

Intelligent Traffic Lights to Reduce Vehicle Emissions

Ciprian Dobre, Adriana Szekeres, Florin Pop, Valentin Cristea, Fatos Xhafa

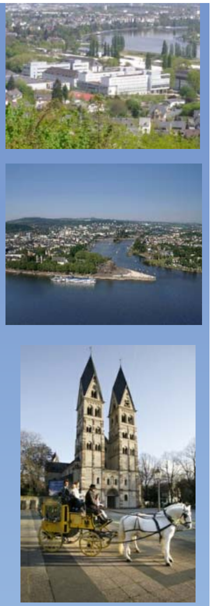
Emails: {ciprian.dobre, florin.pop, valentin.cristea}@cs.pub.ro, fatos@lsi.upc.edu

30.05.2012



Outline

- Scope and motivation
- Model for fuel consumption
- The proposed system
- Decision algorithms
- Experimental results
- Conclusions



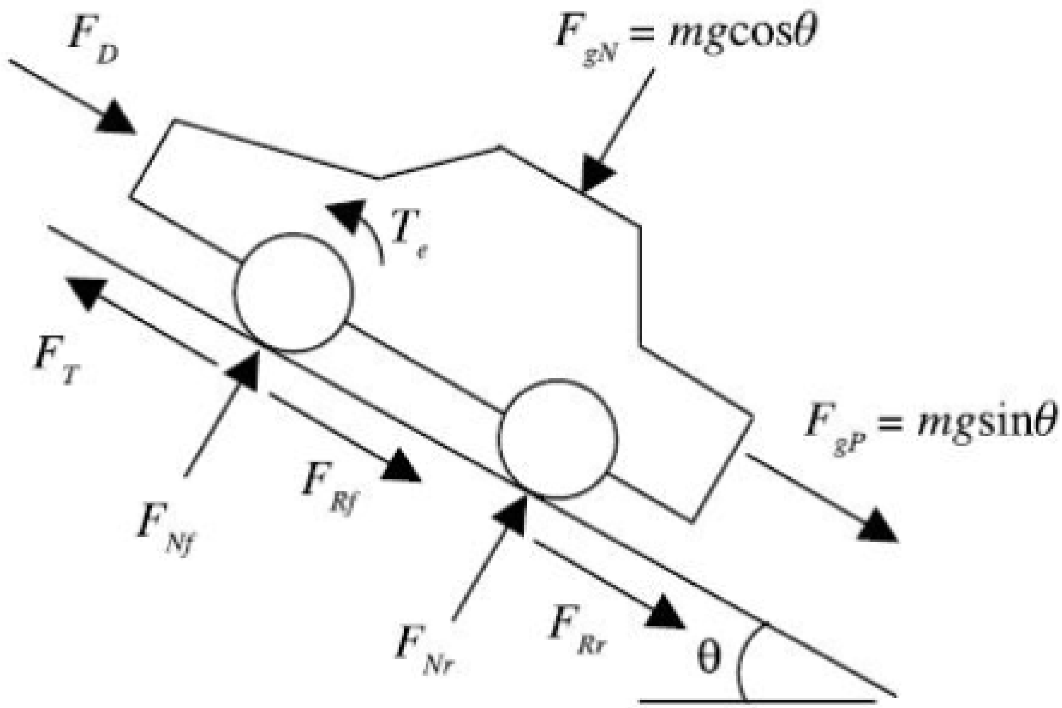
Scope and Motivation

- Road transportation is a major source for emissions of carbon monoxide, carbon dioxide, hydrocarbons, and other organic compounds into the environment
    - o Cars with petrol-driven internal combustion engines pollute
- Direct relation between the car’s emissions and its acceleration
    - o An accelerating car pollutes more than a non-speeding car
- Propose a system to guide driver’s decisions as he/she approaches the traffic light
    - o The goal = reduce vehicle emissions

Model for Fuel Consumption (1)

- Input: characteristics of cars
- Output: recommended cruising speed
- Parameters: distance between traffic light and car
- Total normal force F_N

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





Model for Fuel Consumption (2)

