# DEVELOPMENT OF CAR DRIVE CYCLE FOR SIMULATION OF EMISSIONS AND FUEL ECONOMY

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## KEYWORDS

Simulation, Drive Cycle, Emissions, Fuel Economy

## ABSTRACT

This paper describes the development of car drive cycle for simulation of vehicles exhaust gas emissions and fuel economy. In this research work, the development of light vehicle drive cycle for city of Tehran has been performed. First, the approach to develop a drive cycle has been described. The necessary measuring tools and software have then been provided, and the car speed has been recorded in the city traffic condition. Based on the analysis of the recorded data, a drive cycle has been developed for city of Tehran. Applying the statistical analysis, the cycle has then been modified, and a real world smoothed cycle has been presented. Finally, characteristics of this cycle have been compared with some of light vehicles cycles provided for other countries.

## INTRODUCTION

Air pollution is a major problem for big cities, and vehicles are the most important air pollution source. In addition, the fuel consumption of city cars is a great share of energy usage. Therefore, it is necessary to assess the vehicles exhaust gas emissions and fuel economy using both simulation studies and laboratory tests. Both simulation studies and test procedures are performed based on drive cycles [Bata and Yacoub 2000]. Figure 1 shows the vehicle gas emissions and fuel economy simulation model using advanced vehicle simulator (ADVISOR) where the first block is drive cycle.

A drive cycle is a speed-time sequence developed for a certain type of vehicles in a particular environment to represent the driving pattern with the purpose of measuring and regulating exhaust gas emissions and monitoring fuel consumption, as shown in figure 2.

As driving patterns vary from city to city and from area to area, the available drive cycles obtained for certain cities or countries are not usually applicable for other cities. Therefore, many research works are targeted to develop drive cycles using recorded real world driving tests (complex transient) as well as steady state (cruise) conditions encountered in road driving. Such drive cycles have not been developed for city of Tehran yet, and at the moment, the European ECE standard cycles are used for simulation and test. However, it has been shown [Kuhler and Karstens 1978] that the European "ECE" driving cycle has lack of ability to represent the actual driving conditions.

In this paper, the development of vehicle drive cycles are described, and based on the data collected from in use cars, a car drive cycle has been developed for city of Tehran. Development of emissions standard that can be the next step of this research is very useful for Tehran that has serious problem of air quality in many days of a year.

## AVAILABLE DRIVE CYCLES

Several drive cycles have been developed in different countries to represent the driving conditions. The most important cycles are developed for the United States, European community and Japan. In the United States, the "FTP-75" is a transient test cycle used for emission certification testing of cars and light duty trucks. The "SC03" Supplemental Federal Test Procedure (SFTP) has been introduced to represent the engine load and emissions associated with the use of air conditioning units in vehicles certified over the FTP-75 test cycle. The "US06" Supplemental Federal Test Procedure was also developed to address the shortcomings with the FTP-75 test cycle in the representation of aggressive, high speed and/or high acceleration driving behavior, rapid speed fluctuations, and driving behavior following startup. The "IM-240" test is a chassis dynamometer schedule used for emission testing of in-use light duty vehicles in inspection & maintenance programs implemented in a number of states. The "LA92" is a dynamometer driving schedule for light-duty vehicles developed by the California Air Resources Board. It is a more aggressive driving cycle than the federal FTP-75 characterizing by higher speed, higher acceleration, fewer stops per mile, and less idle time.

In European countries, the ECE+EUDC test cycle is performed on a chassis dynamometer. The cycle is used for emission certification of light duty vehicles in Europe. It is also known as the MVEG-A cycle.

In Japan the 10-15 mode cycle is currently used for emission certification and fuel economy for light duty vehicles and the 13-mode cycle for the testing of heavy duty engines.

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## DEVELOPMENT OF CAR DRIVE CYCLE

To develop a drive cycle, the first step is to measure and record the real driving behaviors. Subsequently, the recorded data should be analyzed in order to obtain a representative cycle from real condition. Due to essentially different driving conditions, data should be classified in different categories based on traffic conditions. Statistical calculations will then be performed on the representative data, and an individual cycle for each traffic condition will be obtained. The final cycle is a sequence of these individual cycles. These steps have been described in the following.

