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USING ROAD TEST FOR INSPECTION OF AN AUTOMOTIVE ENGINE

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ABSTRACT

The engine power could be measured accurately using an engine dynamometer but this process is time and money consuming due to difficulty of coupling the engine to the dynamometer. The coupling process can be eliminated using chassis dynamometer. Hence the chassis dynamometer is a road resistance simulator. Why not to take the actual road as the source of resistance instead of using chassis dynamometer? This process will be faster and cheaper taking less than a minute on road for a single test and will help to detect the condition of the engine and power train easily.
The aim of this paper is to evaluate the use of the road as a source of resistance for the calculation of engine power. Nowadays, there are many software products that claim the possibility to measure the engine power on road.
In our study road tests have been performed using OBD (On Board Diagnostic System) reader devices and high-speed GPS (Global Positioning System) receiver to measure vehicle speed variation with time during acceleration process. Three different vehicles are used to validate the road tests obtained data using chassis dynamometer. The proposed method proved its ability of using road test during automotive engine inspection process. Based on the validation the OBD and GPS data shows a difference between both methods by ±2% .

INTRODUCTION:

The process of measuring engine power could be performed on engine dynamometer after dismantling the engine from the vehicle. But this process is not economical and not reasonable for routine determination of the condition of the engine on the other hand using chassis dynamometer for such inspection. In the second method, previous studies described the calculation of engine power by assuming power train efficiency. The value of power train efficiency is the product of transmission efficiency and final reduction (differential) efficiency.
J. Hromádko et al [1] presented that the process of measuring the engine power could be performed by two ways using steady state method or modern acceleration method under no load. They concluded that the steady state test method gave more accurate results. The acceleration method accuracy was improved at no load when inertia flywheel was added.
M. Pexa et al [2] presented the option of using GPS receiver to determine the torque of the engine and its backup torque seemed to be an appropriate option. The compression between measured curve using GPS and engine dynamometer is shown in figure 1. They thus concluded that GPS data thus collected would contribute to detection of engine defects. Monitoring the progress of engine parameters (torque and engine power) is possible mainly by dynamometer, which is not affordable for common use.

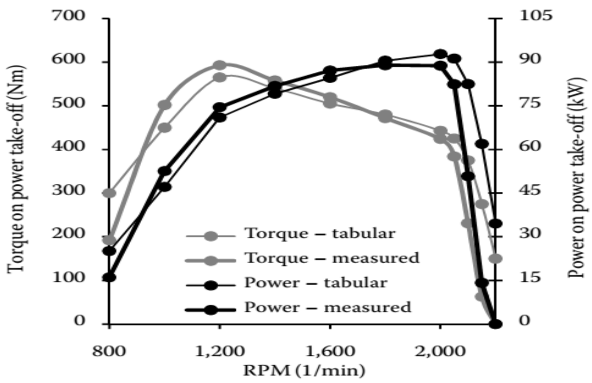

Fig. 1. Fendt Farmer 412 Vario power parameters determined by M. Pexa et al [2]

There are different programs that can be installed on PC(such as SCANXL 3and Dyno Scan) or even smart phones (such as Dynomaster, and OBD 2 Dyno+Diagnostics) that clam the ability to measure engine power. All programs adopt the idea of using the acceleration test method to calculate engine power, but they differ in the source of data by which they record the engine parameters. Some of the programs record the engine speed and vehicle speed using the OBDII reader, others use the built in or external GPS to record the vehicle speed. The error of the obtained data from these programs is reported to be 10-20 % from the actual engine performance characteristics. This rises the need to define whether or not the on road acceleration power measurement method can be used to inspecting the automotive engine power for fault diagnoses and maintenance.

Road resistances

This part is directed to evaluating the calculation of the engine power using acceleration method. The source of power is the engine and its relation to the available wheels power can be calculated as follows in equation 1:

$$P_{wheels} = \eta_{trans}\, \eta_{fr}\, P_e \quad (1)$$

Where P_{wheels} and P_e are the wheels power and the engine power respectively (kW), η_{trans} is the transmission efficiency and η_{fr} is the final reduction ratio efficiency. The value of η_{trans} was studied in SAE J2453[4] and is found to vary from 0.93 to 0.98. The final reduction ratio efficiency η_{Fr} was presented in Bosch handbook 5]and by J.Y. Wong [6] is found to vary from 0.93 to 0.95.

