxide, carbon dioxide, hydrocarbons, and many other organic compounds into the environment. There is a direct relation between the car's emissions and its acceleration: an accelerating car will pollute more than a non-speeding car. In this paper we present a mobile system capable of guiding the driver's decisions with the goal of reducing vehicle emissions. The system considers parameters ranging from the car's characteristics to human reactions. In this we present results demonstrating the capability of the system to produce decisions that reduce pollution in urban traffic environment.

1. INTRODUCTION

Experts predict that by 2030 the number of cars will reach 2.2 billion (Cars 2011). Today cars are already major sources of emissions, with negative effects on the environment and health (Sovacool 2010). Cars emit tons of pollutants in the air every day: ground level ozone (O3) produces smog (causing visibility and lung medical problems); carbon dioxide is responsible for Global Warming.

To reduce air pollution car manufacturers consider today various alternatives: manufacturing of electrical cars, the creation of new environmentally friendly fuels (Sovacool 2010). Unfortunately, today the reality is that cars do pollute. Even though manufacturers try to reduce this problem, people behind the wheel are also responsible for creating a better future for themselves and their children. The solution to environmental degradations involves unselfish and compassionate behavior, a scarce commodity.

In this we propose a system designed to assist drivers adapt their behavior and take informed decisions to minimize fuel consumption (and, implicitly, air-pollution). We consider the special case of minimizing fuel consumption as drivers approach an intersection. In case of an intersection equipped with traffic lights, previous studies showed that drivers tend to accelerate more than usually to catch the green light (Kuroyanagi et al. 2011). This is also a major cause of the over 5,000 fatal crashes that occur each year in intersections with traffic signals or stop signs.

"Smart" vehicles of the future are envisioned to aid their drivers to reduce fuel consumption and emissions by wirelessly receiving phase-shifting information of the traffic lights in their vicinity, and computing and presenting drivers with suggestions for braking and acceleration decisions. We present models, methods and algorithms to be used in a real-world implementation. In our approach the traffic light periodically broadcasts its scheduling information over the wireless medium to the vehicles in its vicinity. From this information, vehicles compute their required speed in order to hit a green light and offer this information to their drivers who can in turn adapt their speed accordingly.

We also present a methodology for evaluating the impact on the reduction of pollution, using modeling and simulation. While field tests so far have focused on a technical proof of concept, simulation is still the means of choice for an estimation of the achievable large-scale benefits of applications designed for complex vehicular-based scenarios. Our evaluation results provide insights on the positive impact that such a small change in driver's behavior can bring on the environment.

The rest of this paper is organized as follows. Section 2 presents Related Work. In Section 3 we present the theoretical model for predicting fuel consumption, based on the car's characteristics. Section 4 describes the solution, and presents the proposed model to estimate vehicle emissions. We also present the proposed system that uses a prediction algorithm to recommend the cruising speeds to the driver. In Section 5 we present an analysis and experimental results and, finally, in Sections 6 we give conclusions and propose future work.

2. RELATED WORK

A generic solution to reducing air-pollution using vehicular networks was previously presented in (Gradinescu et al. 2007). The authors propose an adaptive traffic light system that uses wireless communication with vehicles and fixed controller nodes deployed in intersections to improve traffic fluency in intersections. They show that traffic fluency has an impact on the

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pollution caused by cars. A similar solution is presented in (Alsabaan et al. 2010). However, these are generic solutions to the problem of air pollution. We make the steps towards a concrete solution to decrease pollution, and identify key factors on the level of detail and characteristics required for a concrete real-world implementation. We propose the use of "smart" traffic lights to reduce car emissions in the particular situation of an intersection equipped with traffic light.

Regarding the emission model, previous studies that tend to rely on mathematical formulae, calibrated for average personal cars, to compute fuel consumption and emissions (Wegener et al. 2008)(Sanchez et al. 2006). Others use more detailed emission models (Alsabaan et al. 2010), with studies that addressed particular aspects like cold/warm start, gear shifting and different vehicle and emission types. In this we present a more generic model that considers all these aspects combined. Haworth and Symmons (2001) relate speed to fuel consumption and emissions rate. They emphasize on the importance of the driver's behavior on reducing car emissions. Estimating fuel consumption and pollutant emissions is a necessity when evaluating traffic management applications. Similar to our approach, the authors use the method proposed by Akcelik and Besley (2003) to model fuel consumption and emissions (CO2 , CO, HC, N Ox). But, unlike our work, the authors willingly simplified the model to consider only light vehicles. We present a more complex model, similar to the theoretical one, which we believe to more accurately reflect real-world traffic situations.