### Speed Measurement and Recording Methods

The primary need for this work is to measure and record vehicles speed. The methods of measurement can be divided into two groups: 1) Using vehicles facilities to measure speed. We know that all vehicles have speed measurement system. The data from this system may be recorded and used for analysis. However, the vehicle owners do not like to change their vehicle system. Therefore, this method was rejected. 2) Using some additional equipment to measure the vehicle speed. For this method, it was required to design and install a device on all vehicles so that it could give a peace of mind to vehicles owners. For this purpose, an auxiliary wheel was designed as shown in figure 3. This wheel rotates together with the vehicle wheel. This wheel has a cam shaped part so that it makes a pin to reciprocate and open and close an electromechanical switch. As the wheel is rotating, a pulse chain is generated. By measuring the frequency of the wheel rotation, the speed of vehicles can be computed.

The electronic part of the device is an electronic network that works together with a notebook computer as a data logger. By this PC Based system, the output of the network is connected to the notebook parallel port where the frequency of pulse signal can be converted to vehicle speed.

### Analysis of The Recorded Data

Development a drive cycle is based on "microtrips". Microtrip is an excursion between two successive time points at which the vehicle is stopped. This part of motion consists of acceleration, cruise and deceleration modes. By convention, a period of rest is at the beginning of a microtrip.

To analyze the data, a computer program has been developed. This program calculates the vehicle speed and acceleration and save them as a text file. The program can also find and separate "microtrips" and the required parameters including the idle time, acceleration time, deceleration time and cruise time. This program also calculates the average and maximum speeds, acceleration and deceleration, and the number of "microtrips" for each car trip. At the beginning of recording, the Id. number of test, path of trip, vehicle brand and vehicle registration number are inserted by user. When program starts by user, the date and time will also be saved.

### Parameters Used for Data Analysis

To develop a drive cycle, the data recorded from real driving tests should be analyzed. As mentioned before, the analysis is based on microtrips. The parameters used for analyzing microtrips are:

- Average speed (km/hr),
- Idle time percentage (%).

### Classification of Traffic Conditions

Traffic condition varies from region to region in a city, and therefore, classification of traffic situation is necessary. The classification parameters are considered to be the average speed and the percentage of idle time for each "microtrip". In this research work, to categorize the traffic condition, the idle time vs. average speed distribution chart shown in figure 4 is used. The 4 different traffic conditions are then defined as follows:

1. *Congested Urban Condition:* for central business district flow with low driving speed and frequently stops with the average speed less than 10 km/hr and a wide range of low to high idle time.
2. *Urban Condition:* for non-free flows with moderate and low idle time and average speed between 10 to 25 km/hr.
3. *Extra Urban Condition:* for relatively free flows with low idle time and average speed between 25 to 40 km/hr.
4. *Highways:* for completely free flows with very low idle time and average speed more than 40 km/hr.

Based on the classification above, the microtrips that fall outside the homographic range of idle time are omitted.

By applying these thresholds, the classification used for traffic conditions may be illustrated as shown in table 1.

Table 1: Classification of Traffic Conditions

| | **Congested** | **Urban** | **Extra Urban** | **Highway** |
|---|---|---|---|---|
| **Average Speed (km/hr)** | ≤10 | 10-25 | 25-40 | >40 |
| **Idle Time (%)** | 0-100 | <60 | <24 | <13 |

### Duration of Each Traffic Condition in Final Cycle

To obtain the duration of each category of traffic condition in the final cycle, the proportion of each category in the whole recorded data is used. In other words, it is equal to the duration of each category of traffic condition in the final cycle divided by the duration of the overall cycle as follows:

$$t_i = \frac{t_{drivecycle}}{t_{Overall}} \sum_{j=1}^{n_i} t_{i,j} \quad (1)$$

where:

$t_i$ is duration of category number i (i = 1, 2, 3, 4) in the cycle,

$t_{drivecycle}$ is duration of the final drive cycle,

$t_{overral}$ is duration of all recorded data,

$t_{i,j}$ is the time of microtrip number j in category number i,

$n_i$ is the total number of microtrips within category number i.