So by substituting in equation 1 and rewriting

$$P_e = P_{wheels}/[0.864\text{-}0.931] \quad (2)$$

So in order to calculate the engine power it is required to accurately measure P_{wheels}. Generally power equals to force times velocity:

$$P_{wheels} = F_{wheels}.V_{wheels} \quad (3)$$

Where F_{wheels} is the forces on wheels in the direction of motion (N), V_{wheels} is the linear velocity of the vehicle (m/s). F_{wheels} which is the sum of the resisting forces (N); air resistance, rolling resistance, gradient resistance and inertia force J.Y. Wong [6].

$$F_{wheels} = F_{ar} + F_{rr} + F_{gr} + F_i \quad (4)$$

Where F_{ar} is the air resistance force, F_{rr} is the rolling resistance force, F_{gr} is the gradient resistance force and F_i is inertia force.

$$F_{ar} = 0.5\rho C_D A V^2 \quad (5)$$

Where ρ is the air density (m^3/kg), C_D is the drag coefficient, V is the vehicle speed (m/s) and A is the frontal area of the vehicle (m^2) which can be calculated as from SAE J1349 as follows:

$$A = 0.8W H \quad (6)$$

Where W is the width of the vehicle without mirrors and H is the height of the vehicle in (m)

$$\text{Rolling resistance} = F_{rr} W \quad (7)$$

Where F_{rr} is the rolling resistance coefficient and W_g is the vehicle weight N.

$$F_{gr}= W_g \sin\theta \quad (8)$$

Where θ is the road gradient. Gradient resistance could be neglected on level road.

Inertia force from Newton's law

$$\text{Inertia force} = \text{linear inertia force} + \text{rotational inertia force} \quad (9)$$

From Newton's Second Law:

$$\text{Linear inertia force} = m\, a \quad (10)$$

Where m is the mass of the vehicle (kg) and a is the acceleration of the vehicle (m/s^2). Rotational parts have resisting inertia effect that should be taken based on J.Y. Wong [6]. Neglecting of rotational parts inertia led to reduced accuracy by J. Hromádko et al [1] and [3] when testing engine power. J.Y. Wong [6] formulated the rotating parts effect as follows:

$$RE = 1.04 + 0.0025\gamma^2 \quad (11)$$

Where RE is the rotating parts effect and γ is the total reduction ratio so if the wheel power is calculated the engine power is equal to rotating parts effect multiply by wheel power and by total efficiency

$$Pe = RE.P_{wheels}/\eta_{trans}.\ \eta_{Fr} \quad (12)$$

H.B. Pacejka[8] studied the combination of modeling longitudinal and lateral tire's slip and presented Magic Formula which is widely used in tires slip calculations. So in order to overcome the calculation of slip actual vehicle speed is measured using GPS. This leads to the possibility of measuring engine power on road.

Experimental Work:

The main target from experimental work is to find whether is it possible to calculate the engine power from on road tests or not? Based on the previous calculations it is required to measure the instant actual vehicle velocity accurately to overcome the problem of tires' slip. A high speed GPS QSTARZ BT-Q818XT (with sample rate 10 Hz) is used in order to measure the vehicle speed (with resolution of 0.01 km/hr) in addition to a recording device a smart phone with software Racechrono[9]. The data is extracted from the smart phone and then engine power is calculated. The engine speed and vehicle speed are also recoded simultaneously using OBDII reader and software (OBD 2 Dyno+Diagnostics) on another smart phone. The ambient conditions is taken into consideration for correcting the engine power according to SAE J1349 [7]. Coast down test is performed in order to calculate drag coefficient and rolling resistance coefficient to be used in engine power calculation.

Comparative Tests have been performed on three different passenger cars. Laboratory steady state power tests are performed on the same vehicles used by chassis dynamometer in order to check the agreement of on road test with the chassis dynamometer test.

1- LADA 2107 (specifications are in appendix A) is tested using GPS for road test and results are compared with chassis dynamometer test results.

2- Hyundai Verna (specifications are in appendix B) is tested using both GPS and OBD reader for road test and results are compared with chassis dynamometer test results.
3- Renault Logan (specifications are in appendix C) fitted with automatic transmission is is tested using both GPS and OBD reader for road test and results are compared with chassis dynamometer test results.