The authors of (Tielert et al. 2010) show that Traffic-light-to-vehicle communication (TLVC) has the potential to reduce the environmental impact of vehicular traffic by helping drivers avoid braking and accelerating maneuvers at traffic lights. However, the focus is not on the algorithm to be used for speed recommendations, but rather on a methodology to use modeling and simulation to evaluate such solutions. The motivation is that equipping traffic lights with communication technology requires significant financial expenditures. Thereby, credible large-scale simulation studies are an important means to assess the return on investment. In this we propose a complex simulation model to evaluate our solution. Unlike (Tielert et al. 2010), we also propose a concrete solution to use TLVC to disseminate information, and an algorithm to make recommendations considering the characteristics of the car that optimize fuel consumption.

Asadi and Vahidi (2010) find fuel consumption to be lowered by up to 47% for a traffic-light scheduling based cruise control algorithm when evaluating 9 traffic lights in a row and have vehicles consider the phases of the subsequent traffic lights. Richter (2005) states a maximum of 35% and an average of 14% for a single road and traffic light. Providing hard figures on how much fuel/emissions can be saved is difficult, since simulation results depend highly on the simulation setup, models and implementations used as well as on the way of evaluation. For example, when analyzing a single road and traffic light, the ratio of fuel saved depends on the length on the evaluated road segment. Thus, it is not the objective of this paper to provide hard figures, but to identify key influencing factors and quantify the degree of their influence.

3. COMPUTATIONAL MODEL FOR FUEL CONSUMPTION

To estimate fuel consumption we first developed a model that takes as input the car's characteristics, and estimates an optimal cruising speed based on the distance to the traffic light. The prediction of the car's movement is based on a model of the mechanical physics involved. Figure 1 illustrates the forces that act on the car. The force of gravity pulls the car towards the earth. The total normal force, F_N , is the sum of the forces on the front and rear tires and it is equal to the mass of the car multiplied by the acceleration due to gravity and the cosine of the slope angle, θ.

$$F_N = F_{Nf} + F_{Nr} = mg\cos\theta \tag{1}$$

The engine generates torque, which when applied to the wheels causes them to rotate. The force applied to the tires, F_T , is equal to the torque applied to the wheels, T_w , divided by the wheel radius, r_w . When the car is in motion, an aerodynamic drag force develops. This drag force can be modeled as a function of the air density, ρ , frontal area, *A*, the square of the velocity magnitude, *v*, and a drag coefficient, C_D . The last important force in the car diagram (see Figure 1) is due to rolling friction. This force acts on all four wheels and resists the rolling motion of the car. The total rolling friction force, F_R , is equal to the total normal force, F_N , multiplied by the coefficient of rolling friction for the vehicle, μ_r .

The total force that acts on the car parallel to the direction the car is driving, F_{total} , is equal to the sum of the forces due to engine torque, gravity, aerodynamic drag, and rolling friction:

$$F_{total} = \frac{T_W}{r_w} - \mu mg\cos\theta - mg\sin\theta - \frac{1}{2}C_D\rho v^2 A \tag{2}$$

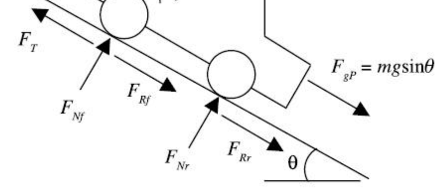

Figure 1. Force balance on a car.

The acceleration of the car at any given time is the net force on the vehicle divided by the mass of the vehicle, *m*:

$$a = \frac{T_W}{r_w m} - \mu g \cos\theta - g \sin\theta - \frac{1}{2}\frac{C_D \rho v^2 A}{m} \quad (3)$$

The engine generates a torque that is used to move the car. The torque generated by the engine is not the same as the torque applied to the wheels (the engine is not coupled directly to the wheels, but to some set of gears). The engine torque is a function of the rate at which the engine is turning over. The engine turnover rate is expressed in revolutions per minute, *rpm*. There is a relation between the engine torque and the engine's turnover rate, which vary from car to car. One characteristic of engine torque is that it does not always increase with the increase of the engine turnover rate.