### Total Duration of Cycle

There should be an agreement between representative rate of a cycle and low cost test procedure on dynamometer, while the former implies long duration and the latter requires short duration cycle. It is more appropriate to develop a cycle with adaptation to reference cycle characteristics and with short duration suitable for dynamometer tests. Considering the existing drive cycles, it seems that a cycle with the duration of about 30 minutes can well represent the driving situation on a city as a reference cycle.

### Selection of Representative Microtrips

The final cycle consists of the representative microtrips selected from all existing data. In this study, we have defined the representative microtrip as follows:

"The representative microtrip is the one that minimizes difference between its parameters and those of the whole data in a certain category of traffic condition".

Based on the above definition, the following calculation is used for relative parameters:

$$\bar{v}_{rel,i} = \frac{\bar{v}_{mt,i}}{\bar{v}_{total}} \quad (2)$$

$$\%idtime_{rel,i} = \frac{\%idtime_{mt,i}}{\%idtime_{total}} \quad (3)$$

where $\bar{v}_{mt,i}$ is the average speed of microtrip number i and $\%idletime_{mt,i}$ is its idle time percentage. These parameters designated by index "total" for all the data in a certain category of traffic condition as well.

An ideal microtrip is selected so that its relative parameters are equal to 1 [Hann and Keller 2001]. However, such a microtrip is rarely exists. Therefore, the following indicator is defined for each microtrip:

$$N_i = \left|\bar{v}_{rel,i} - 1\right| + \left|\%idtime_{rel,i} - 1\right| \quad (4)$$

where $N_i$ is the indicator for microtrip number i.

Finally, the representative microtrips are selected so as to minimize the indicator $N_i$.

## SMOOTHING THE CYCLE

In order to remove the high frequency noise in speed-time series, a filter has been applied. Instead of non-optimal arithmetic mean, the filter of the following form has been used [Hann and Keller 2001]:

$$v_{smoothed}(t) = \frac{1}{h} \sum_{s=-h}^{h} K\left(\frac{s}{h}\right).v(t+s) \quad (5)$$

The function k(x) weights the measured speed just before and after the time t to be smoothed. In this study, h= 4 sec together with the so-called "biweight" smoothing kernel has been used [Hann and Keller 2001]:

$$K(x) = \left\{ \begin{array}{ll} \frac{h^2 - 1}{h^2}(1 - x^2)^2 & (x^2 < 1) \\ 0 & otherwise \end{array} \right\} \quad (6)$$

## TEHRAN CAR DRIVE CYCLE

Based on the recorded data from the cars in the city of Tehran and using the above calculations, the cycles for all traffic conditions are obtained. The primary or non-smoothed and the smoothed cycles consist of congested urban, urban, extra urban and highway traffic conditions are shown in figures 5 and 6, respectively.

The characteristics of these cycles and differences between the non-smoothed and smoothed cycles have illustrated in table 2.

The smoothed cycle is presented as the final drive cycle of cars in Tehran. This cycle is named "TEH_CAR "cycle.

## COMPARISON BETWEEN "TEH_CAR" AND OTHER LIGHT VEHICLES CYCLES

In order to compare the driving patterns of TEH_CAR and other light vehicles cycles in other countries, the characteristics of this cycle and some other important cycles are illustrated in table 3. In addition, the speed distribution charts are shown in figures 7 and 8.

The ECE and J10-15 mode cycles are constructed from only straight lines. They do not have maximum acceleration and deceleration near to real aggressive driving. However, the FTP cycle has higher maximum acceleration and deceleration and is comparable with the TEH_CAR cycle. It is clear that the maximum acceleration and deceleration of TEH_CAR cycle are greater than FTP cycle. This fact is due to driving pattern in city of Tehran that can affect the exhast emmisions and fuel consumption levels.