- The engine generates torque, which when applied to the wheels causes them to rotate
- The force applied to the tires F_T

$$F_T = T_w / r_w$$

T_w – Torque applied to the wheels

r_w – wheel radius

- When the car is in motion, the aerodynamic drag force is a function of density ρ, frontal area A, the square of the velocity magnitude, *v*, and a drag coefficient, C_D
- The rolling friction force F_R

$$F_R = F_N * \mu_r$$

F_N – Total normal force

μ_r – the coefficient of rolling friction for the vehicle



Model for Fuel Consumption (3)

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

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

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

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

Model for Fuel Consumption (4)

- The torque applied to the wheels of a car determines its acceleration.
  - 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.
  - 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.
- Thus, 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

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



Model for Fuel Consumption (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:

$$v = r_w \omega_w = \frac{r_w 2\pi\Omega_e}{60 g_k G}$$

- The engine torque, T_e, can be obtained from the torque curve of the engine. The curve can generally be modeled by three equations (units in N-m):

$$T_e = 220 \longleftarrow \Omega_e \le 1000$$

$$T_e = 0.025\Omega_e + 195 \longleftarrow 1000 < \Omega_e < 4600$$

$$T_e = -0.032\Omega_e + 457.2 \longleftarrow \Omega_e \ge 4600$$

- The general equation:

$$T_e = b\Omega_e + d$$



Model for Fuel Consumption (6)

- Acceleration of the car as a function of the current velocity is:

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

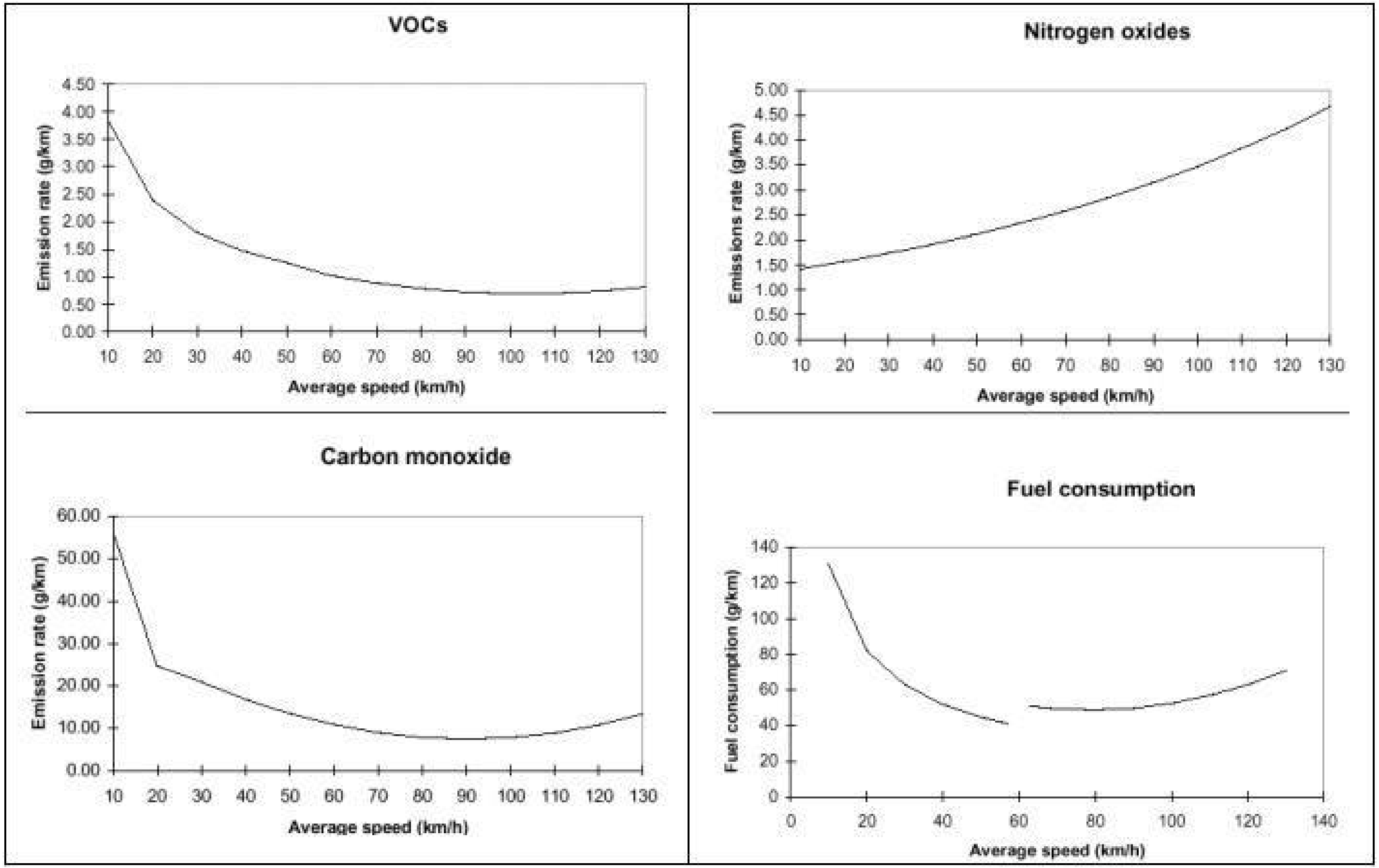
- We solved this differential equation using the fourth-order Runge-Kutta method
  - Typical parameters for the rolling friction coefficient (0.015), the average frontal area of a car (1.94 m2), the wheel radius (0.3186)
- The relation between speed and fuel consumption and emission rate is given by the Haworth and Symmons model[1]
  - Clearly shows that by accelerating or decelerating a car consumes relatively larger or smaller fuel quantities than it would consume normally