The torque applied to the wheels of a car determines its acceleration. Generally the torque applied to the wheels is not the same as the engine torque. Before the engine torque is applied to the wheels, it passes through a transmission. The gears inside a transmission change the angular velocity and torque transferred from the engine. This can greatly increase the acceleration of a car. The gear ratio between two gears is the ratio of the gear diameters. Car transmissions will typically have between three and six forward gears and one reverse gear. There is also an additional set of gears between the transmission and the wheels. The gear ratio of this final gearset is known as final drive ratio.

The wheel torque, T_w, is equal to the engine torque, T_e, multiplied by the gear ratio, g_k, of whatever gear the car is in and the final drive ratio, G, of the car. Using the previous equations, the car's acceleration can be computed as:

$$a = \frac{T_e g_k G}{r_w m} - \mu g \cos\theta - g \sin\theta - \frac{1}{2}\frac{C_D \rho v^2 A}{m} \quad (4)$$

Transmission gears also change the angular velocity of the wheel relative to the turnover rate of the engine (the factor "60" is to transform from *rpm* in *revolutions per second*):

$$\omega_w = \frac{2\pi\Omega_c}{60 g_k G} \quad (5)$$

If the tires roll on the ground without slipping (the "burn rubber" effect), the translational velocity of the car, *v*, can be related to the angular velocity of the wheel, and therefore to the engine turnover rate:

$$v = r_w \omega_w = \frac{r_w 2\pi\Omega_e}{60 g_k G} \quad (6)$$

In order to estimate the movement of a car, it is necessary to determine the acceleration and velocity of the car at any point in time. The starting point for this analysis is eq. (4). If the slope angle, frontal area, and air density are known, the only unknown quantity in this equation is the wheel torque, T_w. As explained, the wheel torque is the product of the engine torque, T_e, the current gear ratio, g_k, and the final drive ratio, *G*. The engine torque, T_e, can be obtained from the torque curve of the engine. The torque curve can generally be modeled by three equations. The units for engine torque in all three equations are in N-m.

$$T_e = 220 \,, \; \Omega_e \le 1000 \quad (7a)$$

$$T_e = 0.025\Omega_e + 195 \,, \; 1000 < \Omega_e < 4600 \quad (7b)$$

$$T_e = -0.032\Omega_e + 457.2 \,, \; \Omega_e \ge 4600 \quad (7c)$$

The general equation for the three previous ones is:

$$T_e = b\Omega_e + d \quad (8)$$

Using equations (8), (6), and (4), the expression for the acceleration of the car as a function of the current velocity of the car becomes:

$$a = \frac{60 g_k^2 G^2 b v}{2\pi m r_w^2} + \frac{g_k G d}{m r_w} - \mu g \cos\theta - g \sin\theta - \frac{1}{2}\frac{C_D \rho v^2 A}{m}$$

Knowing this equation that expresses the car motion equation, and some typical parameters for the rolling friction coefficient (0.015), the average frontal area of a car (1.94 m2), the wheel radius (0.3186), etc., we solved this differential equation using the fourth-order Runge-Kutta method.

The relation between speed and fuel consumption and emission rate is given by the Haworth and Symmons model (Haworth and Symmons, 2001). These are results relative to the car's characteristics. However, they clearly show that by accelerating or decelerating a car consumes relatively larger or smaller fuel quantities than it would consume normally (in such a model the normal value is defined depending on the type of car and its characteristics).

A number of curves relating emissions to fuel consumption, and to the average cruising speed have been developed in the related literature (Smith and Cloke, 1999). Emissions of Volatile Organic Compounds (VOCs or HCs) and carbon monoxide (CO) generally decrease as average speed increases and then increase somewhat over 100 km/h. Emissions of nitrogen oxides increase more than proportionally with average speed. The relationship between fuel consumption and average speed is somewhat more complex. It appears to decrease as average speed increases to about 60 km/h to 80 km/, and then it increases. Other authors have presented curves of similar shapes, but with different gradients or minima. For example, Andre and Hammarstrom (2000) report that CO emission reaches a minimum at about 70 km/h, whereas CO emissions decrease monotonically with speed.

These previous studies show a clear relation between acceleration and the car's emissions. Emissions tend to be higher during acceleration, when the fuel to air ratio is higher. The conclusion of this analysis is that the driver can greatly influence the emissions rate through smooth accelerations (i.e., no rapid speed changes), constant speed at cruising, and reduced number of cold starts (by combining several shorter trips into one longer trip).