Table 2: Comparison between Non-smoothed and Smoothed Cycles Characteristics

| | Time (Sec) | Dist (km) | $V_{max}$ (km/hr) | $V_{avg}$ (km/hr) | Max accel $(m/s^2)$ | Max decel $(m/s^2)$ | Avg accel $(m/s^2)$ | Avg decel $(m/s^2)$ | Idle time (%) | Accel time (%) | Decel time (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Non-smoothed** | 1955 | 15.8 | 83.6 | 29.1 | 3.31 | -3.31 | .71 | -.76 | 12.8 | 36.6 | 34.1 |
| **Smoothed** | 1955 | 15.9 | 84.0 | 29.3 | 1.93 | -2.21 | .45 | -.51 | 12.4 | 38.5 | 33.7 |
| **Difference (%)** | 0 | .6 | .5 | .7 | 41.69 | 33.23 | 36.62 | 32.89 | 3.1 | 5.2 | 1.17 |

Table 3: Comparison of TEH_CAR and other Light Vehicles Cycles

| Idle Time (%) | Avg decel $(m/s^2)$ | Avg accel $(m/s^2)$ | Max decel $(m/s^2)$ | Max accel $(m/s^2)$ | Vavg (km/hr) | Vmax (km/hr) | Dist (km) | Time (sec) | |
|---|---|---|---|---|---|---|---|---|---|
| 12.4 | -.51 | .45 | -2.21 | 1.93 | 29.3 | 84.0 | 15.9 | 1955 | **TEH_CAR** |
| 18.92 | -.57 | .5 | -1.48 | 1.48 | 31.51 | 91.25 | 11.99 | 1369 | **FTP-72** |
| 32.3 | -.75 | .63 | .-83 | 1.06 | 18.35 | 50 | .99 | 195 | **ECE** |
| 27.38 | -.79 | .54 | -1.39 | 1.06 | 32.23 | 120 | 10.93 | 1220 | **ECE+EUDC** |
| 32.58 | -.65 | .57 | -.83 | .79 | 22.68 | 69.97 | 4.16 | 660 | **J10-15 mode** |

## SIMULATION RESULTS

The object in the car simulation can be defined as the exhaust gas emissions (g/km) and its fuel consumption (L/100 km). In this study, car simulation performed for different drive cycles to view the effect of changing driving patterns on mentioned parameters. The simulation results obtained for a typical car are shown in table 4. It can be seen as the average acceleration and deceleration of a cycle increase, the emissions and fuel consumption increases.

Table 4: Simulation Parameters for Different Drive Cycles

| | HC | CO | NOx | Fuel Consumption |
|---|---|---|---|---|
| **TEH_CAR** | .937 | 6.157 | 1.121 | 6.1 |
| **FTP72** | .979 | 6.785 | 1.446 | 6.0 |
| **ECE** | 4.01 | 15.520 | 1.780 | 8.1 |
| **EUDC** | 1.081 | 6.885 | 1.668 | 5.3 |
| **ECE+EUDC** | 1.004 | 6.752 | 1.436 | 6.1 |
| **J10-15 mode** | 1.562 | 8.585 | 1.532 | 7.0 |

## CONCLUSIONS

In this paper, development of car drive cycle was presented. Drive cycle is necessary for both simulation and test of vehicles gas emissions and fuel economy.

Using the designed measurement system, the data were collected from the cars in Tehran. These data were analyzed using a developed computer program, and the Tehran car drive cycle (TEH_CAR) was presented. Comparing TEH_CAR with other cycles, it was shown that TEH_CAR cycle has greater maximum acceleration and deceleration but smaller average acceleration and deceleration similar to FTP cycle, implying lower emissions and fuel consumption.

