Suitable Deceleration Rates for Environmental Friendly City Driving

Harwin Saptoadi

***Abstract*—**Urban driving is not environmental friendly due to frequent traffic congestions which result in high fuel consumption and CO_2 emission. Higher car speed is recommended because it saves fuel. However, drivers must be alert to apply brake at anytime. A typical city car is tested on a dynamometer. The test displays torque, power and AFR (air-fuel ratio) at various engine rotational speeds, car velocities and gear positions. The diagrams can further be utilized to calculate fuel consumption and CO_2 emission. Traffic densities of 60 – 100 cars/km and deceleration rates of 2 – 5.5 m/s^2 are simulated. Moderate deceleration rates of between 3 and 3.5 m/s^2 are desired, which is in well accordance with those endorsed by AASHTO and ITE. The effect of deceleration rates on fuel consumption and CO_2 emission is not as substantial as that of traffic density and gear position. Therefore, environmental friendly city driving can not rely solely on deceleration rates.

***Keywords*—**CO_2 emission, Deceleration rate, Dynamometer, Fuel Consumption, Traffic Density, Vehicle Speed.

I. Introduction

VEHICLE driving is expected to be smooth, fast and accident-free. Basically, higher car speed can considerably save fuel, time and money. Moreover, taking our environment into account, vehicles should move with constant speed, because frequent acceleration and braking will result in higher fuel consumption and pollutant emission. Unfortunately, it is almost impossible to maintain constant velocities in busy urban traffics, especially during rush hours. Therefore, drivers must be ready to apply brakes anytime, otherwise there will be front-end crash with a lead vehicle which suddenly decelerates ahead or rear-end collision from a vehicle following close behind. Drivers really depend on reliable brakes to produce sufficient deceleration in order to avoid collisions. High constant vehicle speed to minimize fuel requirement and emission is still possible during city driving, provided that all drivers agree to move with the same speed and they are highly alert to exert brake at whatever unexpected situation ahead.

Polynomial models of speed change profiles are derived for estimating instantaneous deceleration rates. However model calibration is still required, considering vehicle types, specific traffic facilities, traffic demand levels, road types and wide range of initial and final speeds. Normally, average deceleration rates of light vehicles are between 1.1 and 2 m/s^2, although a maximum value of 3.09 m/s^2 is achievable [1]. Another research shows that most vehicles slow down over the same distance irrespective of the initial speed. As a result, deceleration rates are proportional to the initial speed. Based on the measurements, vehicles with approaching speed of 60 – 70 km/h experience mean decelerations of 0.46 – 1.39 m/s^2, whereas those with initial velocity of 90 – 100 km/h endure average decelerations of 1.39 – 2.34 m/s^2 [2].

Field measurements are carried out on vehicles which slow down before signalized intersections on streets with low (< 64.3 km/h) and high (> 64.3 km/h) speed limits. Cars approaching intersections on streets with low speed limit will decelerate between 2.59 and 2.98 m/s^2 and those with high speed limit will slow down hastily with 3.07 - 3.62 m/s^2 [3]. High deceleration rates can be found also in a study conducted by Najm et al. who exerted normal and hard braking to cause deceleration rates of 1.47, 2.74 and 3.83 m/s^2. It was not surprising if several trials with the highest deceleration rate ended up with front-end crashes, although the following cars were allowed to steer and change lanes to avoid the decelerating vehicle ahead [4]. In an emergency situation, when the lead car suddenly brakes and stops, the average deceleration rate of the following car can even range from 4 to 7.5 m/s^2, whereas in a normal driving situation it is between 2.5 and 3.5 m/s^2. Such a very high deceleration rate is made possible for new light vehicles [5].

As most researchers focus on car deceleration in homogeneous traffic, Maurya et al. observes those in heterogeneous traffic, consisting of not only cars but also trucks, motorized two and three wheelers. The conclusion is the same, whereas vehicle with higher maximum speed had higher maximum and mean deceleration rates. Cars with higher maximum velocities (92 - 100 km/h) were able to slow down between 1.15 and 1.62 m/s^2. On the contrary, trucks which move 20 – 60 km/h could decelerate only in the range of 0.47 – 0.88 m/s^2 [6].

Basically, most of those investigated deceleration rates for normal driving rarely exceed values of 3 m/s^2 recommended by ITE (Institution of Transportation Engineers) or 3.4 m/s^2 proposed by AASHTO (American Association of State Highway and Transportation Officials) as comfortable deceleration rate. Those thresholds can be easily achieved by most vehicle braking systems and wet tire – pavement friction levels [3,6].

