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ABSTRACT

The objective of this work was to determine the effect of one form of traffic calming on emissions. Traffic calming is aimed at reducing average vehicle speeds, especially in residential neighborhoods, often using physical road obstructions such as speed bumps, but it also results in a higher number of acceleration/deceleration events which in turn yield higher emissions. Testing was undertaken by driving a warmed-up Euro-1 spark ignition passenger car over a set of speed bumps on a level road, and then comparing the emissions output to a non-calmed level road negotiated smoothly at a similar average speed. For the emissions measurements, a novel method was utilized, whereby the vehicle was fitted with a portable Fourier Transform Infrared (FTIR) spectrometer, capable of measuring up to 51 different components in real-time on the road. The results showed that increases in emissions were much greater than was previously reported by other researchers using different techniques. When traffic-calmed results were compared to a smooth non-calmed road, there were substantial increases in CO_2 (90%), CO (117%), NO_x (195%) and THC (148%). These results form the basis for a good argument against traffic calming using speed bumps, especially for aggressive drivers. Slowing traffic down with speed restrictions enforced by speed cameras is a more environmentally friendly option.

INTRODUCTION

In the UK, over 3000 people die every year in traffic accidents, 25% of them pedestrians [1], mainly due to excessive speed in congested urban roads. Due to public safety fears regarding the levels of traffic currently present on our inner city and town road systems, several measures have been put in place over the years that have tried to allay these fears. This was done either by decreasing the volume of traffic on the roads (e.g. congestion charging, city of London) or reducing the speed of the traffic (using speed bumps or speed cameras) or by diverting heavy vehicles away from the small roads which are commonly used as short cuts by haulers. Not only are the fears to do with pedestrian safety (especially children) but they are also about the environment. A measure that has been widely used as a general ‘all-purpose’ solution in the UK is traffic calming. This method is strongly supported by the public and the evidence of this can be seen throughout the country with speed bumps, roundabouts, bottlenecks and speed cushions now commonplace within cities, towns and villages. Traffic calming helps drivers make their speed appropriate to local conditions through measures that are self-enforcing.

The UK schemes undertaken to produce traffic calming are covered under the Traffic Calming Act 1992, which amended the Highways Act 1980 by the addition of Sections 90G, 90H and 90I which allows works to be carried out ‘…for purposes of promoting safety and preserving or improving the environment…’. These regulations were again further amended by the Roads (Traffic Calming) Regulations 1993, which came into effecting in August of that year and were introduced to allow local highway authorities the power to construct particular measures for traffic calming purposes which are not otherwise clearly authorized. Hence the increase in the amount of traffic calming devices present on our roads today.

There are problems faced with traffic calming; some schemes such as speed cameras or bottlenecks can work out expensive, while speed bumps are low cost and easily installed. Within villages where there is very little alternative road network available, reduction in traffic volume will be negligible and the effects these traffic calming measures have on the environment is often not considered both in terms of air quality and noise.

Taking all this into account, the methodology behind the selection of the correct traffic calming measure is of paramount importance and is unique for each stretch of road. The planning, consultation and execution of the correct measure must be done accordingly, remembering that any scheme undertaken must be for the long term. A good traffic calming scheme will blend well into the environment, and will continue to operate with little fuss or concern [2].

Traffic calming has now revolutionized thinking with regards to town and city planning. The ability of a certain scheme to reduce speeds at any part of a road network, while in some circumstances improving capacity, has been exploited globally. Measures that have been undertaken are shown in table 1, along with their proposed effect and some problems that have been encountered [3].

Table 1: Road traffic calming measures [3]

Device	*Max comfortable speed (mph)*	*Associated problems*
Road-top hump	21-25	Original, cheap and still effective tool on urban roads, but rough and noisy
Speed table	15-25	Slope of ramp determines control speed
Speed cushion	20-30	Effect dependant on exact size
Speed limit sign	No direct control	Reliant on drivers compliance
Pinch point	Controlled by opposing flow	Dependent on opposing flow (priority writing not usually recommended)
Chicane	Varies hugely	Control based on forced level of lateral curvature of vehicle paths
Road narrowing	Any	May reduce speed slightly, but may have a large effect when it becomes a pinch point
Mini roundabout	21-25	Entirely dependent upon geometry and turning flows
Speed camera	Any	Expensive

The particular traffic calming device that was investigated in this paper was the speed cushion. The pollution problems associated with the braking and accelerating of a passenger vehicle in order for it to deal with the device correctly were investigated. The method behind the size and shape of these cushions is down to the size of the vehicle that dominates the traffic on the roads. Hard sprung vehicles such as busses, ambulances and fire engines are more affected by the vertical deflection than cars or small van. Therefore the width of the cushion is such that it is able to differentiate between the types of vehicle, so vehicles such as the ambulance are held up less and buses are unaffected if the driver aligns the bus correctly. These vehicles will feel some lurching, however not as much as a small car. The outer edges of the speed table are rounded so the bus or emergency vehicle does not suffer as much as a small car that has to pass over a steeper incline, therefore feeling more deflection, resulting in the need for slower speeds [3]. It is recommended that the gradient on and off the cushion should not be more than 1:8 due to the grounding of smaller vehicles on the speed table and for the same reason the height should not exceed 75mm. The length of the cushion should be between 1.7 and 2.5 meters to avoid discomfort while a width of 1.9 meters offers greater effectiveness for slowing a vehicle down [4].

The cushions are situated in the center of the car’s path, with no gap between them that may allow drivers to avoid them. In order to cause less damage or inconvenience to the driver, they are required to line the car up correctly which in itself means that the speed of the car must be reduced. It is the effect of this slowing down process and the acceleration away from the speed cushion on the levels of emissions produced by a passenger vehicle that was investigated in this study. In the road investigation carried out, there were seven bumps per kilometer so the spacing between the speed bumps was on average 140 meters, which is higher than is usually encountered on the roads.

PREVIOUS WORK

As far as the authors are aware, on-road real-world emissions data quantifying the effect of speed bumps has not been published so far. Since this study is the first of its kind, there was no literature to compare its results to. Nevertheless, in some respects a traffic calming investigation is similar to studies concerned with driving behavior. This is because aggressive drivers tend to be on and off the throttle more often and more aggressively compared to normal drivers. A normal or calm driver tends to be smoother, therefore producing a smooth speed-time profile similar to a non-traffic calmed road. The aggressive driver has a speed-time profile similar to a traffic calmed road since acceleration and braking events will be more frequent. Consequently, parallels can be drawn between driver behavior studies and traffic calming studies.

De Vliger’s work [5] investigated driver behavior and found that aggressive driving produced a dramatic increase in CO and THC emissions, but less so for NO_x. CO emissions were up to three times higher for aggressive drivers, while HC and NO_x were up to two times higher. Fuel consumption was generally 30-40% higher for aggressive urban driving compared to rural and motorway traffic. Average trip speeds remained almost the same.

In a similar study performed by Rapone [6] comparing congested and free flowing traffic conditions, HC was found to be 12 times higher, NO_x was 5 times higher and CO was 4 times higher. This test used a small-engined, instrumented car to obtain on-road data which was then reproduced on a chassis dynamometer for emissions analysis.

The most comprehensive and authoritative study carried out on the impact of traffic calming measures was set up by the Charging and Local Transport Division of the DETR. It commissioned a three-year study on the impacts of traffic calming measures on exhaust emissions from passenger vehicles. The study was carried out by the TRL and included in it was an analysis of nine types of traffic calming measures using many types of vehicles [3]. It was the first study of its kind and the results are important in assessing the impact of traffic calming measures on the environment and the local community. It was a wide reaching study that took nine different measures into account, assessing the emissions produced, speed, safety and delays caused to emergency vehicles. The test procedure involved using a LIDAR (Light Detection and Ranging) system to produce speed-time profiles for the vehicles passing through each of the schemes. Afterwards, the impacts on the emissions were determined using the driving cycles and a chassis dynamometer with constant volume sampling. The pollutants measured were CO, CO_2, HC, NO_x and particulates. The results, which are summarized in table 5 for two types of vehicles, clearly show that the calming measures increase the emissions of the pollutants. Catalyst cars were shown to be most sensitive to traffic calming methods, although they tended to have the lowest absolute emissions rates compared to the diesel and non-catalyst vehicles which were also studied.