EQUIPMENT

Equipment used can be classified into two types: equipment used in testing in the laboratory and equipment used for road tests. The main laboratory equipment is the chassis dynamometer which is used to measure the wheel power and hence to calculate the engine power.
1-The chassis dynamometer is roller type fitted with water cooled eddy current dynamometer to absorb the energy generated by the engine shown in figure 2. The control software of the dynamometer is built using Labview software, which is used to measure the rollers speed through encoder and load through a load cell fitted with amplifier through a data acquisition of type NI- USB 6005 our built software controls the load of the eddy current dynamometer according to specified road resistances. Figure 3 shows control laptop and data acquisition and figure 4 shows the front panel of the control software.

Fig. 2. Chassis Dynamometer

Fig. 3. Control Laptop and data acquisition

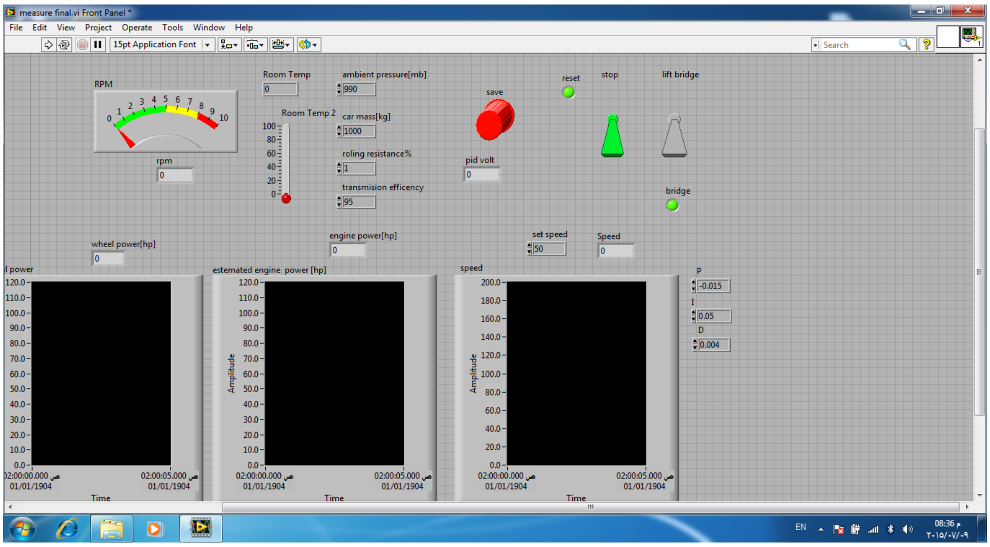

Fig.4. shows the front panel of the control software

2-The equipment used for road test are mainly three devices,

a) A high performance GPS of type Qstarz 818XT for reading the effective vehicle speed on road, shown in figure 5.

b) USB or bluetooth OBDII readers for reading engine speed and vehicle speed: Figure 6 shows USB OBDII reader.

c) Two smart phones for recording GPS and OBD data instantaneously and simultaneously.

Fig. 5. Bluetooth Qstarz 818XT GPS Figure 6 USB OBDII Reader

Procedure of experimental work

Two sets of experiments is presented below:

1. Experiments on a chassis dynamometer where tests are performed in steady state conditions according to SAE J2264 1995 [10].
2. Experiments on road. The road tests are divided into two sets of tests the first is the coastdown test which is used to calculate the drag and rolling resistance coefficients of the vehicle. The second test is acceleration test; the vehicle is taken to level road, third gear engaged and starting from engine speed about 2000rpm, a full pressing on the accelerator pedal is applied. While the vehicle speed is recorded by the smart phone from the external GPS at a frequency 10Hz and OBDII reader is used to read engine speed and vehicle speedometer speed and another smart phone till the engine speed reaches the maximum permissible engine speed (in the tested vehicles about 6000 rpm).

These tests have been repeated for three different passenger cars one of them without OBDII device (LADA 2107) where only GPS data is recorded in order to overcome error in speed measuring due to tires slip. The second vehicle (Hyundai Verna) is with manual transmission and OBDII and the third vehicle (Renault Logan) is with automatic transmission of type steptronic and OBDII. The data are then compiled using MS Excel. The compilation of the data includes filtration of noise using running average method and eliminating the wheel slip as the GPS measures the actual vehicle speed and OBDII is used to measure engine speed so eliminating the effect of clutch slip.

RESULTS AND DISCUSSIONS

The three vehicles are tested on road and on dynamometer then the results are compared beginning with a LADA 2107 that covered 20000 km. The comparison between the road test and the dynamometer test is shown in figure 7. It is noted that there is a good agreement between the results of the two tests with error between the two power curves from -1.5 % to 4.5 % for the power curve and error between the two torque curves from -0.7% to 3%.