[1]Haworth, N.; M. Symmons. "Driving to reduce fuel consumption and improve road safety", Proc. Road Safety Research, Policing and Education Conference, Melbourne



Model for Fuel Consumption (7)

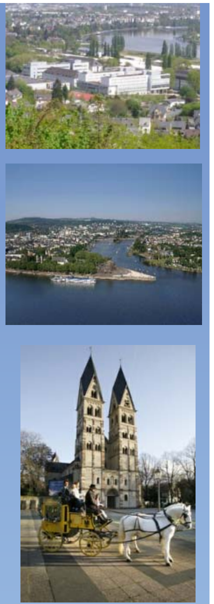
- Typical emission rates for volatile organic compounds (Hydrocarbons - HC), carbon monoxide, nitrogen oxides and fuel consumption as a function of average speed for passenger cars conforming to ECE 15-04 regulations



J. Rybicki, B. Scheuermann, W. Kiess, C. Lochert, P. Fallahi and M. Mauve, Challenge: Peers on wheels { A road to new traffic information systems, *Proc. of the 13th Annual ACM International Conference on Mobile Computing and Networking (MOBICOM), Montral, Qubec, Canada, pp.215*-221, 2007.

The proposed system

- Assumption: intersection equipped with traffic light (TL) with wireless communication capabilities
- TL sends information to approaching vehicles
  - 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.
  - The algorithm is based on the computation of speed, movement, as well as fuel consumption



Computing fuel consumption (1)

- 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 (Δt), is given by:

[kg] is the mass of the vehicle (1400 kg on average for light vehicles in a city environment