A theoretical approach shows that vehicle speeds depend on traffic density and deceleration rate, whereas higher deceleration rates always result in environmental friendlier urban driving. The study investigates traffic densities of 50 – 95 car/km and deceleration rates of 1 – 7 m/s^2 [7]. However,

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too hard braking is not comfortable. Therefore, it is advantageous to find out suitable deceleration rates by selecting a typical city car and test it on a dynamometer. That is the aim of the present research.

II. Research Methodology

Firstly, vehicle speeds V must be determined considering traffic density x and deceleration rate d_b using a simple formula [7]:

$$V^2 + 3\, d_b V = 4{,}000 \frac{d_b}{x} - 14.4\, d_b \quad (1)$$

Equation 1 assumes brake reaction time of 1.5 second. Five traffic densities x are chosen, i.e. from 60 to 100 cars per km road length with a constant interval 10 car/km. Moreover, there are eight selected deceleration rates d_b range from 2 to 5.5 m/s^2 with an increment of 0.5 m/s^2.

The city car's representative has a 3-cylinder gasoline-fueled 1 liter engine, 12 valves, DOHC, EFI and 5 speed manual transmission. It is run statically on an AWD 1200 chassis dynamometer. The dynamometer test delivers diagrams which display engine characteristics and performances, such as torque, power and AFR (air-fuel ratio) at various engine rotational speeds, car velocities and gears. The diagrams can further be utilized to calculate fuel consumption and CO_2 emission. Data from the 3rd, 4th and 5th gears are disregarded because drivers never use them in busy city traffics. The similar research procedure can be found elsewhere [8].

The air consumption $\dot{m}_a$ is required for fuel combustion, which is obtained with the equation

$$\dot{m}_a = \eta_V \rho_a V_d \frac{N}{2}, \quad (2)$$

whereas η_V is volumetric efficiency, ρ_a is air density, V_d is piston displacement, N is the rotational speed, and the number 2 indicates that it is a four stroke engine. In this study: η_V = 0.86, V_d = 0.001 m^3 and ρ_a = 1.1321 kg/m^3, according to the ambient air condition of 32 ^oC and 991 mbar. Taking into account that there are x cars/km and the corresponding AFR, the fuel consumption of each car must be multiplied by x and divided by gasoline density ρ_f (assumed to be 0.74 kg/l) in order to get liter of gasoline per km road length, as follows:

$$TFC = \frac{x\ \dot{m}_a}{AFR\ V\ \rho f} \quad (3)$$

Although gasoline is mixture of numerous different hydrocarbons, it is a common practice to consider the fuel as a single compound for convenience. Normally octane (C_8H_{18}) is selected to represent gasoline [9]. Complete combustion is assumed because there is always excess air supplied to engine cylinders. It is identified that roughly 3.0877 kg CO_2 is produced for each kg of gasoline consumed by a car [8]. Considering that there are x cars per km road length, the total amount of emitted CO_2 (in kg/km) is therefore:

$$E_{CO2} = 3.0877\, \rho_f\ TFC \quad (4)$$

III. Results and Discussions

The results of the dynamometer test measurements are shown in the Figure 1.