The results found in the TRL report were compared to an average speed model (MEET) [4]. While the MEET model tended to underestimate CO and overestimate NO_x and CO_2, it was found that the %change in going from a non-calmed road to a calmed road was very similar for the TRL and MEET data for all the pollutants.

EXPERIMENTAL PROCEDURE

A EURO1 vehicle was used for this study as they still constitute a fair proportion of the UK vehicle fleet and hence are still major contributors to air pollution in cities. It takes about 16 years for 90% of vehicles sold in any one year to be no longer in use [7] and this period is becoming longer for modern vehicles. Thus the work on EURO1 vehicles has significance in terms of their current use in city driving and hence their impact on air quality. It will be at least 2013 before 90% of EURO1 vehicles are an insignificant proportion of city traffic. Future work will investigate EURO2, EURO3 and EURO4 vehicles.

The device used for measuring on-road emissions in this investigation was a novel system built around a Temet FTIR. This system is described in detail by Daham et al. [8]. It uses a compact FTIR installed in the boot of the car along with a fuel flow measuring device in order to calculate the total emissions on a g/km basis. The repeatability of the instrument is more than adequate for making comparisons between different drive cycles. In previous work, the FTIR was validated against other measurements systems and shown to be within 7% for steady state and within 20% for transient cycles in terms of the accuracy of drive cycle mass emissions.

Three baseline runs were initially performed while trying to be as smooth as possible on the throttle in order to maintain a constant 30mph (~50km/h), which was the speed limit of the road under investigation. The results from these three runs were averaged in order to obtain the emissions for a non-calmed level road with a 30mph speed limit.

After the baseline 30mph runs were completed, the car was driven over the speed bumps with appropriate braking and accelerations events. Even though the speed cushions were designed to permit an average car to pass over them at the required speed of 20-30mph, for this study the car was slowed down to 10mph and then accelerated back to 20-30mph in 2nd gear. This was done in order to simulate an 80mm round-top road hump which is one of the worst types of speed bumps. Speed cushions allow a vehicle to pass over them at 30mph if the car is positioned correctly, whereas with road-top speed humps, the car must be brought to a very low speed in order to avoid discomfort to the passengers and damage to the vehicle. The action of many drivers at speed bumps is to slow down before the bump and accelerate off the bump as simulated in the present work. The average of the three traffic-calmed runs was obtained and compared to the baseline result at 30mph.

The drive cycle was simply a round trip along the traffic calmed road in non-rush hour traffic. The road used for testing contained seven speed cushions in total. After the seven speed cushions were passed, the car was turned around in a side road for a return trip. Therefore each 2.2km run contained a total of fourteen speed cushions in addition to the turnaround point where speed was almost zero. The average distance between speed bumps was 140 meters.

The distances for the calmed and non-calmed runs are identical since the same road was used. The only difference being that for the traffic calmed runs, the car was slowed to about 10mph and reaccelerated in 2nd gear, thus mimicking the normal action of a driver over a speed bump.

RESULTS

Smooth road results

Figure 1 plots the speed-time profile as well as throttle position for three runs over the non-traffic calmed level road. It can be seen that the first two runs were consistent, but the third run was affected by other traffic at the beginning of the run. The section in the middle of the graph where speed is zero is where the car is turning around, in a side road, to go back to the starting point. Figure 2 shows how the emissions varied during these three smooth runs. It is noticed that there was variability in the emissions, but for the most part it was within acceptable upper and lower limits. It can also be seen from figure 2 that the first run was the smoothest run with the least overall emissions. A brief numerical analysis of the three runs is given in table 2, with the European EURO1 regulations being listed for comparison. The total CO_2 and average speed of the third run confirmed that there was something different compared to the first two runs. In spite of this, the third run was included in the average since it didn't seem to deviate excessively in terms of emissions. A relationship between CO_2 and average speed can be seen in the three runs with higher CO_2 being emitted for lower average speeds.

Run 1 was chosen to be presented in the subsequent analysis since it is the most consistent run with the least speed and throttle position variations. Figure 4 shows how the mass based emissions vary with throttle position, rate of throttle position change and road speed. The emissions are constant for the most part except for three peaks; one at the beginning, one in the middle and one at the end. These peaks respectively correspond to getting on to the main road, turning around, and getting off the main road. CO seems to be most affected by these three transients compared to the other pollutants. This can be clearly seen in figure 3 where the gradient of the CO plot changes drastically when the car gets on to the test road and when it turns around at around the 150-second mark.

Table 2: Smooth runs statistics

	Run 1	*Run 2*	*Run 3*	*Avg.*	*Euro1*
Time (s)	315	331	356	334	784
Fuel (kg)	0.172	0.182	0.181	0.178	n/a
Dist. (km)	2.238	2.291	2.245	2.258	11
Cat. temp pre test (°C)	305	293	320	306	(Cold)
Cat. temp post test (°C)	405	401	393	400	n/a
Avg. Speed (km/h)	41.16	40.10	36.52	39.26	18.7 (urban) 33.6 (overall)
g CO_2/km	294	307	358	320	n/a
g CO/km	1.72	3.45	2.30	2.49	2.72
g NO_x/km	1.07	1.33	1.23	1.21	0.42*
g THC/km	0.12	0.14	0.16	0.14	0.55*

*EURO1 specifies a total NO_x+THC of 0.97g/km, but the EURO3 HC/NO_x ratio is used for the sake of comparison with experimental data