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## AUTHOR BIOGRAPHIES

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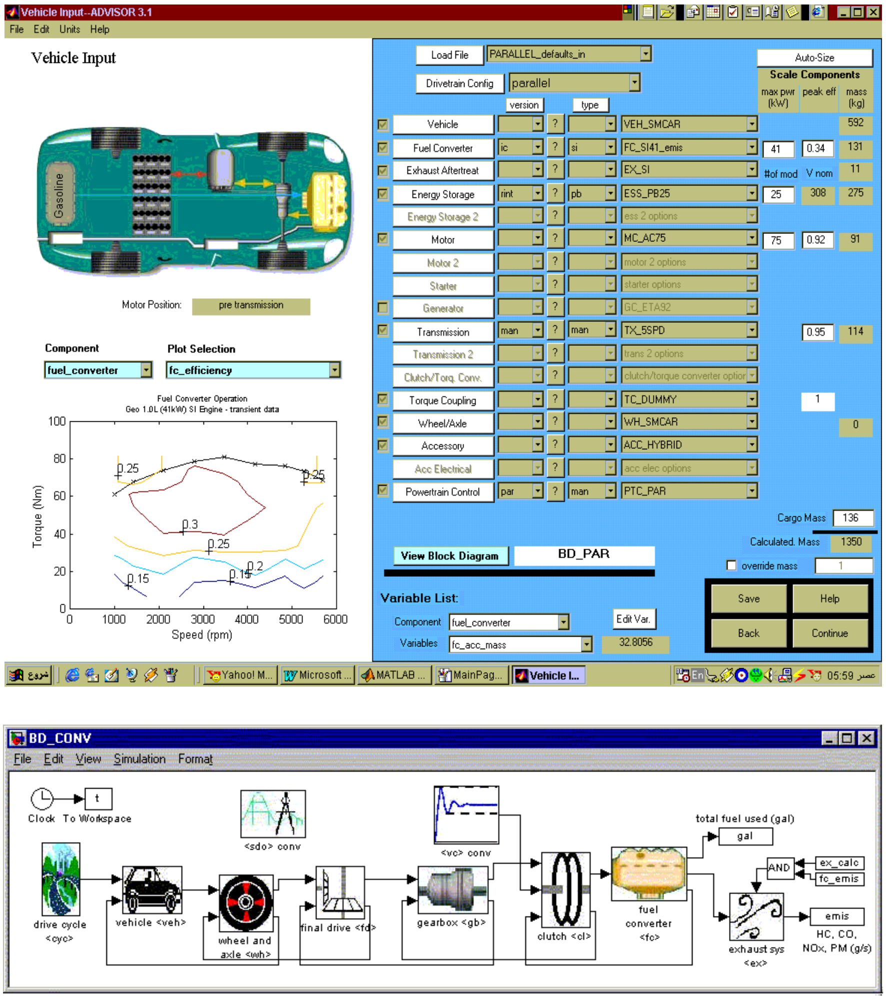


Motor Position: pre transmission

**Component** fuel_converter

**Plot Selection** fc_efficiency

Load File: PARALLEL_defaults_in

Drivetrain Config: parallel

| | | version | type | | Scale Components: max pwr (kW) | peak eff | mass (kg) |
|---|---|---|---|---|---|---|---|
| ☑ | Vehicle | | | VEH_SMCAR | | | 592 |
| ☑ | Fuel Converter | ic | si | FC_SI41_emis | 41 | 0.34 | 131 |
| ☑ | Exhaust Aftertreat | | | EX_SI | #of mod | V nom | 11 |
| ☑ | Energy Storage | rint | pb | ESS_PB25 | 25 | 308 | 275 |
| | Energy Storage 2 | | | ess 2 options | | | |
| ☑ | Motor | | | MC_AC75 | 75 | 0.92 | 91 |
| | Motor 2 | | | motor 2 options | | | |
| | Starter | | | starter options | | | |
| ☐ | Generator | | | GC_ETA92 | | | |
| ☑ | Transmission | man | man | TX_5SPD | | 0.95 | 114 |
| | Transmission 2 | | | trans 2 options | | | |
| | Clutch/Torq. Conv. | | | clutch/torque converter optior | | | |
| ☑ | Torque Coupling | | | TC_DUMMY | | 1 | |
| ☑ | Wheel/Axle | | | WH_SMCAR | | | 0 |
| ☑ | Accessory | | | ACC_HYBRID | | | |
| | Acc Electrical | | | acc elec options | | | |
| ☑ | Powertrain Control | par | man | PTC_PAR | | | |