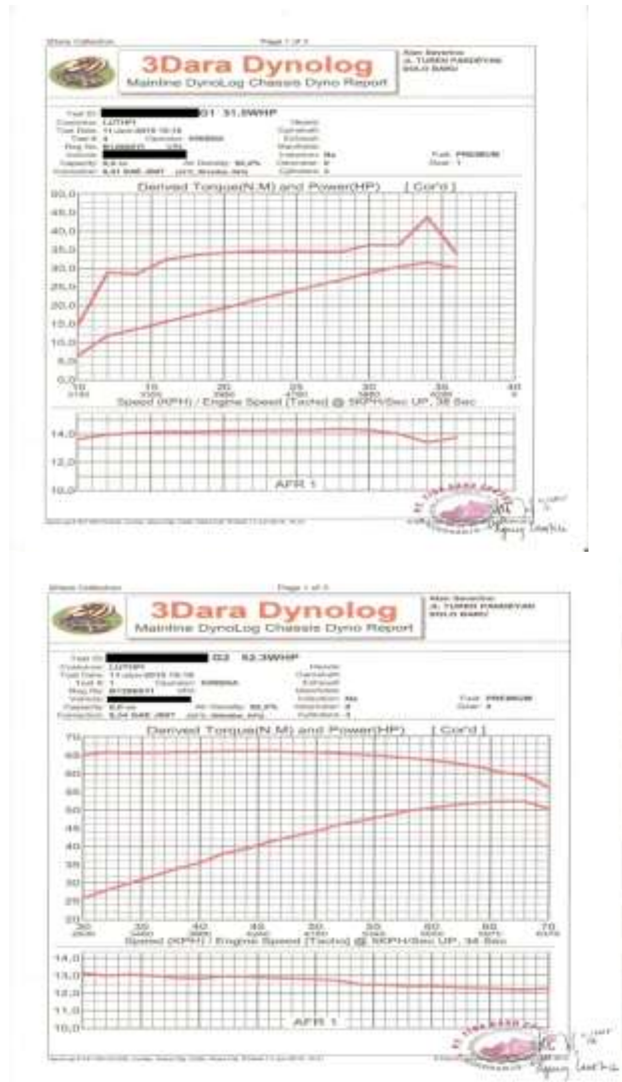

Fig. 1: Results of the dynamometer tests at 1st gear (upper) and 2nd gear (lower).

Just like many other cars, both power and torque initially increase with car velocity V and engine rotational speed N until a certain speed where maximum values are attained. Afterward, power and torque will decline. At the 1st gear position, the maximum torque (43.33 Nm) and power (31.5 HP) are achievable at 6224 rpm (and also at 34 km/h). AFR changes only slightly above 14. At the 2nd gear position, the maximum torque (66 Nm) and power (52.3 HP) occur at 4348 rpm (46 km/h) and 6210 rpm (68 km/h), respectively. AFR changes only slightly around 13. After the speed of 30 km/h is attained, the gear can be switched to the second position.

By using Eq. (1) and considering five traffic densities x : 60, 70, 80, 90 and 100 car/km, the maximum car velocities V as a function of vehicle deceleration rate d_b are shown in Fig. 2.

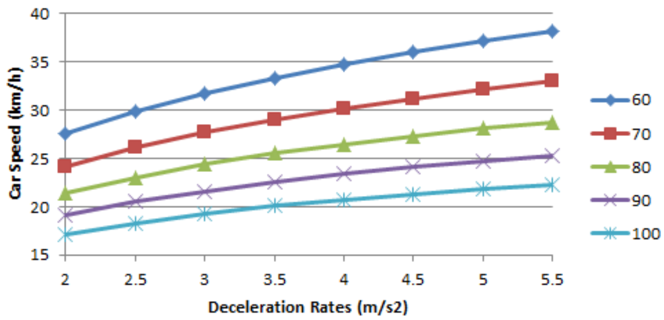

Fig. 2: Vehicle speeds as a function of deceleration rate at various traffic densities

The higher the deceleration rates (or more appropriately: the higher the driver readiness to brake hardly), the faster will be the vehicle. In an extreme case, if a driver is ready to brake strongly in order to create a 5.5 m/s^2 deceleration, while the traffic density is only 60 car/km, he can drive as fast as 38.18 km/h. In contrast, if the driver does not like to slow down hastily and ready with only 2 m/s^2 deceleration, while the street is occupied by 100 car/km, he is limited to drive only with 17.13 km/h.

The aggregated fuel consumptions TFC are obtained by using Eqs. 2 and 3, along with the data shown in Figs. 1 and 2. The results are displayed in Figure 3.

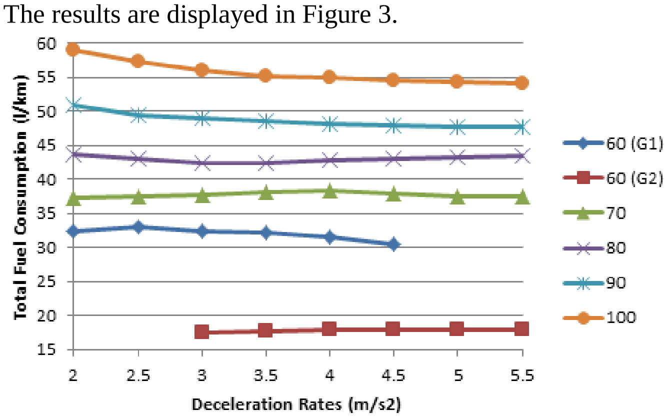

Fig. 3: Total Fuel Consumptions as a function of deceleration rate at various traffic densities.