4. A RECOMMENDING SOLUTION TO DECREASE VEHICLE'S EMISSIONS

We first make the assumption that the intersection is equipped with intelligent traffic lights (ITLs), which are semaphores equipped with sensors and wireless communication capabilities – a concept proposed in (Gradinescu et al. 2007). ITLs can send information to approaching vehicles, to servers, to other traffic lights. In this paper we extend the original ITL approach, and propose a system that uses them to minimize pollution and assist the driver find the optimum cruising speed as he/she approaches the intersection. We consider that messages are constantly exchanged between ITL and vehicles, and also between vehicles. We assume that ITLs and the vehicles are equipped with short range communication devices and computing capabilities. The ITL periodically broadcasts data about the color and the time until it changes, for each segment of road it controls. The broadcasted package contains in addition the local time, which is used for synchronization. The problem of short range communication is resolved by letting cars re-broadcast further all received messages for a limited time period.

The vehicle uses the received information as input for an algorithm that outputs a recommendation speed that optimizes the quantity of car's emissions. To run the algorithm cars are equipped with computational devices. The algorithm is based on the computation of speed, movement, as well as fuel consumption.

4.1. Computing fuel consumption

First we developed a solution to estimate fuel consumption and pollutant emissions. To model fuel consumption and emissions (CO2, CO, HC, NOx), we extended the work of Akcelik and Besley (2003). The qualities of their model are better reflected by the extensive study conducted in (Dia et al. 2007). The method to estimate the value of fuel consumed (mL) or emissions produced (*g*), in a time interval (Δ_t), is given by:

$$\Delta F = \left(f_i + \beta_1 R_T v + \left[\frac{\beta_2 M_v a^2 v}{1000} \right]_{a>0} \right) \Delta t \quad , \quad R_T > 0 \tag{10}$$

$$\Delta F = f_i \Delta t \ , \ R_T \leq 0 \tag{11}$$

where ΔF [mL or g] is the quantity consumed or gas emitted during a time interval, *v* [m/s] is the vehicle's instantaneous velocity, *a* [m/s2] the acceleration, M_V [kg] is the mass of the vehicle (1400 kg on average for light vehicles in a city environment), and R_T [kN] represents total force acting on a car, including air drag and rolling resistance. For the values of f_i, β_1, and β_2 we used the results from (Akcelik and Besley, 2003). Figure 2 presents results for fuel consumption for vehicles passing through an intersection.

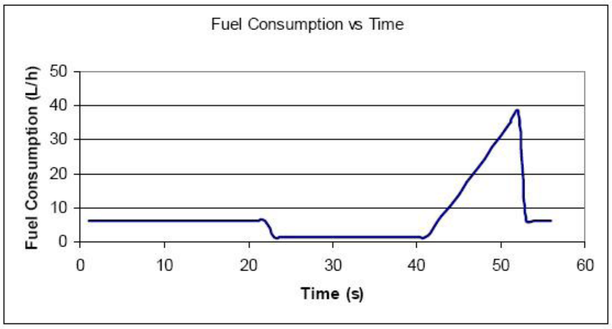

Figure 2. Fuel consumption for vehicles passing through an intersection.

4.2. The decision algorithm

In order to determine the optimal speed when approaching an intersection, we consider that cars are equipped with computational devices. Various experts, in fact, predict this will be a reality on a general-scale in the near future (CARS, 2010). In this section we present the algorithm that runs on the computational device inside a car.

a. Car Movement Prediction

The most important part of the algorithm is the prediction of the movement of the car on a given distance, or in a given amount of time. To make an accurate decision, the algorithm needs to estimate with relatively high precision the future speed and position of the car. For that we use parameters such as the delay to reach a certain speed, the acceleration style of the driver, the characteristics of the road (curves, slopes). The implementation of this part of the algorithm (the content of "*updateSpeedAndLocation*" method in Table 1) is based on the equations for the car's motion previously presented, which consider the forces that act on the car.

b. Green Lights

When the car approaching the intersection is informed that the current traffic light color is green, the device inside the car executes the following algorithm. We consider two scenarios: (1) the driver accelerates to catch the green light, and (2) the driver slowly decelerated to stop at the red light. The first case may not be possible (considering the car's characteristics, the acceleration has an upper limit). If possible, the algorithm will estimate the quantity of emissions for both two cases. If the quantity of gases is smaller in the first case than in the second, it will recommend the accelerating speed to the driver. Otherwise, it will recommend a full stop at the red light.