Cargo Mass 136

Calculated. Mass 1350

☐ override mass 1

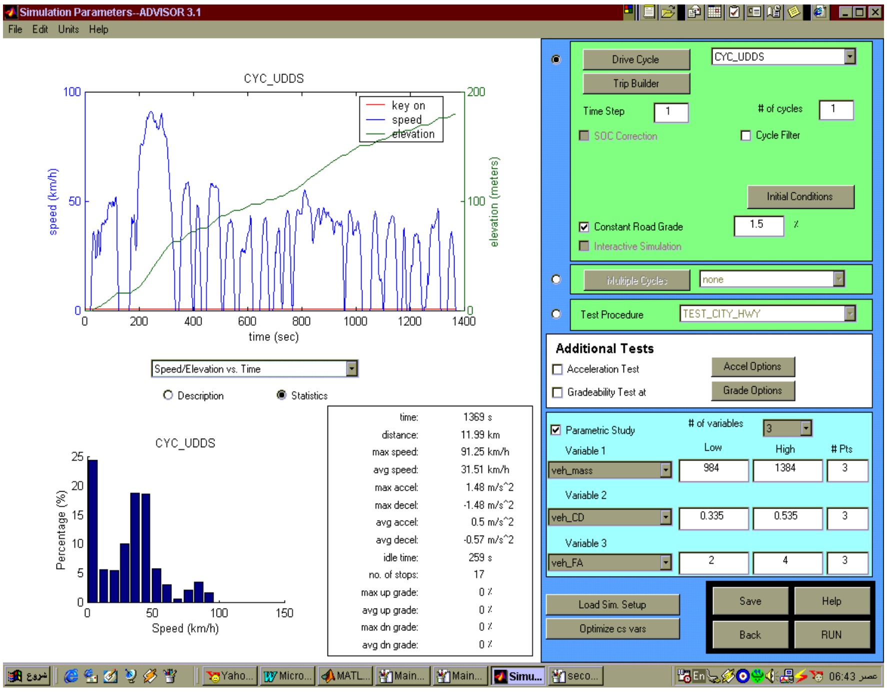
View Block Diagram: BD_PAR

**Variable List:**

Component: fuel_converter

Variables: fc_acc_mass 32.8056

Figure 1: Vehicle Emissions and Fuel Economy Simulation Model



Speed/Elevation vs. Time

| | |
|---|---|
| time: | 1369 s |
| distance: | 11.99 km |
| max speed: | 91.25 km/h |
| avg speed: | 31.51 km/h |
| max accel: | 1.48 m/s^2 |
| max decel: | -1.48 m/s^2 |
| avg accel: | 0.5 m/s^2 |
| avg decel: | -0.57 m/s^2 |
| idle time: | 259 s |
| no. of stops: | 17 |
| max up grade: | 0 % |
| avg up grade: | 0 % |
| max dn grade: | 0 % |
| avg dn grade: | 0 % |

● Drive Cycle: CYC_UDDS

Time Step 1

# of cycles 1

☐ SOC Correction

☐ Cycle Filter

☑ Constant Road Grade 1.5 %

☐ Interactive Simulation

○ Multiple Cycles: none

○ Test Procedure: TEST_CITY_HWY

**Additional Tests**

☐ Acceleration Test

☐ Gradeability Test at

☑ Parametric Study

# of variables 3

| | Low | High | # Pts |
|---|---|---|---|
| Variable 1: veh_mass | 984 | 1384 | 3 |
| Variable 2: veh_CD | 0.335 | 0.535 | 3 |
| Variable 3: veh_FA | 2 | 4 | 3 |