Second vehicle (Hyundai Verna) that covered 60000 km is tested using both GPS. The comparison between the road test with GPS and the dynamometer test is shown in figure 8. It is noted that there is a good agreement between the results obtained from the GPS and the dynamometer with error between the two power curves from -3 % to 5 % for the power curve and error between the two torque curves from -1.5% to 1.6%.

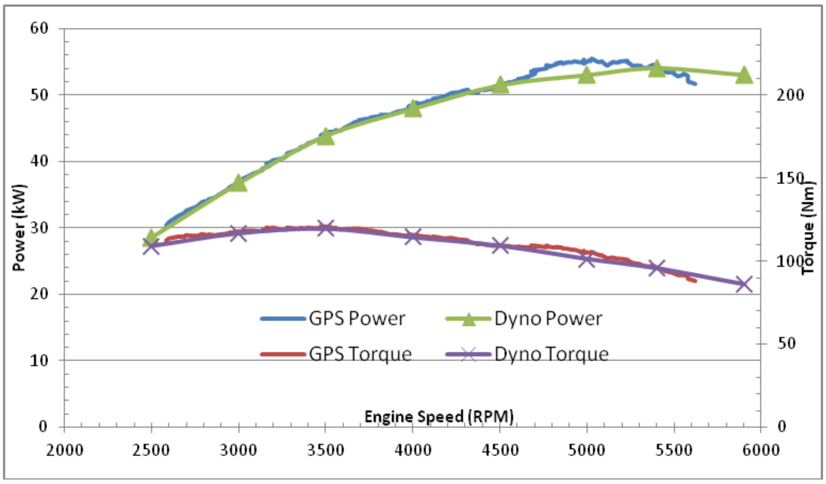

Fig. 7. Engine power and torque curves compared with road using GPS and Dynamometer tests for LADA 2107

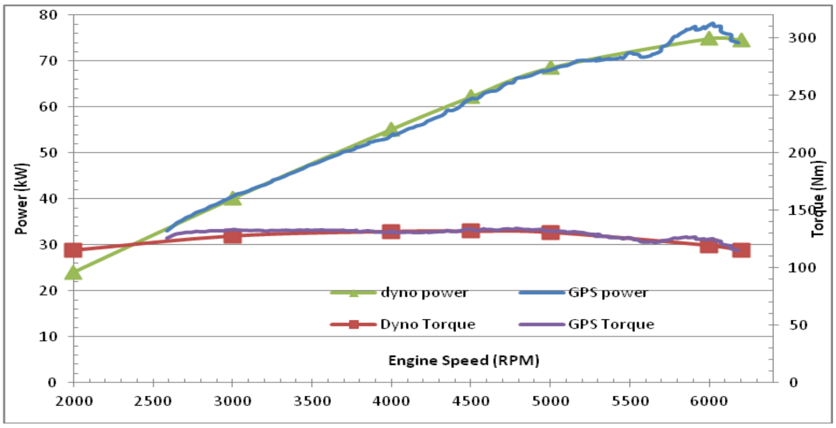

Fig. 8. Engine power and torque curves obtained using GPS versus Dynamometer tests for Hyundai Verna

The comparison between the road test with GPS and OBDII with the dynamometer test is shown in figure 9. It is noted that there is a better agreement between the results obtained from the GPS and OBDII with the dynamometer with error between the two power curves from -0.5% to 0.6%, for the power curve and error between the two torque curves from -0.5% to 0.7%. It is noted that GPS and OBDII results is closer to dynamometer curves. This can be explained by that recording both engine speed and GPS actual vehicle speed overcome the slip in clutch and tires.