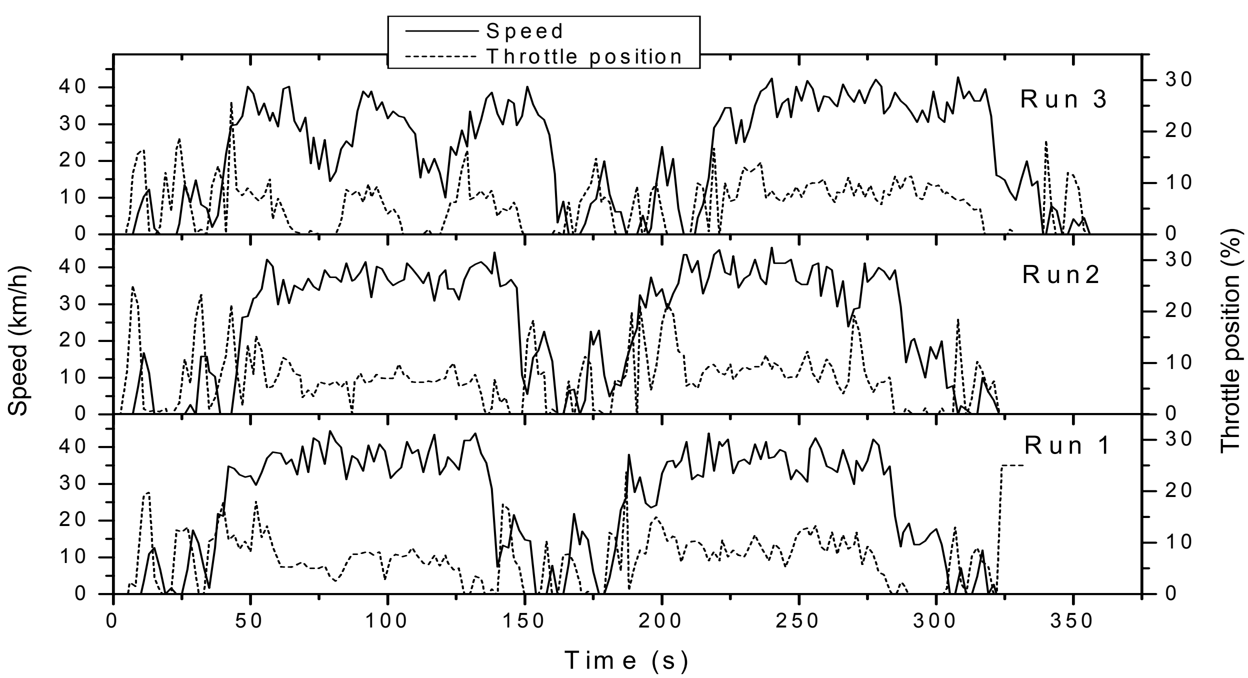

Figure 1: Speed and throttle position for the three smooth runs

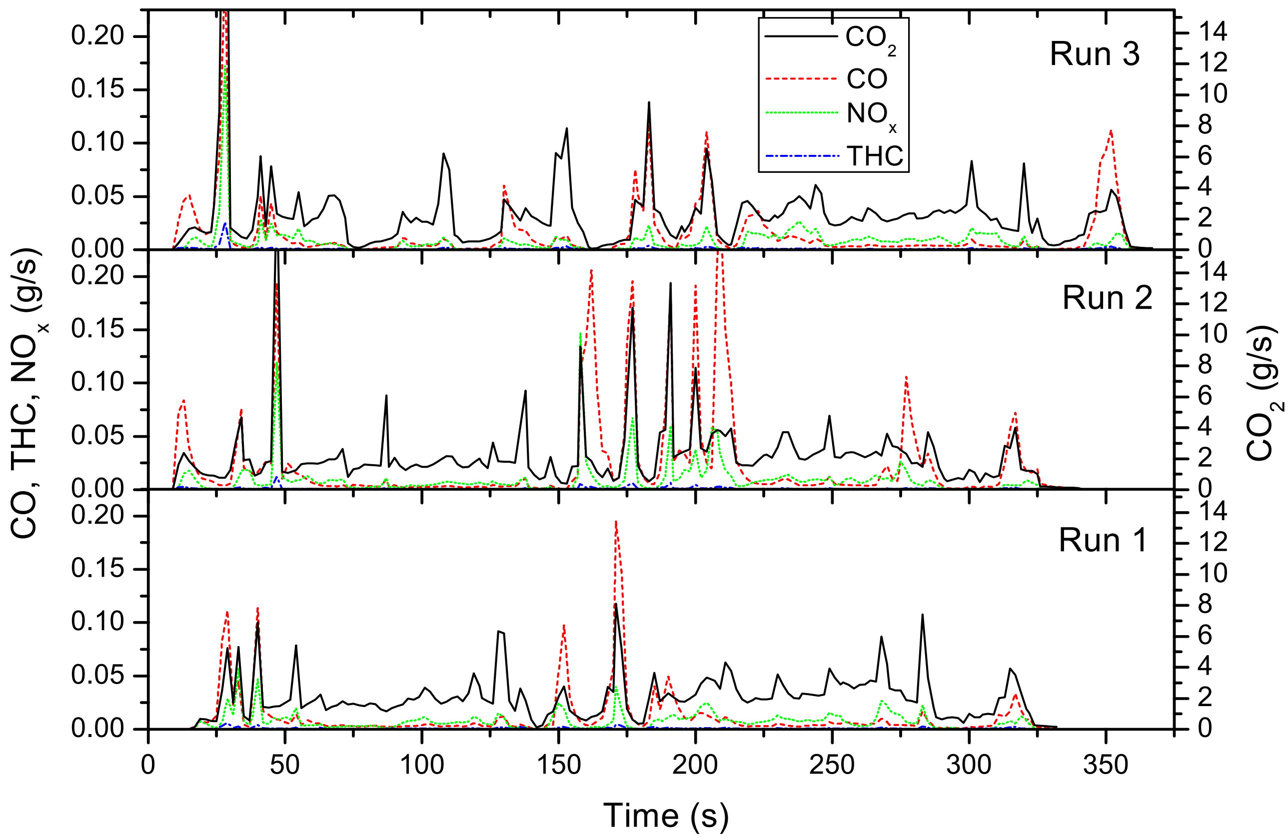

Figure 2: Emissions comparison for the three smooth runs

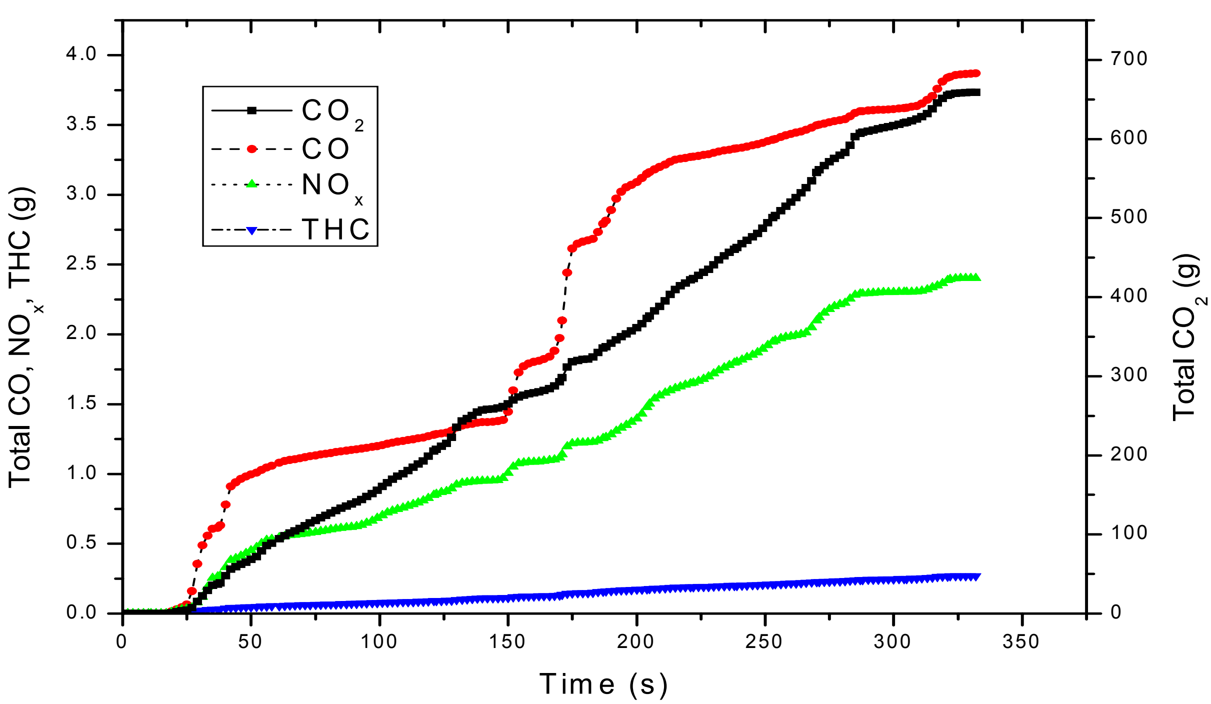

Figure 3: Cumulative emissions plot of smooth run 1

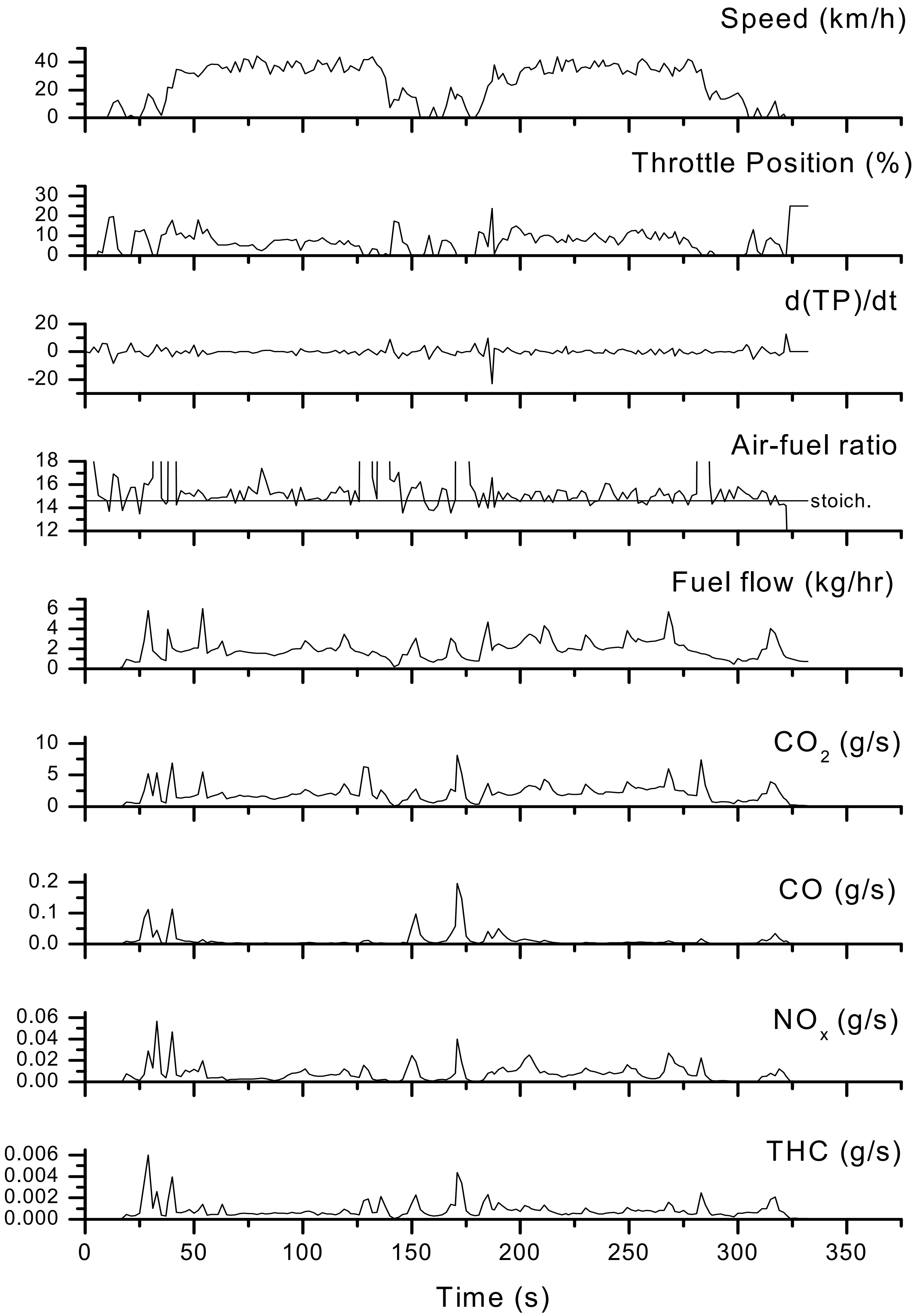

Figure 4: Analysis of smooth run 1 (d(TP)/dt is rate of change of throttle position)

Traffic-calmed road results

Figure 5 plots the speed-time profile in addition to the throttle position for three runs performed on the traffic-calmed road. Coincidently, the first run was again the cleanest of the three. Run 2 had too long an idle time when turning around. This was due to traffic briefly blocking the exit to the main road. During run 3 there was a complete stop around the 136-second mark due to other traffic. The numerical analyses of the three runs are listed in table 3 and it can be seen that the repeatability is very good in spite of the slightly different traffic conditions. The average values of the three runs will be compared to the average values of the smooth runs in table 4.

A graphical representation of the emissions for the three traffic-calmed runs is shown in figure 6. Looking at run 1 and neglecting the first two CO_2 peaks (which correspond to getting on to main road) it can be seen that there are seven distinct CO_2 peaks before turning around. These correspond to the seven speed bumps in the drive cycle. And of course there are another seven peaks for the return journey. All the pollutants show these distinct peaks, with the exception of THC since the scaling isn't conducive to its much smaller magnitude. It should be noted that the y-axis scales of figure 6 are approximately 1.5 times the scales of the non-calmed road in figure 2.

Table 3: Speed bump runs statistics

	Run 1	*Run 2*	*Run 3*	*Avg.*
Time (s)	343	369	349	354
Fuel (kg)	0.237	0.239	0.248	0.241
Dist. (km)	2.217	2.232	2.224	2.224
Cat. temp pre test (°C)	276	240	259	258
Cat. temp post test (°C)	475	450	454	460
Avg. Speed (km/h)	37.44	35.11	36.91	36.45
g CO_2/km	586	633	600	607
g CO/km	6.08	5.52	4.63	5.41
g NO_x/km	3.20	3.75	3.76	3.57
g THC/km	0.35	0.37	0.31	0.34