In congested urban traffics with more than 90 cars in one kilometer road length, higher deceleration rates are recommended. However, additional fuel saving seems to be negligible at deceleration rates of more than 3.5 m/s^2. An optimum deceleration rate appears at the traffic density 80 cars/km where the least fuel consumption (42.471 l/km) is achievable at the deceleration rate of 3 m/s^2. At the traffic density 70 cars/km, high deceleration rates (between 3.5 and 4.5 m/s^2) should be avoided because it consumes even more fuel than those at lower deceleration rates. It is interesting to highlight the traffic density 60 cars/km because car speed of 30 km/h becomes achievable and thus the second gear can be applied. Of course, the drivers can still use the first gear at speeds higher than 30 km/h, but it is not only uncomfortable but more importantly fuel wasting. It is apparently displayed in Fig. 3 that if the drivers agree to slowdown at 3 m/s^2 or more, the engine can be switched to the second gear to affect very significant fuel saving. For example, at the deceleration rate of 3 m/s^2 the car speed can achieve 31.7 km/h. If the drivers still use the 1st gear the total fuel consumption amounts to 32.307 l/km, but if the 2nd gear is applied the total fuel requirement is reduced to 17.49 l/km, which means a remarkable 46% fuel saving. At the 2nd gear and deceleration rates of more than 3 m/s^2 the fuel consumption increase slightly. Fig. 3 shows clearly that deceleration rates play only minor role compared to traffic density and gear position.

Finally, the aggregated CO_2 emissions are obtained by using Equation (4) and Figure 3. The results are displayed in Figure 4 which exhibits exactly the same as Figure 3. It is not surprising because CO_2 emission is linearly proportional to fuel consumption. In city traffics with more than 90 cars/km, higher deceleration rates are also suggested, although the reduction is not significant at deceleration rates of more than 3.5 m/s^2. The best deceleration rate exists only at the traffic density 80 cars/km where the least CO_2 emission (97.04 kg/km) occurs at 3 m/s^2. At the traffic density 70 cars/km, high deceleration rates (between 3.5 and 4.5 m/s^2) should be avoided as well. At lower traffic densities (less than 60 cars/km) the second gear can be applied instead of only the first one. In this case, at the deceleration rate of 3 m/s^2 the car speed can achieve 31.7 km/h. If the drivers still use the 1st gear the total CO_2 emission amounts to 73.82 kg/km, but if the 2nd gear is applied the total emission is reduced to 39.96 kg/km, which also means a noteworthy 46% improvement. Fig. 4 also shows apparently that, in term of gaseous emission, deceleration rates play only minor role compared to traffic density and gear position.

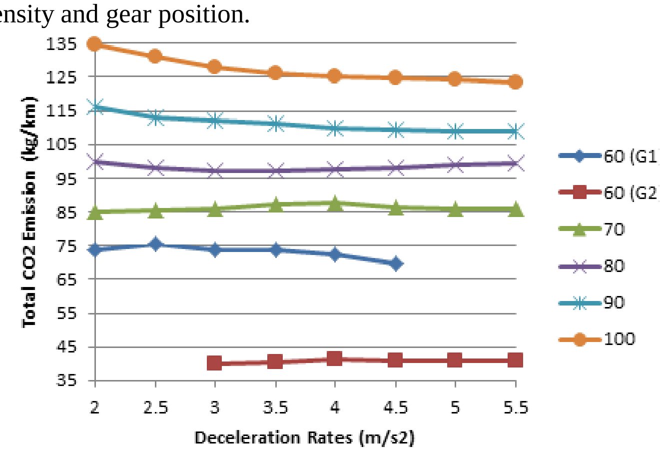

Fig. 4: Total CO_2 emissions as a function of deceleration rate at various traffic densities

IV. CONCLUSION

Moderate deceleration rates of between 3 and 3.5 m/s^2 is recommended, since it is not too low which leads to low vehicle speed and consequently higher fuel consumption and CO_2 emission, nevertheless not too high which is risky and uncomfortable for drivers. It is in well accordance with those officially endorsed by AASHTO and ITE.

The effect of deceleration rates on fuel consumption and CO_2 emission is not as substantial as that of traffic density and gear position. Therefore, environmental friendly city driving can not rely solely on the selection of suitable deceleration rates.

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