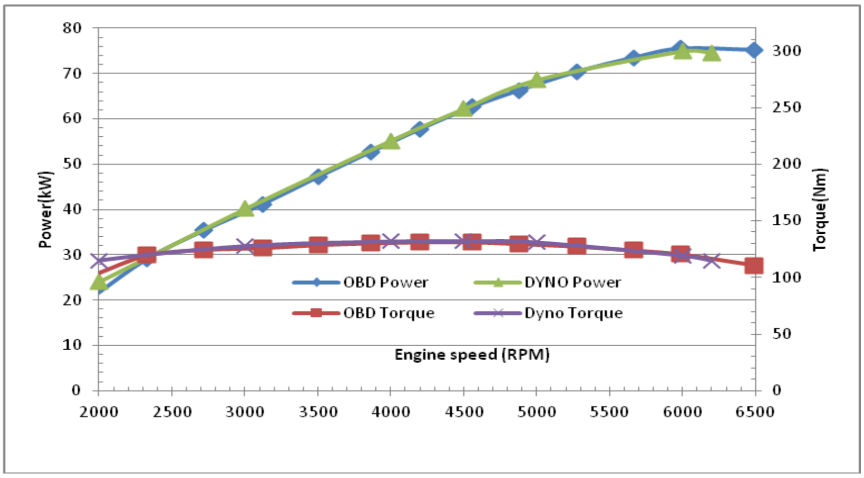

Fig. 9. Engine power and torque curves obtained from both GPS and OBD versus Dynamometer tests for Hyundai Verna

Third vehicle Renault Logan fitted with automatic transmission that covered 20000 km is tested using GPS with OBDII. The efficiency of torque converter is taken into account. The comparison between the road test with GPS and the dynamometer test is shown in figure 10. It is noted that there is a good agreement between the results obtained from the GPS and the dynamometer with error between the two power curves from -5 % to 2 % for the power curve and error between the two torque curves from -1.5% to 1.6%. The comparison between the road test with GPS with OBDII versus the dynamometer test is shown in figure 11. It is noted that there is a better agreement between the results obtained from the OBDII and the dynamometer with error between the two power curves from -1.5% to 2% for the power curve and error between the two torque curves from -1 % to 1.5%. It is noted that OBDII results and taking into account the slips (by using GPS) is closer to dynamometer results. The results are more accurate than the results produced by software products and are with good agreement with M. Pexa et al .

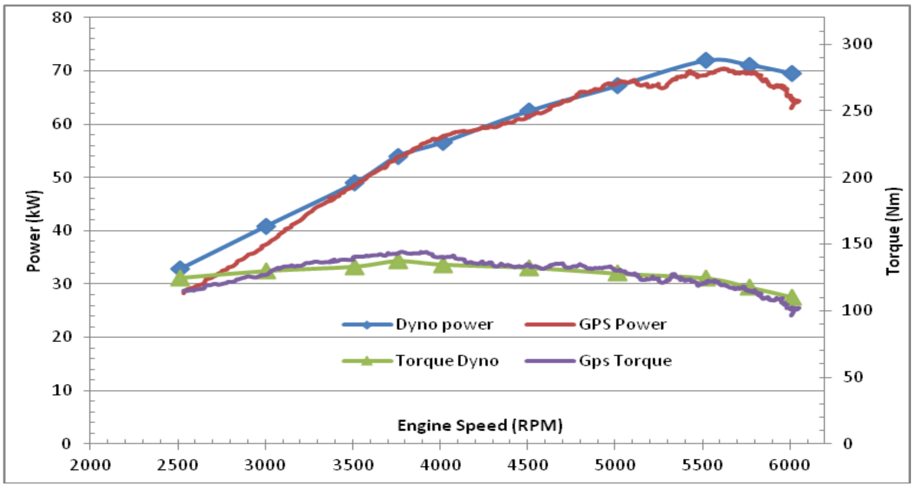

Fig. 10. Engine power and torque curves obtained from GPS versus Dynamometer tests for Renault Logan

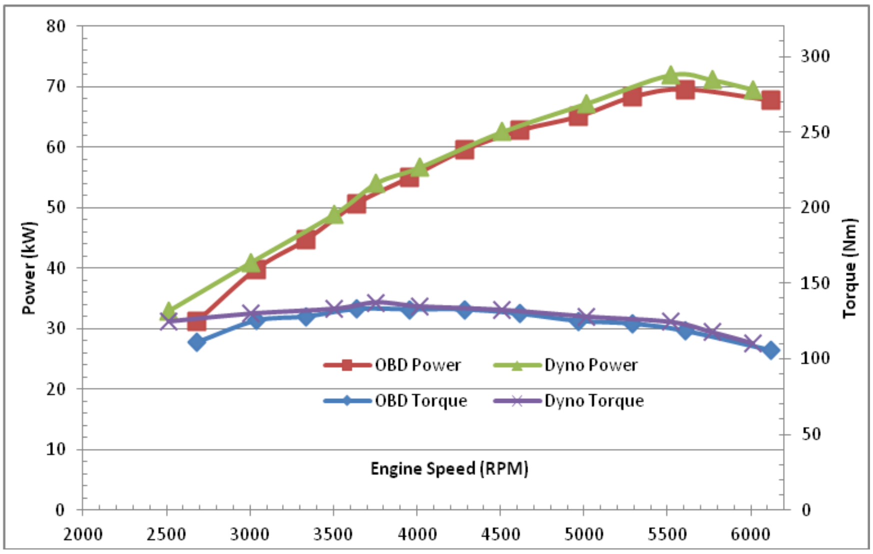

Fig. 11 Engine power and torque curves obtained from both GPS and OBD versus Dynamometer tests for Renault Logan