[m/s] is the vehicle's instantaneous velocity

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

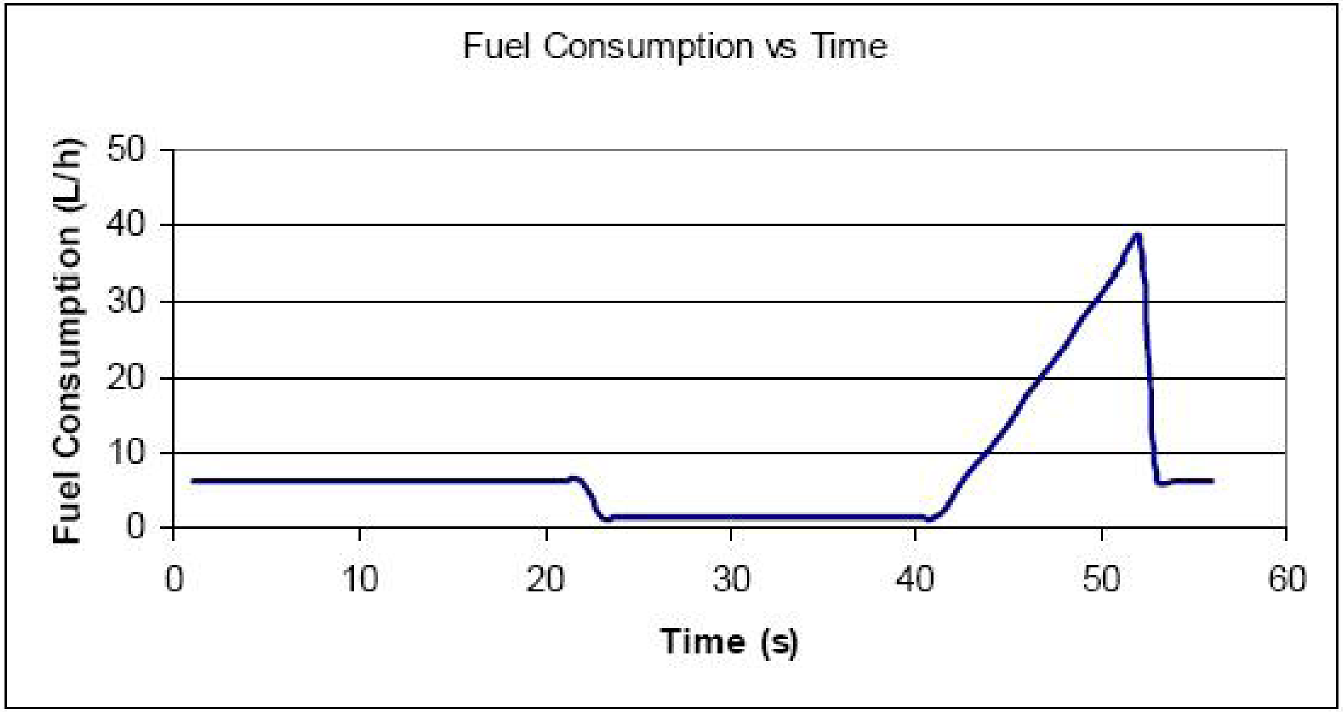
$$\Delta F = f_i \Delta t \quad \leftarrow R_T \le 0$$

[kN] represents total force acting on a car, including air drag and rolling resistance

[mL or g] is the quantity consumed or gas emitted during a time interval

Computing fuel consumption (2)

- Theoretical results for fuel consumption for vehicles passing through an intersection:





Decision algorithm

- Algorithm for prediction of the movement of the car on a given distance or in a given amount of time
  - Estimates the future speed and position of the car
  - Uses parameters such as the delay to reach a certain speed, the acceleration style of the driver, the characteristics of the road (curves, slopes)
- If the car receives Green Light, we consider two scenarios:
  1. the driver accelerates to catch the green light,
  2. the driver slowly decelerated to stop at the red light
- The algorithm estimates the quantity of emissions for both two cases:
  - If the quantity of gases is smaller in the first case, it recommends the accelerating speed to the driver.
  - Otherwise, it recommends a full stop at the red light.



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 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
```



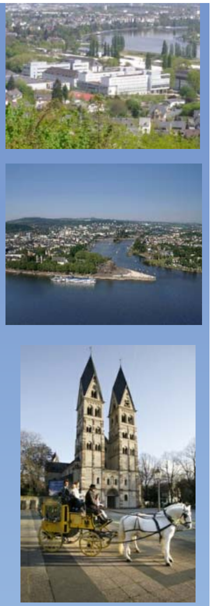
The algorithm for Red Light, case 1

```
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
```

30.05.2012

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
```