Figure 2: Drive Cycle Setup in Simulation Program

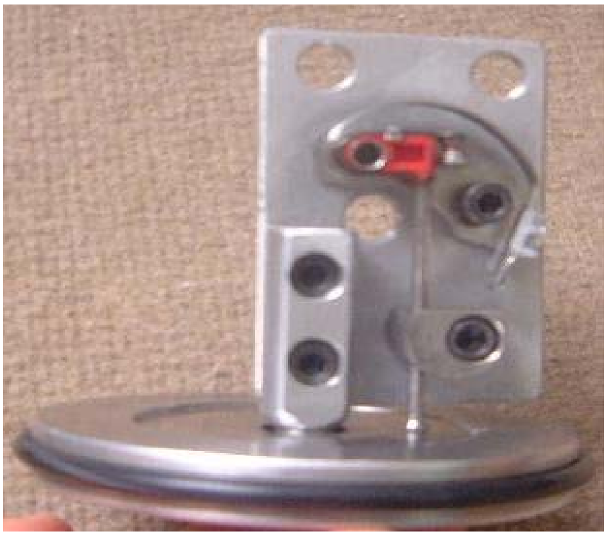


Figure 3: Auxiliary Wheel

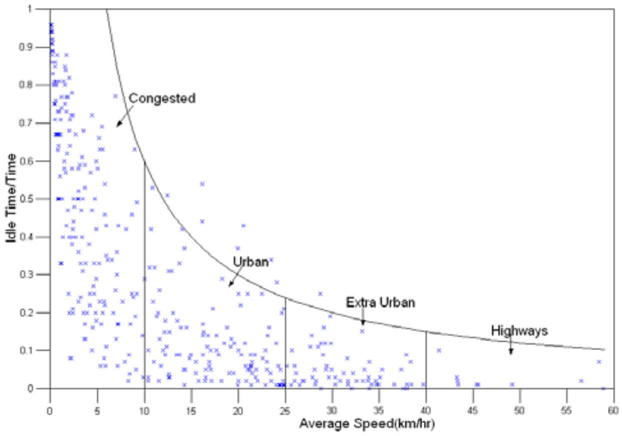


Figure 4: Idle Time vs. Average Speed Distribution for all Microtrips

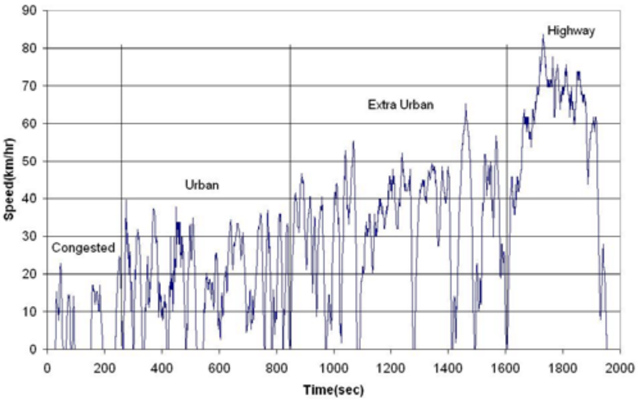


Figure 5: Tehran Cars Primary or Non-smoothed Cycle

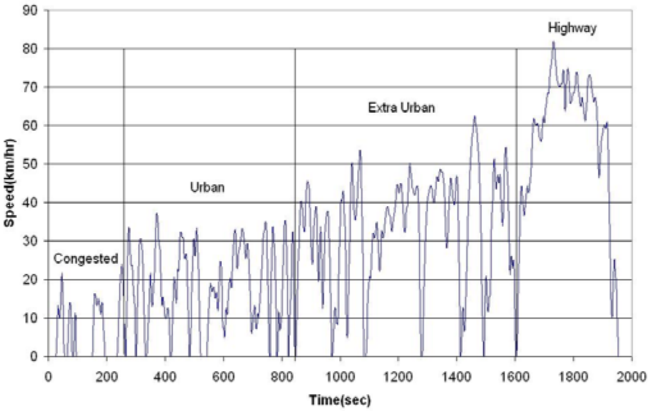


Figure 6: Cars Smoothed Cycle (TEH_CAR Cycle)

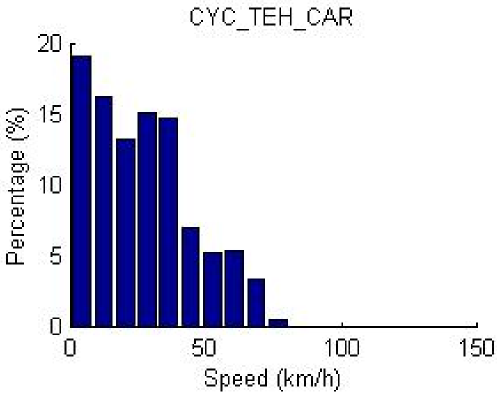


Figure 7: Speed Distribution Chart of TEH_CAR Cycle

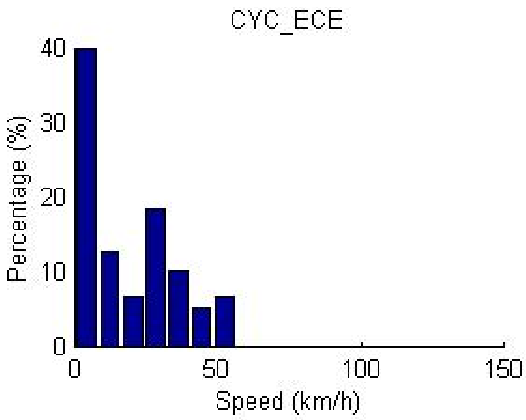


Figure 8: Speed Distribution Chart of ECE Cycle