It should be noted here that the selection of the road is very important as the road should be level road and in a very good condition includes no bumps at all during testing as these bumps can lead to inaccurate results.

CONCLUSIONS

The road test using 10Hz GPS and OBDII could be used as a method of estimating engine operating characteristics if drag and rolling resistance coefficients are measured according to SAE J2264 on level road. The road test using GPS is proved to measure engine power with an error varying from ±5% and measure torque with an average error ±3%. The road test using GPS with OBDII is proved to measure engine power with an error varying from ±2% and measure torque with an average error ±1.5%. This paper gives an economical method to inspect the engine power using road test, GPS and/or OBDII reader. This process can be used in workshops where there is no availability of dynamometer which give the workshop engineer a tool for inspecting automotive engine condition.

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Nomenclatures and abbreviations

P_{wheels}	wheels power	kW
P_e	engine power	kW
η_{trans}	transmission efficiency	
η_{fr}	final reduction ratio efficiency	
F_{wheels}	forces on wheels in the direction of motion	N
V_{wheels}	linear velocity of the vehicle	m/s
F_{ar}	air resistance force	N
F_{rr}	rolling resistance force	N
F_{gr}	gradient resistance force	N
F_i	inertia force	N
ρ	air density	m^3/kg
C_D	aerodynamic drag coefficient	
V	vehicle speed	m/s
A	frontal area of the vehicle	m^2
F_{rr}	rolling resistance coefficient	
W	width of the vehicle without mirrors	m
H	height of the vehicle in	m
W_g	vehicle weight	N
θ	road gradient	°
RE	rotating parts effect	
γ	total reduction ratio	
OBD	On Board Diagnostic System	
OBDII	improvement over OBD	
GPS	Global Positioning System	
NI	National Instruments	

Appendix A

LADA 2107specifications

	Engine
1569cc	Engine capacity
4-cylinder in-line 8-valve DOHC	Engine type
9.5	Compression ratio
(79 x 80.0) mm	Bore x Stroke
	Performance
55 kW @ 5600rpm	Power
120.0 Nm @ 3000rpm	Torque
16s (0-100 km/h)	Acceleration
	Misc technical data
5-speed (M)	Transmission
Rear-wheel drive	Drive type
	Measurements
Sedan	Vehicle type
(4145 x 1620 x 1446) mm	Dimensions (L x W x H)
2424 mm	Wheelbase
1,060 kg	Curb weight
175/70 R13	Tire Size

Appendix B

Hyundai Verna specifications

	Engine
1,599 cc	Engine capacity
4-cylinder in-line 16-valve DOHC	Engine type
10	Compression ratio
(76.5 x 87.0) mm	Bore x Stroke
	Performance
78.2kW @ 5800rpm	Power
138 Nm @ 5000rpm	Torque
10.6s (0-100 km/h)	Acceleration
	Misc technical data
5-speed (Manual)	Transmission
Front-wheel drive	Drive type
	Measurements
Sedan	Vehicle type
(4260 x 1680 x 1395) mm	Dimensions (L x W x H)
2440 mm	Wheelbase
1,110 kg	Curb weight
185/65 R14	Tire Size

Appendix C

Renault Logan**1.6i 16V sedan** specifications

	Engine
1,598 cc	Engine capacity
4-cylinder in-line 16-valve DOHC	Engine type
10	Compression ratio
(79.5 x 80.5) mm	Bore x Stroke
	Performance
78.2 kW **@**5750 rpm	Power
145Nm@ 3750 rpm	Torque
11.9 s (0-100 km/h)	Acceleration
	Misc technical data
4-speed (Automatic Steptronic)	Transmission
Front-wheel drive	Drive type
	Measurements
Sedan	Vehicle type
(4250 **x** 1735 **x** 1525**)** mm	Dimensions (L x W x H)
2630mm	Wheelbase
1,130 kg	Curb weight
185/65 R15	Tire Size