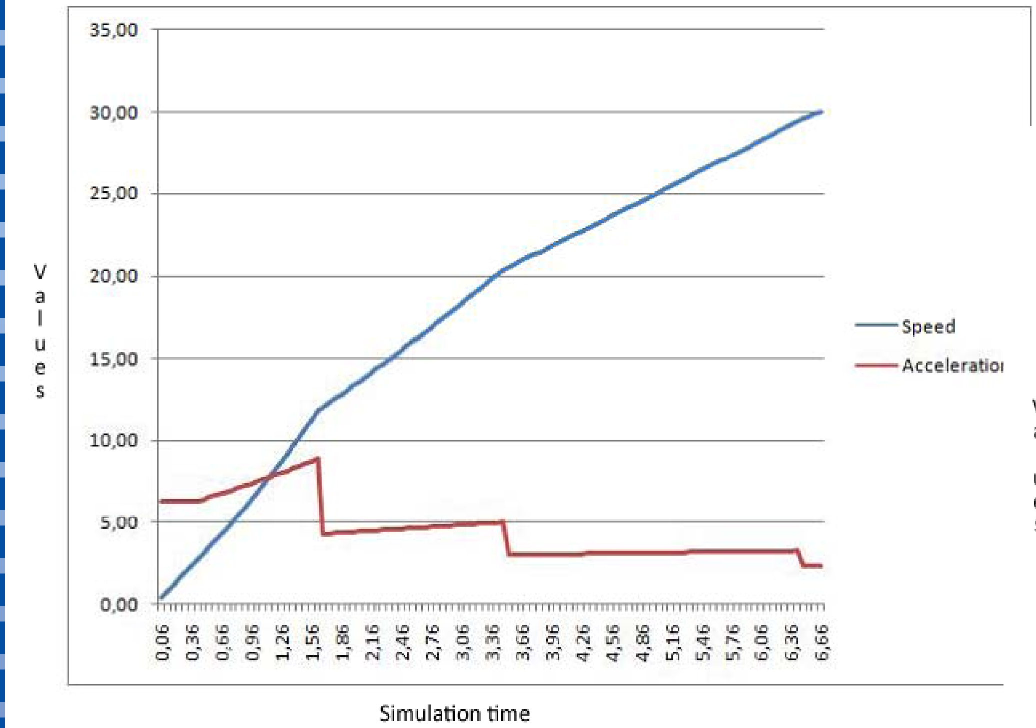


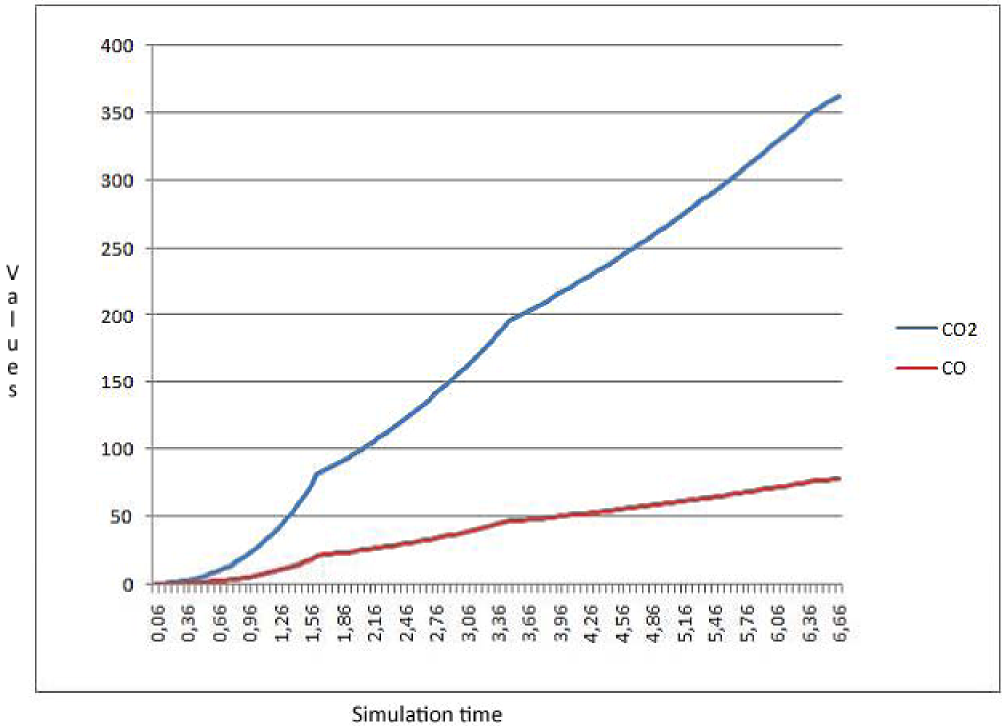
Experimental results

- The evaluation was done using modeling and simulation.
  - Model vehicular traffic, communication from traffic lights to vehicles, driver behavior (speed adaption) and fuel consumption and emissions.
- We were interested how acceleration relates to pollutant emissions
  - These experiments verify that the simulation model corresponds in known-cases to the expected mathematical results
  - We considered the case of an average car - the entry values for these experiments followed the analysis of Smith&Cloke (1999).
- We conducted two experiments that evaluate the fuel consumption for the typical driver behaviors.