The application starts by first predicting the movement of the car when we assume the driver will try to catch the green light (case 1). In this case the driver's intention is to accelerate until the speed he/she anticipates is needed to catch the green light. The pseudocode for this algorithm is:

Algorithm 1. The algorithm for Green Light, case 1.

```
car.distance ← 0 // the total distance traveled by the car
car.time ←0 // the total time the car traveled
timeIncrement ← 0:06 // the time increment to apply runge-kutta
car.setMode("accelerate") // the driver accelerates
while car.distance < distanceToTrafficLight do
    neededSpeed ← (distanceToTrafficLight – car.distance) ÷ (greenTime – car.time)
    if neededSpeed > MaxSpeedAllowed then
        return // the driver cannot catch the green light
    end if
    if neededSpeed <= car.speed then
        car.setMode("cruise")
    end if
    car.updateSpeedAndLocation(timeIncrement)
    // this updates car.time, car.speed and car.distance
    car.estimateEmissions()
end while
```

The application further estimates the emissions of the car, assuming the driver maintains a constant speed, stops at the red color, then accelerates to the speed he/she previously had before stopping (case 2). The pseudocode for this algorithm is:

Algorithm 2. The algorithm for Green Light, case 2.

```
car.distance ← 0 // the total distance traveled by the car
car.time ← 0 // the total time the car traveled
timeIncrement ← 0:06 {the time increment to apply runge-kutta}
car.setMode("cruise") // the driver maintains a constant speed
while car.distance < distanceToTrafficLight - 100 do
    // assume the driver starts to break 100m before the intersection
    car.updateSpeedAndLocation(timeIncrement)
    car.estimateEmissions()
end while
car.setMode("break") // the driver breaks to stop at the red light
while car.distance < distanceToTrafficLight do
    car.updateSpeedAndLocation(timeIncrement)
    car.estimateEmissions()
end while
car.setMode("accelerate") // the driver accelerates to the speed he had before stopping
while car.speed < WantedSpeed do
    car.updateSpeedAndLocation(timeIncrement)
    car.estimateEmissions()
end while
```

In the end the application compares the results obtained in these two cases and recommends a speed to the driver that will lead to the least fuel consumption.

c. Red Lights

When the car approaches an intersection and is informed that the current color of the traffic light is red, it executes an algorithm that decides to (1) reduce the speed to enter the intersection when the light color is turning green, or (2) continue to a full stop using the same constant speed. The decision depends on the smaller quantity of emissions when comparing the estimated for these two cases. Again, the algorithm involves two steps.

First the application runs an algorithm to predict the movement of the car, assuming the driver reduces the speed in an attempt to avoid the red light – by the time he/she would reach the intersection the current light will have changed to green in this approach. In this case the algorithm estimate the quantity of emissions. The pseudocode for this case is:

Algorithm 3. The algorithm for Red Light, case 1.

```
car.distance ← 0 // the total distance traveled by the car
car.time ← 0 // the total time the car traveled
timeIncrement ← 0:06 // the time increment to apply runge-kutta
car.setMode("accelerate") // the driver accelerates
while car.distance < distanceToTrafficLight do
    neededSpeed ← (distanceToTrafficLight - car.distance) ÷ (redTime – car.time)
    if neededSpeed < MinSpeedAllowed then
        return // the driver cannot avoid stopping at the red light
    end if
    if neededSpeed >= car.speed then
        car.setMode("cruise")
    end if
    car.updateSpeedAndLocation(timeIncrement)
    // this updates car.time, car.speed and car.distance
    car.estimateEmissions()
end while
```

Next, it runs an algorithm to predict the movement of the car, assuming the driver maintains constant speed, stops at the red color, then when the color changes he/she accelerates to the speed needed to catch the green light (and possible avoid a new change to red light). The pseudocode for this case is:

Algorithm 4. The algorithm for Red Light, case 2.

```
car.distance ← 0 // the total distance traveled by the car
car.time ← 0 // the total time the car traveled
timeIncrement ← 0:06 // the time increment to apply runge-kuttag
car.setMode("cruise") // the driver maintains a constant speed
while car.distance < distanceToTrafficLight - 100 do
    // assume the driver starts to break 100m before the intersection
    car.updateSpeedAndLocation(timeIncrement)
    car.estimateEmissions()
end while
car.setMode("break") // the driver breaks to stop at the red light
while car.distance < distanceToTrafficLight do
    car.updateSpeedAndLocation(timeIncrement)
    car.estimateEmissions()
end while
car.setMode("accelerate")
// the driver accelerates to the speed he had before stoppingg
while car.speed < NeededSpeed do
    car.updateSpeedAndLocation(timeIncrement)
    car.estimateEmissions()
end while
```

In the end the application compares the results obtained in these two scenarios and recommends the optimal speed to the driver, depending on the least fuel consumption.