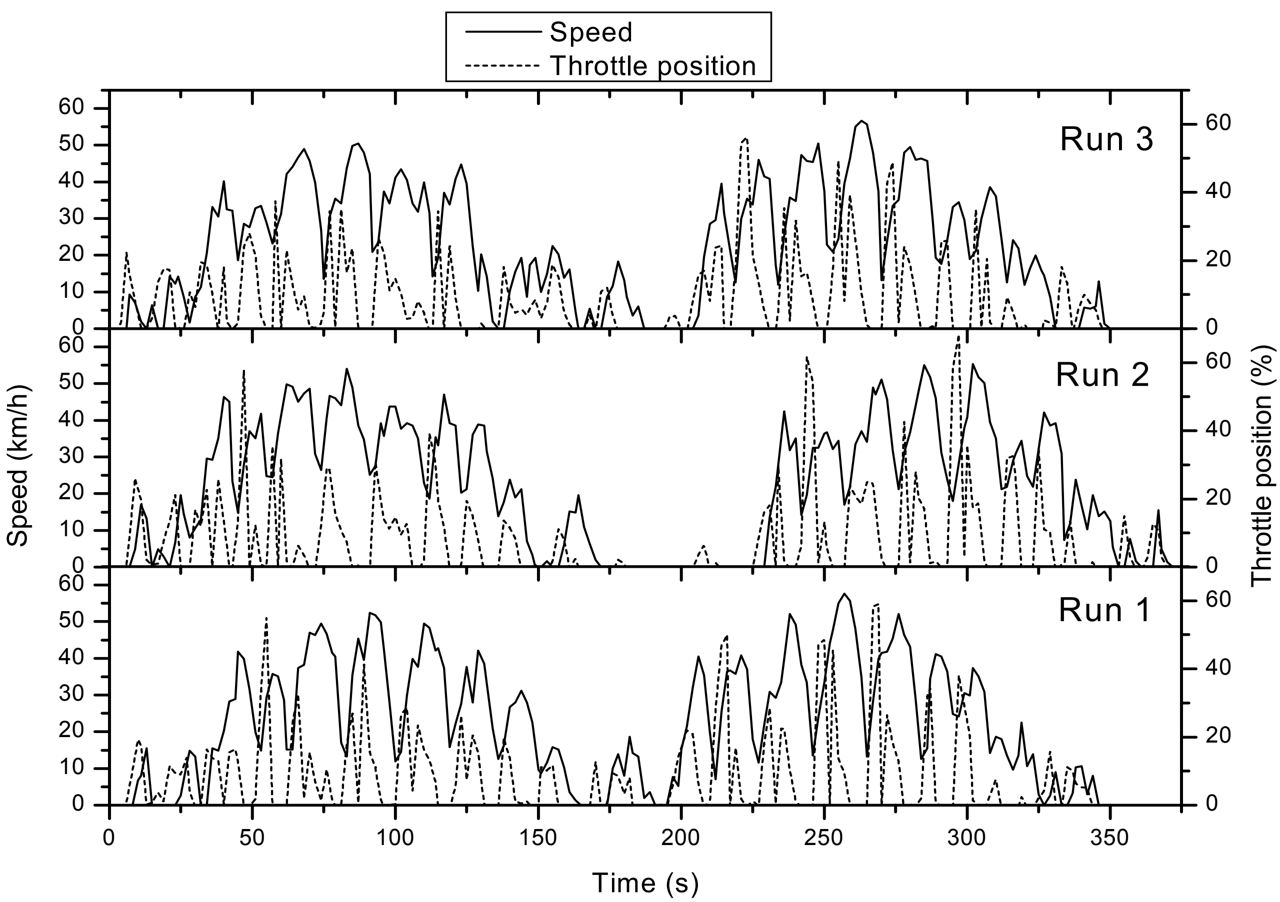

Figure 5: Speed and throttle position for the three speed bump runs

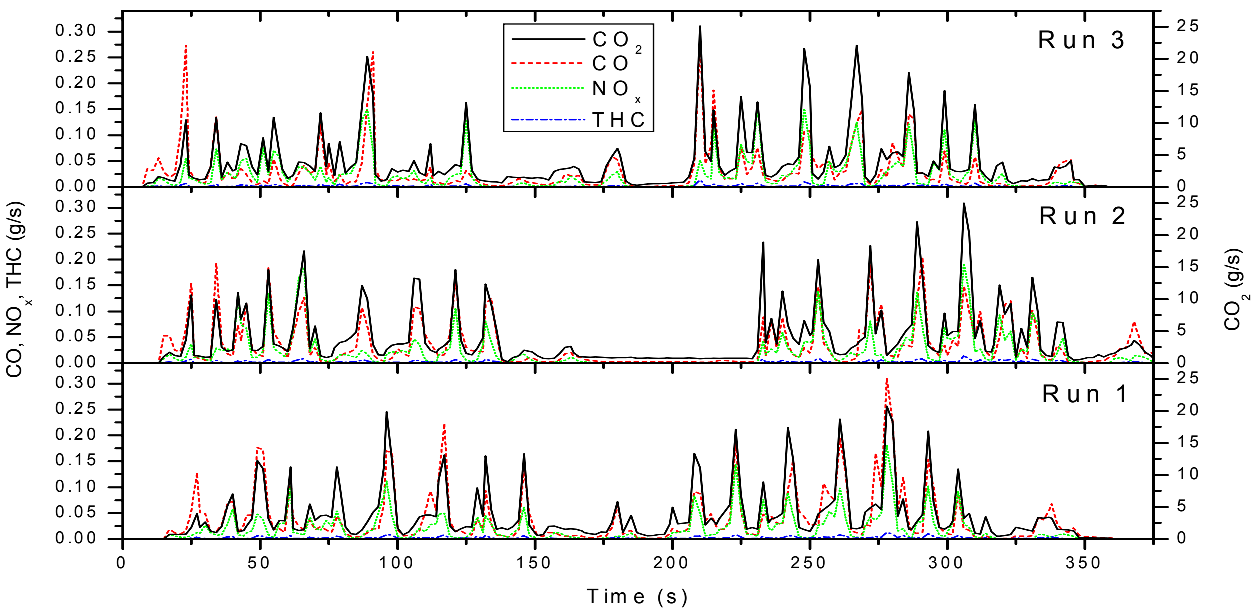

Figure 6: Emissions comparison for the three speed bump runs

Figure 7 plots the post-catalyst emissions, throttle position, rate of change of throttle position and road speed for the first traffic-calmed run. The first run was chosen for the detailed graphical representation since it was the cleanest run of the three. Throttle position seems to have a major effect on NO_x emissions. As a speed bump is approached, the throttle is closed and the level of NO_x produced is very low. Then as the vehicle passes over the speed bump and accelerates away, thus opening the throttle, the level of engine-out NO_x increases owing to the higher combustion pressure and temperature. This increase in engine-out NO_x is the principal reason for the post-catalyst NO_x peaks shown in figure 7. Another important factor is the momentary decrease in catalyst efficiency that results from a brief lean period experienced immediately after any sudden throttle application. This would be less of a problem on a fresh catalyst, but on a high mileage vehicle as used in this study, air-fuel ratio deviations away from stoichiometry can drastically affect catalyst efficiency. One final potential contributor to the post-catalyst NO_x peaks is catalyst temperature fluctuations whilst negotiating the speed bumps. Since the catalyst in this study was hot and already lit off, then catalyst efficiency changes as a result of higher combustion temperatures are not likely.

A similar trend can be seen for CO because the air-fuel mixture is slightly enriched when the ECU detects a sudden change in throttle position, as shown in figure 7. This is done so that the car accelerates smoothly and effectively when the driver demands a power increase by depressing the throttle. This fuel enrichment strategy is worse in older cars compared to the newer generation of EURO3 and EURO4 cars, where the ECU is programmed to maintain stoichiometry for as long as possible without sacrificing driveability. This is possible in direct injection systems, but for port fuel injection, some enrichment is necessary to overcome the brief period when there is more air than fuel in the intake manifold. THC follows the same trend as CO for the same reasoning. CO_2 follows the throttle position plot as well as the fuel flow plot since throttle position is proportional to engine load which is proportional to fuel flow rate as mentioned previously. Thus when the load increases, the fuel injected increases and hence more CO_2 is produced from the combustion process of this fuel.

The numbers in square brackets to the left of figure 7's y-axis are an indication of the scaling. Each number is the ratio of the y-axis scale after calming to the same scale before calming. It can be noted that for traffic-calming most of the scales had to be doubled, and for NO_x tripled, in order for the peaks to be visible.

Figure 8 shows a cumulative plot of the emissions of run 1. For all the pollutants, a flat region can be seen where the car was turned around. This is a low power condition and therefore very little emissions were produced relative to the main drive on the traffic calmed road. This is in contrast to figure 3 for the non-calmed road, where a flat region was observed during the drive on the main road and a sharp increase was recorded (especially for CO) while turning the car around. In figure 8, the numerous jagged edges on the plots correspond to all the speed bumps encountered. The times where there are sharp increases in the emission levels correspond with the passing of each speed bump, which in turn is followed by the leveling off of emissions as the car travels between the speed bumps.