Experimental results

- 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)

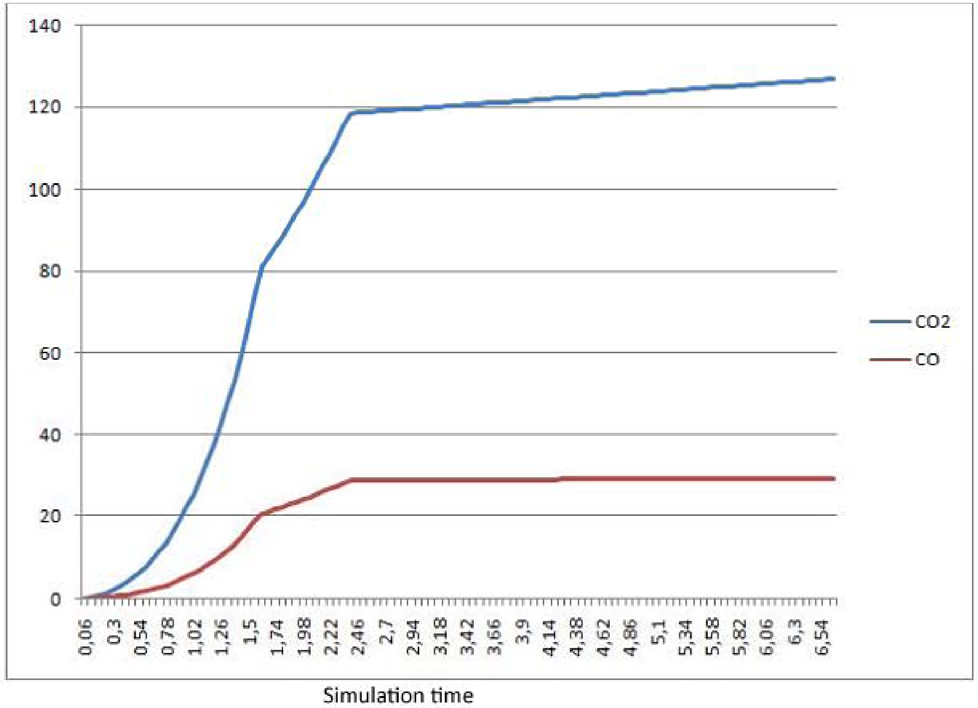




Experimental results

- 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 maintains a constant speed

Comparing the results of the two scenarios, it can be noticed that the quantity of gases emitted by the car in the second scenario (≈ 129g of CO_2), is smaller than the one obtained in the first scenario (≈ 360g of CO_2)