5. RESULTS

The evaluation in terms of the environmental impact of the proposed solution was done using modeling and simulation. This cost-effective method of evaluation required us to model at least four components: vehicular traffic, communication from traffic lights to vehicles, driver behavior (speed adaption) and finally fuel consumption and emissions. These and other components were integrated into VNSim (Gradinescu et al. 2007), a VANET simulator which is able to model complex traffic conditions, with real-world mobility assumptions and state-of-the-art networking protocols (Gainaru et al. 2009). Its extensibility allowed us to implement the models for the estimate of fuel consumption and pollutant emissions proposed in the current work.

We were first interested in how acceleration relates to pollutant emissions. These experiments were conducted as a calibration stage, to verify that the simulation model corresponds in known-cases to the expected mathematical results (Section 3). In these experiments we considered the case of an average car - the entry values for these experiments followed the analysis of Smith&Cloke (1999).

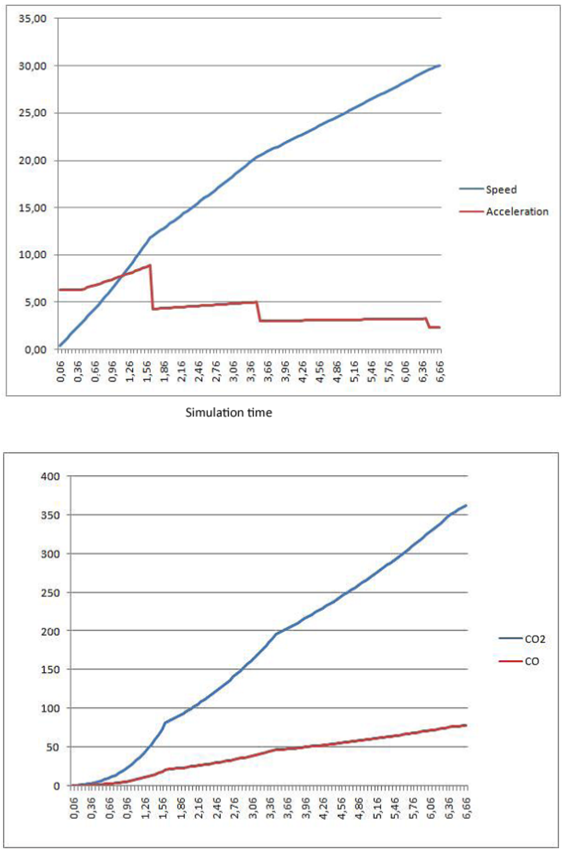

Figure 3. The case of a car that accelerates from 0 km/h to 108 km/h.

We conducted two experiments that evaluate the fuel consumption for the typical driver behaviors. In the first experiment the driver keeps accelerating until the car reaches 30 m/s (or 108 km/h). This speed was chosen based on the theoretical estimated Haworth and Symmons model and ECE 15-04 regulations (a car would not cruise with a higher speed in an urban area – official regulations limit speeds in such situations to much lower values). Figure 3 shows how speed and acceleration change in time. In the second scenario, the driver accelerates until the car reaches 15.22 m/s (or 54.8 km/h, a speed which is more acceptable for urban areas) and then he/she maintains a constant speed (see Figure 4).