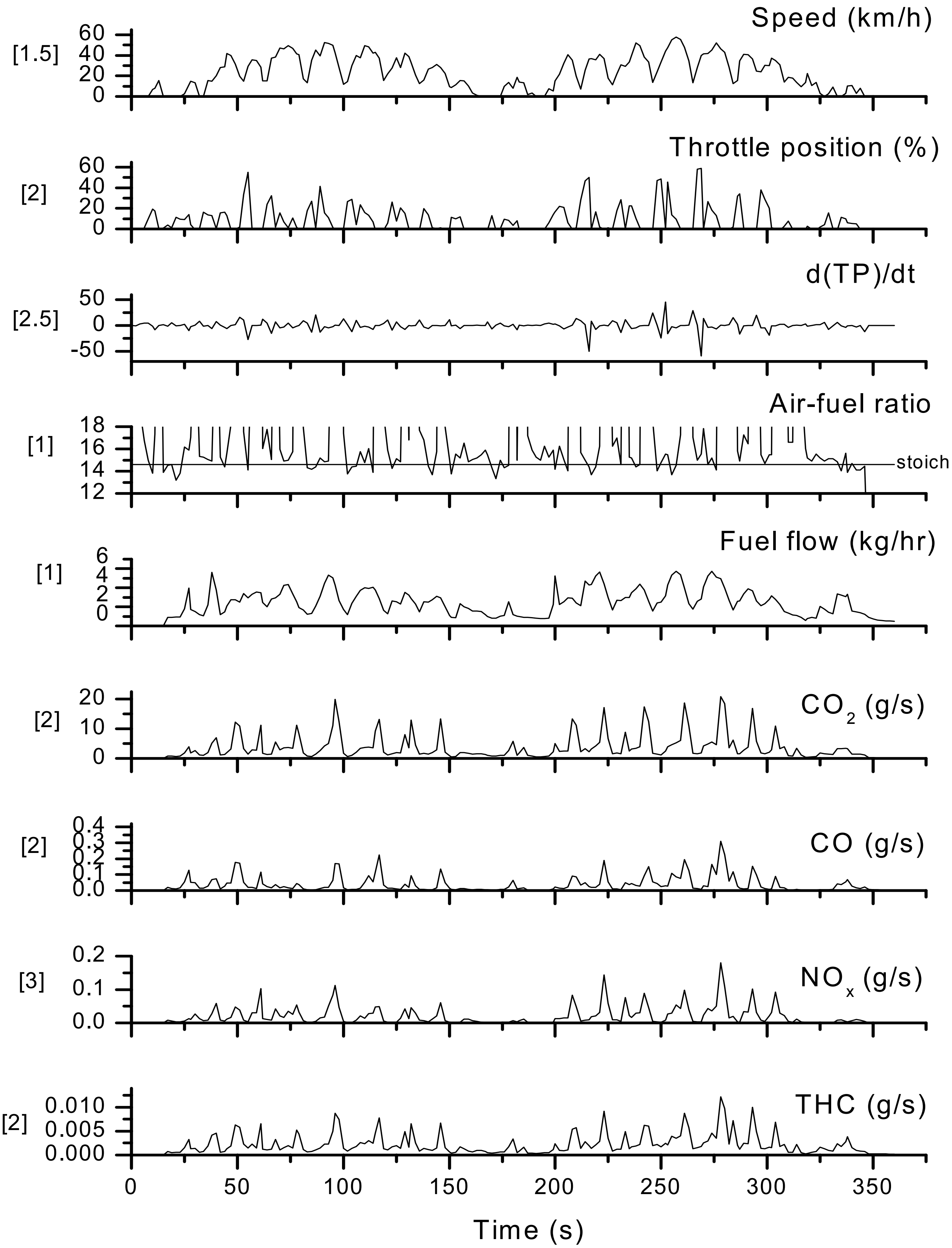

Figure 7: Analysis of speed bump run 1 (numbers in square brackets to the left of y-axis are the ratio of 'speed bump' axis scale to 'smooth run' axis scale; d(TP)/dt is rate of change of throttle position)

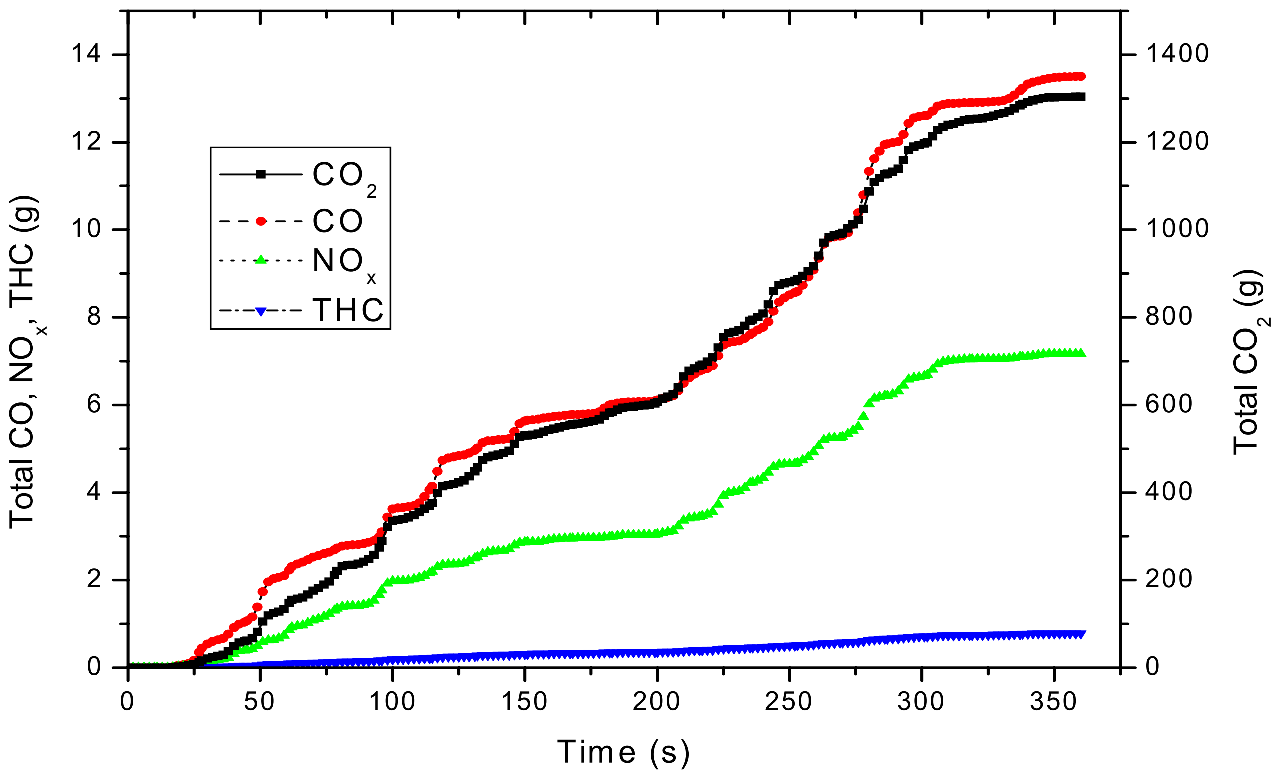

Figure 8: Cumulative emissions plot of speed bump run 1

Table 4: %change due to speed bumps

	Smooth run	*Bumps run*	*% change*
Time (s)	334	354	+6
Fuel (kg)	0.178	0.241	+35
Dist. (km)	2.258	2.224	-1.5
Avg. speed (km/h)	39.26	36.46	-7.1
g CO_2/km	320	607	+90
g CO/km	2.49	5.40	+117
g NO_x/km	1.21	3.57	+195
g THC/km	0.14	0.34	+148

Table 4 is a comparison of the various parameters calculated previously for the smooth runs and the traffic-calmed runs. As can be seen from the results, speed bumps have a dramatic effect on the levels of pollution entering the atmosphere and the percentage change varies depending on the pollutant in question. The catalyst temperatures were left out of this table as they had no bearing on related performances due to the fact that the catalyst was hot for each run so the efficiency of the catalyst was more or less the same for all the runs. This was not surprising considering the car was fully warmed up before testing.

The results revealed in this study are compared against the results obtained by the TRL when they carried out their own investigation [4] into the effects of speed bumps using various vehicles driven over various types of traffic calming devices. Even though TRL conducted a study of 1.7m and 1.9m wide speed cushions, it was decided that their 80mm round-top speeds hump study was more representative of the speed profiles recorded in the present work. This was because the vehicle in this study was slowed to ~10mph while negotiating the speed cushion, and this is normally only necessary for a round-top speed hump. For this scheme (80mm round-top speed humps), the TRL tested two different medium-sized, EURO1 certified, catalyst-equipped cars that are comparable to the vehicle used in the present work. The 1995 Ford Mondeo and 1996 Vauxhall Astra vehicles were both 1.6-liter petrol cars, while the test vehicle used in this study was a 1992 Ford Orion EURO1 petrol 1.8-liter. A comparison is shown in table 5. For its investigation, TRL conducted two test runs per vehicle and it must be noted that the variability between these two runs for the Mondeo vehicle was much higher than the variability for the Astra vehicle. This means that the Mondeo results are not as reliable as the Astra results.

Compared with the Mondeo TRL results, this study yielded almost twice the CO_2, three times the CO, four times the THC and five times the NO_x for a traffic-calmed road versus a non-calmed road. The results are closer when a comparison is made with the Astra vehicle. Even though the TRL study included a Ford vehicle, it is not appropriate to make a direct comparison between the TRL data and the current study since the cars are slightly different in terms of their mileage and ECU strategy.

The discrepancy in results between this study and the TRL study could be due to the fact that the TRL used a rolling road dynamometer and therefore the rates of acceleration were limited due to slippage between the tire and the roller. This would explain the much higher NO_x obtained in this study since real-world testing does not have the same limitations on acceleration as dynamometer testing. Another difference between the two studies is the speed bump spacing. The speed bumps in the TRL investigation were spaced 60 meters apart on average, whereas they were 140 meter apart in the present work. This allowed the car to accelerate to a higher speed and therefore producing higher NO_x than the TRL study. Yet another difference is that the vehicle used in this study was close to fully laden (thus producing a higher load on the engine) due to the heavy equipment, whereas dynamometer testing is not usually based on a fully laden car. The final reason is the different ECU strategies which are used by the different manufacturers of the vehicles tested. The data presented in this investigation is probably a representation of an unsmooth driver who is in a hurry to negotiate a traffic-calmed road driving a heavily laden car. Smoother driving will always produce cleaner emissions even if there are speed bumps to negotiate.