30.05.2012

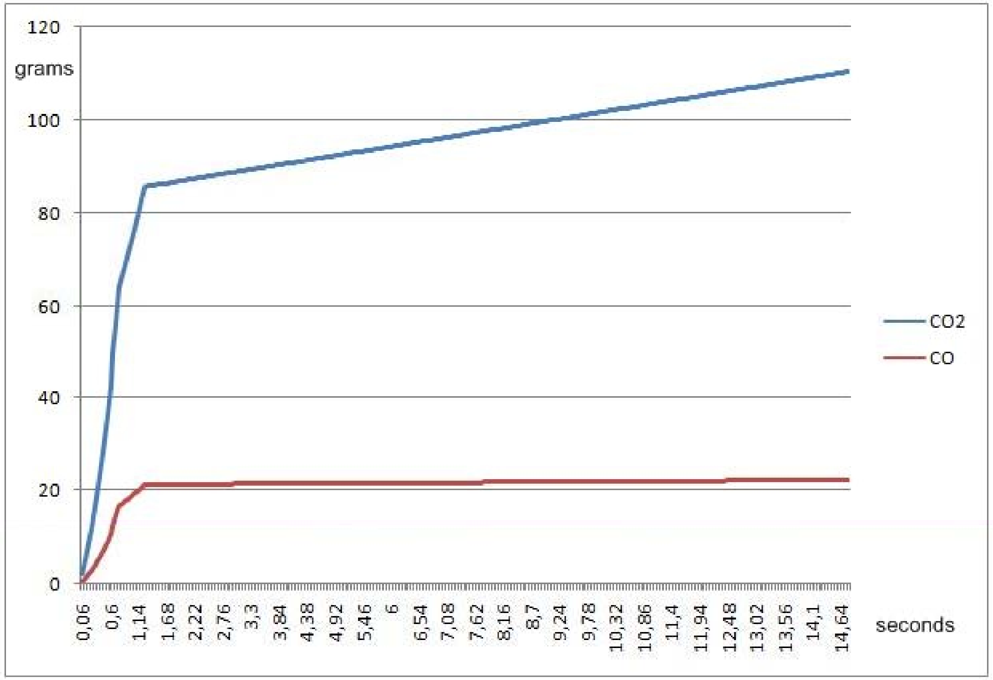


Case – Green light

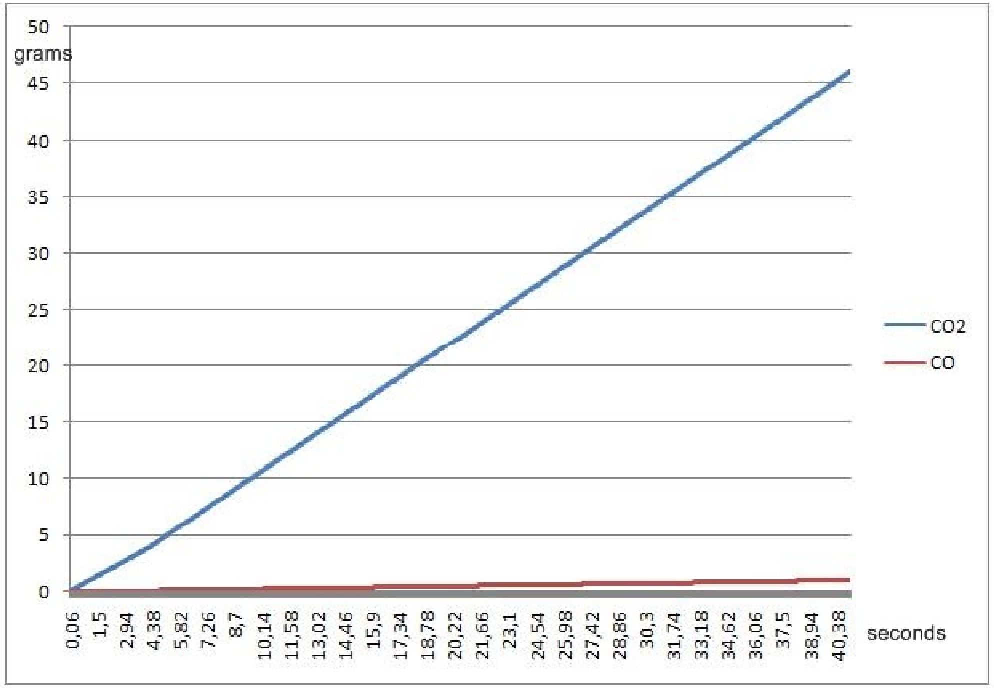
- A car is traveling at 40 km/h (~11 m/s) and has 15 seconds to catch the green light. The distance between the traffic light and the car is 200 m.
  - This corresponds to the case when a car cruising at a relatively high speed in town approaches the intersection.
- The car predicts estimates the quantity of emissions:
  - 1) driver catch the green light and accelerates until the needed speed is reached and
  - 2) 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 CO_2, and in the second situation ~96 grams of CO_2.
- 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 CO_2 by approximately 42 grams (going at high speed, but this higher limit depends on the maximum speed imposed by legislation in that particular location).



Experimental results



Quantity of emissions in situation 1



Quantity of emissions in situation 2

30.05.2012



Conclusions

- Solution that uses traffic lights, mobile devices and wireless communication to reduce car emissions
- 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
  - We use the motion equation of a car to predict its speed and position at any time
- 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.
- The solution was evaluated using modeling and simulation
  - The results show that the proposed algorithm can recommend speeds that, in fact, lead to a decrease in the emissions of a car

Q&A

Thank you!