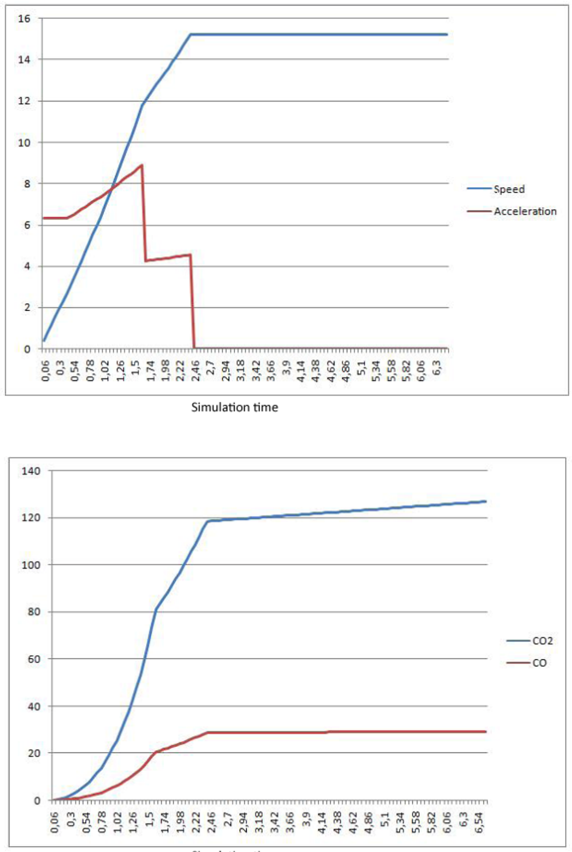

Figure 4. A car that accelerates from 0 km/h to 54.8 km/h and then maintains a constant speed.

Looking at the acceleration curves in Figures 3 and 4, two observations can be made: 1) the very steep slopes (three in Figure 3 and two in 4) are due to gear shifting and 2) acceleration is decreasing in time, due to the gear ratio (and this concurs to the mathematical estimations previously presented, and the increasing drag force). The quantity (in grams) of emitted CO_2 and CO in the first scenario is shown in Figure 3 and the results of the second scenario can be visualized in Figure 4 (in which the car traveled for the same amount of time as the one in the first scenario). Comparing the results of the two scenarios, it can be noticed that the quantity of gases emitted by the car in the second scenario ($\approx$ 129g of CO_2), is smaller than the one obtained in the first scenario ($\approx$ 360g of CO_2). Based on the slope of the emissions curve in Figure 4, we can compute the total distance the car can travel until its emissions reach the ones in Figure 3.

5.1. Case 1 – Green light

We next experimented with the proposed algorithms. We started with the case of the green traffic light. The algorithm has been used in two relatively different scenarios.

In the first scenario, a car traveling at 40 km/h (~11 m/s) has 15 seconds to catch the green light. This corresponds to the case when a car cruising at a relatively high speed in town approaches the intersection. Also, to avoid potentially dangerous situations, the driver has sufficient time to cross the intersection. The distance between the traffic light and the car is 200 m. According to the proposed algorithm, the car predicts the speed and acceleration of the car until it crosses the intersection, and it estimates the quantity of emissions in the two possible scenarios: 1) the driver tries to catch the green light and accelerates until the needed speed is reached and 2) the driver maintains a constant speed, stops and waits at the red light, and then he/she accelerates until the previous speed is obtained. The quantity of emissions in the first situation was ~54 grams of CO2, and in the second situation ~96 grams of CO2. Based on these results, the system advises the driver to accelerate to catch the green light. By doing this, the driver could reduce the quantity of CO2 by approximately 42 grams (going at high speed, but this higher limit depends on the maximum speed imposed by legislation in that particular location).

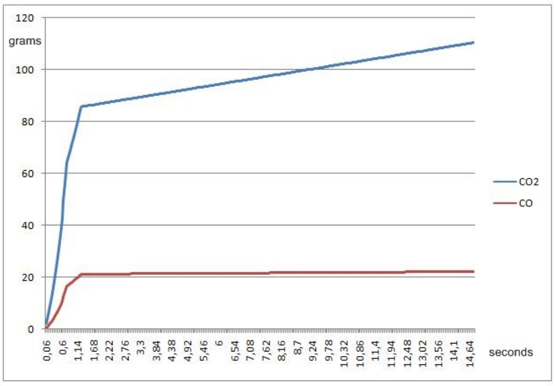

Figure 5. Quantity of emissions in scenario 2, situation 1.

In the second experiment, the same car, now traveling at 22km/h (~6 m/s), has to catch the green light, given the same conditions as in the previous scenario. This corresponds to a slower car approaching the same intersection. As before, the algorithm predicts the speed and acceleration of the car until it passes the intersection, and it estimates the quantity of emissions in the two scenarios previously described. The estimated quantities of emissions are presented in Figure 5 (~110 grams of CO2 emitted). Based on these results the system advises the driver not to accelerate, in the attempt to catch the green light. If the driver complies with this suggestion, he/she would reduce the quantity of CO2 by ~52 grams.