Table 5: Comparisons with TRL data [4]

	This study	*TRL Mondeo*	*TRL Astra*
Avg. Speed (km/h)	-7.1	-67	-67
g CO_2/km	+90	+43	+28
g CO/km	+117	+41	+169
g NO_x/km	+195	+37	+48
g THC/km	+148	+34	+185

It's worth noting that for the same 80mm round-top speed hump scheme, the TRL measured much smaller changes in emissions for non-catalyst petrol cars and diesel cars. These results are listed in table 6 along with the results from the catalyst equipped car. All vehicles are medium sized, with the catalyst-equipped petrol car and the diesel car being EURO1 certified.

Table 6 : Comparison of TRL cat, non-cat and diesel cars [3]

	Petrol Non-catalyst	*Petrol Catalyst*	*Diesel*
Avg. Speed (km/h)	-67	-67	-67
g CO_2/km	+32	+43	+34
g CO/km	+25	+41	+111
g NO_x/km	+16	+37	+53
g THC/km	+55	+34	+53

Non-regulated hydrocarbons

It must be noted that all the THC results reported using the FTIR are not representative of a true total hydrocarbon measurement. This is because the FTIR does not count the C-H bonds as does a conventional FID analyzer. The FTIR simply identifies all the hydrocarbons it can (30 in this case) and then sums them to derive a methane-based THC count. Based on previous experience [8] the THC results from the FTIR need to be multiplied by a factor of three in order to be a rough approximation of a FID. In this study, it was more important to investigate the change in emissions rather than the absolute level of emissions. For this purpose, the THC readings from the FTIR were not corrected in this report.

Table 7: %change in non-regulated HC's

	Smooth run	*Bumps run*	*% change*
Toluene (g/km)	0.002	0.014	600
Formaldehyde (g/km)	0.006	0.014	133
Acetaldehyde (g/km)	0.001	0.002	100
1,3-Butadiene (g/km)	0.003	0.021	600
Benzene (g/km)	0.013	0.052	300

One of the main advantages of an FTIR is its ability to speciate 30 out of the ~160 hydrocarbons present in the exhaust [9]. These non-regulated hydrocarbons such as benzene and 1,3-butadiene can cause cancer and other serious health problems [10], and therefore they are taken into consideration when assessing air quality. Figures 9 and 10 show graphs of five important hydrocarbons plotted against road speed and throttle position for the smooth and speed bump runs respectively.

For the smooth run, it can be seen that benzene dominates the analysis with peaks that are 5-10 times higher than the other four pollutants. Toluene seems to have peaks only at the beginning and the end of the drive cycle, with almost no toluene being emitted when traveling at a constant speed. Formaldehyde is different from the other four, with no obvious peak, but rather a series of peaks that are seem to be proportionally related to throttle position. Acetaldehyde has a very similar trend to formaldehyde but with an overall smaller magnitude. Benzene and 1,3-butadiene have similar trends and they seem to produce most of their emissions at idle and low power conditions.

For the traffic-calmed run in figure 10, Toluene has started to show up during the drive cycle, but the two peaks at the beginning and the end of the drive cycle are still present. Formaldehyde now has two distinct peaks, each peak corresponding to the beginning of the drive in each direction. Acetaldehyde also shows peaks during the drive cycle, whereas in the smooth run the peaks were produced at low power conditions when the car was being turned around. Benzene and 1,3-butadiene show a similar trend with most of the peaks produced during the drive cycle as expected.

The numbers in square brackets to the left of the y-axis in figure 10 are ratios. Each number is a ratio of the maximum y-axis scale of the traffic-calmed run to the maximum y-axis scale of the smooth run. The numbers are a rough indication of the increase in the peaks of each of the parameters shown in figures 9 and 10. The pollutant that seems to be most affected by the traffic calming is formaldehyde with a scale 10 times as high as the smooth run. Toluene and 1,3-butadiene are also strongly affected by the traffic calming with a factor of 5. Benzene and acetaldehyde are least affected, but they are still approximately twice the magnitude of the smooth run results. This is made clearer in table 7, which indicates that the highest total emission increases are for toluene and 1,3-butadiene, with a seven-fold difference between smooth and traffic calmed results. The aldehydes are least affected by traffic calming, but they are still double the smooth run levels.