5.2. Case 2 – Red light

This section presents the experimental results obtained with the use of the proposed algorithms applied in case of red traffic light. Again we experimented with two situations.

In the first case, a car traveling at 60 km/h (~16.6 m/s) approaches a traffic light showing a red color, which will change after 20 seconds. This corresponds to a high-speed car approaching the intersection. Again, the distance between the traffic light and the car is 200 m. The algorithm predicts the speed and acceleration of the car until it passes the intersection, and it estimates the quantity of emissions in two possible situations: 1) the driver tries to reduce the speed to avoid the red color and 2) the driver maintains a constant speed, stops waits at the red light, and when the color changes back to green accelerates until the speed needed to avoid the next change to red color is obtained. In the first case the estimated quantity of emissions was ~28 grams of CO2. For the second case ~75 grams of CO2 were emitted. Based on these results, the system advises the driver to reduce the speed until he/she reaches approximately the speed of 34 km/h (~9.47 m/s), such that to avoid waiting at the red light color. By doing this, the driver reduces the quantity of CO2 by ~47 grams.

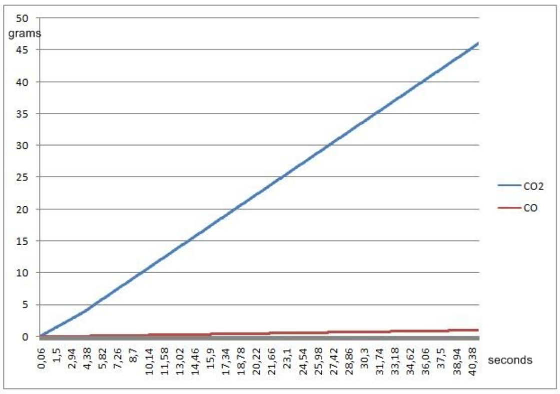

Figure 6. Quantity of emissions in scenario 2, situation 2.

In the second scenario, the same car, traveling at the same speed (60km/h), approaches a red traffic light color which, this time, will last for the next 40 seconds. As before, the algorithm predicts the speed and acceleration of the car until it passes the intersection and estimates the quantity of emissions in the two cases described earlier. The estimated quantities of emissions was ~46 grams of CO2 (first case), and, respectively, ~37 grams of CO2 (second case, see Figure 6). Based on these results the system advises the driver not to reduce the speed, in an attempt to avoid the red light. If the driver complies with this recommendation, he/she will reduce the quantity of CO2 by ~9 grams.

The obtained results show good progress towards decreasing the amount of fuel being consumed. The scenarios consider several parameters which might change depending on the local legislation, characteristics of cars, etc. However, in the different considered scenarios we showed that our recommendations can lead to significant changes in the fuel consumption, with positive results on the environment on the long term.

6. CONCLUSIONS

In this we presented a solution that uses intelligent traffic lights, mobile devices and wireless communication to reduce car emissions. The solution minimizes the number of stop-starts due to the red light and the accelerations needed to catch the green light (happening quite frequent and having an important influence on the emissions rate). Periodically the traffic lights broadcast information about the status of the current traffic light color. This information is used by a decision algorithm. The role of this algorithm is to assist the driver make informed decisions to 1) avoid the red traffic light and 2) catch the green traffic light, if possible, and reduce the quantity of emitted gases.

In order to decide whether the driver's action of catching the green light leads to less fuel consumption, by recommending accelerate/decelerate, we devised a method to predict the car's movement. For this we use the motion equation of a car to predict its speed and position at any time. The prediction of the movement of the car is among the most challenging part. To estimate a specific driver's behavior and predict how the car is going to move in different situations is a difficult task, because of the number of parameters to be considered: all forces that act on the car, coupled with the human factor. In the end we proposed a solution that was evaluated in an implementation on top of the VNSim simulator. The obtained results are promising and show that the proposed algorithm can recommend speeds that, in fact, lead to a decrease in the emissions of a car.

In the future we plan to further optimize the models and the solution, mainly because of several simplifications made in this current version. They are due mainly to the lack of information: in determining the motion equation, just the x-axis was considered. The weather was also ignored (this means that the slopes and the curves of the roads were ignored - 3D maps are needed to obtain complete information about the roads).

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