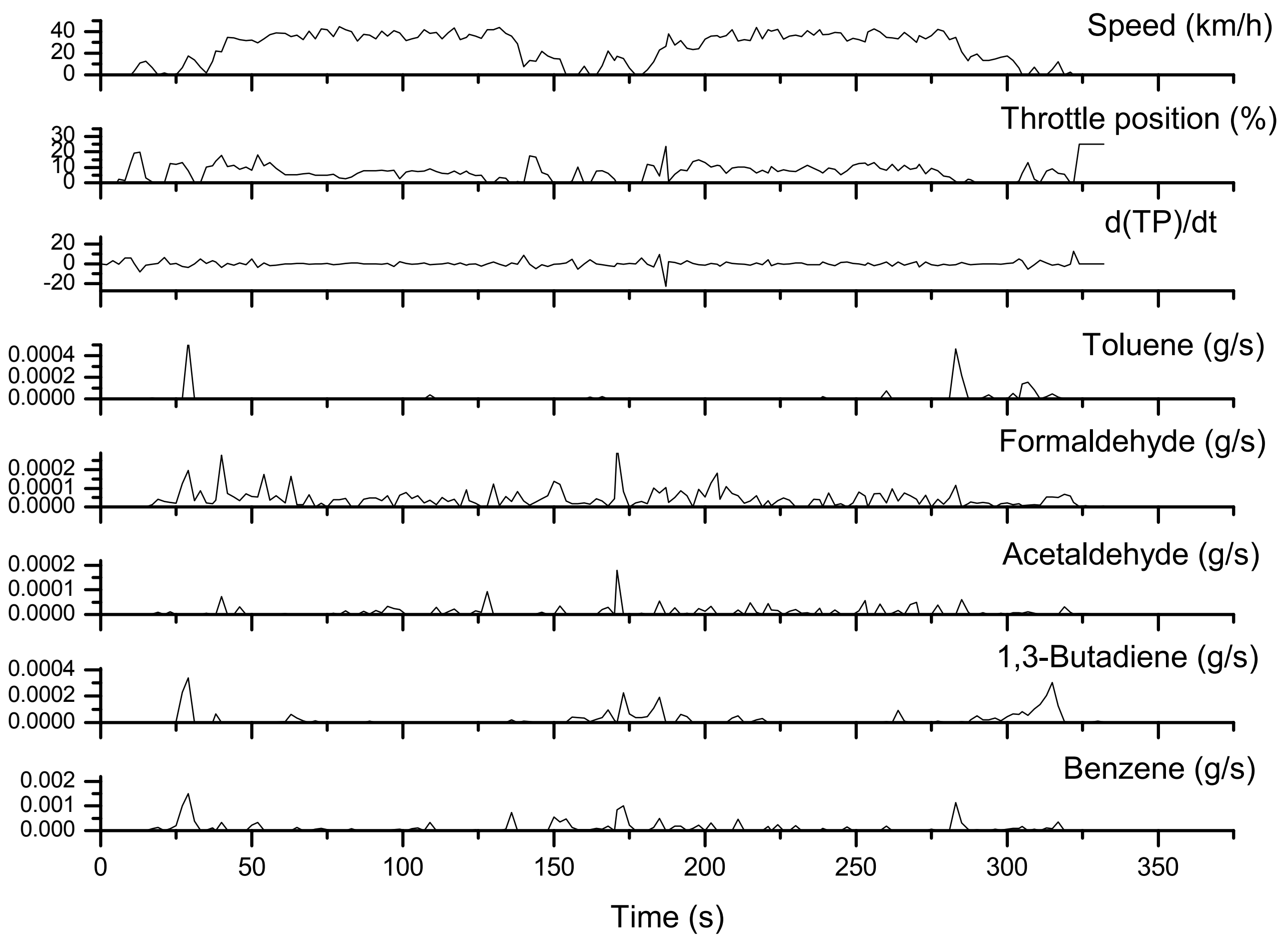

Figure 9: Non-regulated hydrocarbons from smooth run

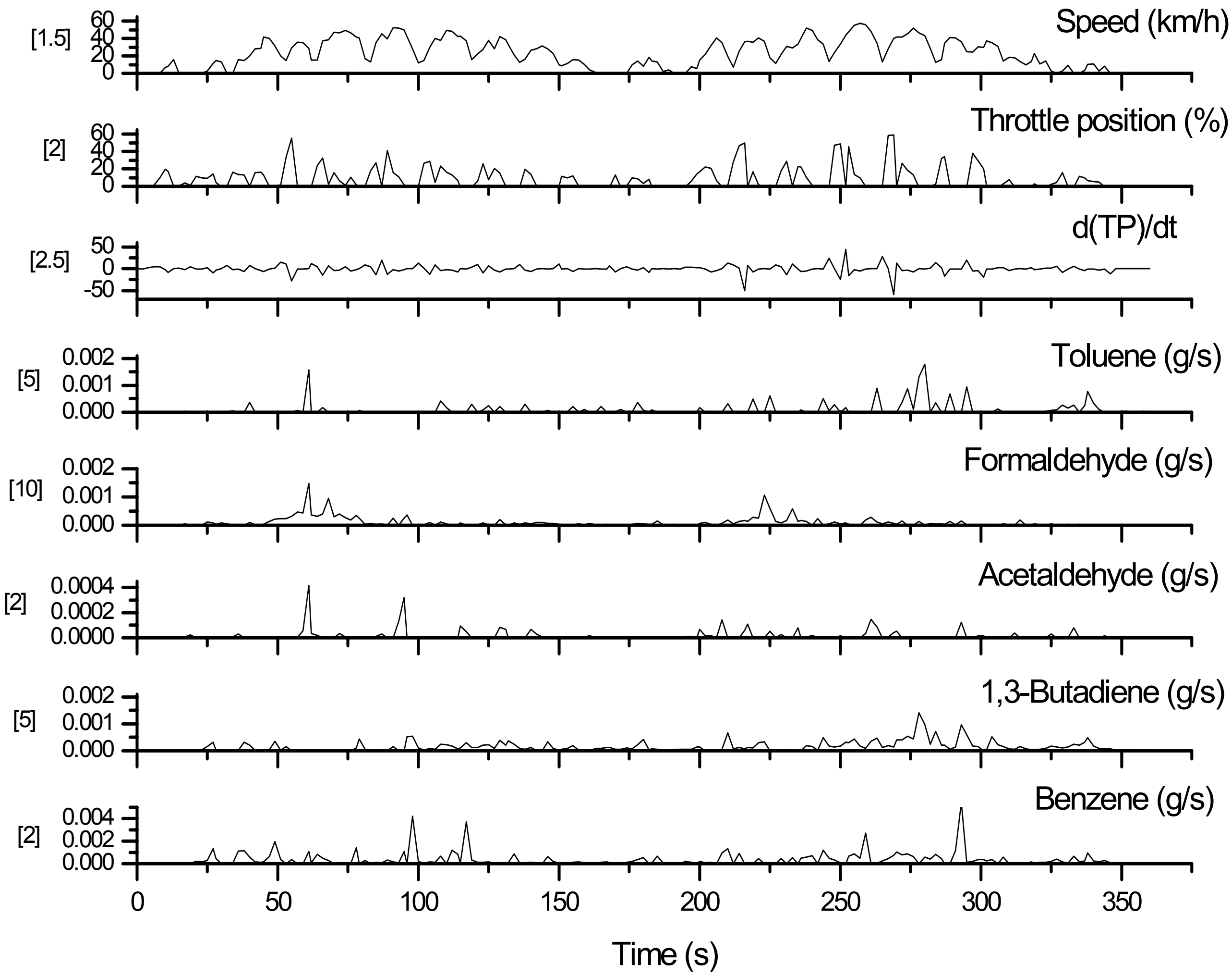

Figure 10: Non-regulated hydrocarbons from speed bump run 1 (numbers in square brackets to the left of y-axis are the ratio of 'speed bump' axis scale to 'smooth run' axis scale)

DISCUSSION

A comparison of exhaust emissions was made between a traffic-calmed and a non-traffic calmed scenario on the same road. The road had a set of seven speed cushions which were mild enough to negotiate at a constant average speed of about 25mph. Baseline data was obtained for a 2-way journey along the road at a constant speed. Data was then obtained while driving across the same speed cushions as if they were the more aggressive road-hump type of speed bumps.

Even though the average speeds of the calmed and non-calmed runs were similar, a large change in emissions was recorded. Had the non-calmed speed been higher than 25mph as was initially planned, it would have made the difference (compared to the traffic-calmed run) even greater. This is because a vehicle produces fewer emissions as the average speed increases since the engine operates in a more efficient regime at higher speeds (up to ~40mph). At speeds higher than ~40mph, the aerodynamic drag of the vehicle tends to push emissions back up [11].

The results obtained from this study were compared to a similar investigation carried out by the TRL. The present work yielded much higher changes in emissions compared to the TRL study. One reason is that the TRL study used a rolling road dynamometer to reproduce drive cycles that were obtained from real-world driving speed profiles. Consequently, the emissions produced were not obtained on-road and therefore might have been limited in terms of acceleration due to slippage between the tire and the rolling road. Another reason for the increase is the unsmooth nature of the driver negotiating the speed bumps in this study. Normally, well-designed speed cushions do not require the driver to slow to 10mph as was done in this study. That much of a retardation is only necessary for the more aggressive round-top speed-hump type of traffic calming. Another factor is the heavy weight of the car. The car used in this study was almost fully laden with equipment and two people on board. Even though the vehicles used in this and the TRL studies are similar in size, ECU strategies used by different manufacturers have a large influence on the levels of emissions produced. For all the reasons mentioned, it was not surprising to see that the results from this study do not agree very well with the TRL report.

Speed cushions do limit speeds to around 30mph as evidenced by the fact that the car was driven over them at a constant average speed of ~23mph without much discomfort to the occupants. Therefore this study is more a representation of the effect of round-top speed humps on emissions rather than speed cushions.

It can be argued the traffic calming in this case was not as effective as the TRL reported, with a 7% reduction in average speed versus a 67% reduction. This is not necessarily true since a car would be able to maintain a higher speed than was done in this study if the speed cushions had not been present. Even if a comparison had been made between a 50mph non-traffic calmed run and a 25mph traffic calmed run, the results would not have been significantly different, and might even have exaggerated the %change in emissions.

A EURO1 vehicle was used in this study, but in future work, similar tests will be performed on EURO2, 3 and 4 vehicles as part of an ongoing project to measure and model real-world traffic emissions.

CONCLUSION

Emissions for a traffic calmed road employing speed humps were shown to be 2-3 times as high as a non-calmed road negotiated smoothly. This was measured on a mass basis using an FTIR installed in-vehicle on a EURO1 petrol-fuelled passenger car. CO_2 was found to increase by 90%, CO by 117%, NO_x by 195% and THC by 148%. Five toxic species of hydrocarbons were also examined and found to increase dramatically due to speed bumps. As far as the authors are aware, this is the first on-road study of the real-world effects of traffic calming on exhaust emissions. The use of the FTIR for emissions measurements can provide quantitative hydrocarbon speciation data which can potentially be used to calculate ozone forming potentials in future.

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ACRONYMS

MEET: Methodologies for Estimating Air Pollutant Emissions from Transport.
MODEM: MODeling of EMissions and consumption in urban areas
ITE: Institute of Transport Engineers
FHWA: Federal HighWay Administration
TRL: Transport Research Laboratory
FID: Flame Ionization Detector
DETR: Department of the Environment, Transport and the Regions
THC: Total HydroCarbons