Vehicular emissions and fuel consumption for street characteristics in residential areas.

by

Lena Smidfelt Rosqvist, Licentiate in Engineering

Traffic Planning, Department of Technology and Society, Lund University, Sweden

Abstract

The objective of the study was to examine the connection between street characteristics in built-up residential areas and environmental effects. The objective was to find out what impact speed-reducing characteristics have on emission and fuel consumption. A study using the chase-car method provided actual driving patterns from different residential areas. A driving cycle simulation model was used to calculate vehicular emissions (CO and NO_x) and fuel consumption. Accumulated emission and fuel consumption factors for streets with and without speed-reducing measures were compared. Further the results from the simulation together with the complete information about the frequency of identified street characteristics, such as different types of streets, junctions, humps and street configuration, were analysed through regression analysis to obtain the effects on vehicle emissions and fuel consumption for each characteristic separately. The results showed that kilometre driven on larger streets add somewhat less to pollution than kilometre driven on smaller streets. The analyses however also showed that junctions and humps had a reducing effect on almost all pollutants. The reductions for humps were around ten times the reduction for junctions. The reducing effect of one hump was as much as 100 meters driven on a larger residential street. Conclusions that could be drawn from these results were that junctions and especially humps encourage a driving pattern that has a reducing effect on vehicle emissions and fuel consumption. This has implications for traffic planning where regard should be taken to traffic safety as well as environmental concerns. Characteristics of the street configurations affect the driving pattern in a way that can not be limited to a certain spot in space or time. The reducing environmental effect of humps, and to a certain degree also junctions, showed that they have a wider impact on the driving pattern than usually assumed.

Key words: driving pattern, street characteristics, speed-reducing measures, traffic design

1 Introduction

To understand and thereby being able to plan the traffic structure in a safe as well as sustainable way we need to study all different parts of what add to vehicular pollution. Both higher emission factors and more vehicular mileage add to the total pollution caused by traffic. Emission factors are influenced by type of fuel and vehicle and also the driving pattern. In traffic planning the driving pattern is the factor we strive to influence. Factors influencing the driving pattern are, apart from the different traffic planning measures, driver behaviour and also what vehicle is being driven. It is sometimes argued that there is a conflict between safety and environmental concerns in traffic planning (Höglund & Niittymäki, 1999, Vi bilägare, 1998). That claimed conflict can only refer to measures influencing the driving pattern, and therefore the emissions factors, since traffic safety (Várhelyi, 1996) as well as pollution will benefit from a general reduction in vehicular mileage. New studies also indicate that calmer traffic gained by implementing speed-reducing humps actually might reduce emissions and fuel consumption (New Scientist, 1999).

When studying the impact speed-reducing measures has on pollution the outcome will vary according to kind of method used to calculate the effects. Different approaches and methods used to study the environmental impact of different traffic planning devices have different advantages as well as disadvantages. It seems that the approach has been somewhat different when studying the effects of speed-reducing measures on traffic safety or environmental effects. When studying the safety effects of different measures the objective seems to be to look upon the traffic situation as a whole, to reduce the number and severity of traffic accidents. When trying to model the environmental impact of different measures the starting point often appears to be in different traffic simulation models (Karlsson *et al*., 1996). To be able to calculate the impact of an object in the street net the way to do that has been to define the length of the impact that object has on the driving pattern. The influence of the object then has for practical reasons been limited within the stretch of road or street where the object is actually situated. From this limitation the emissions have been calculated based on assumptions and simulations of how this driving pattern passing the device/object looks like for this specific length of road/street. A problem with this approach is that the knowledge of how the driving patterns actually look like in real traffic is scares (Thunberg *et al*., 1997).

Driving pattern is hard and expensive to collect. This study however had access to driving patterns measured in residential areas for a different purpose (Ericsson, 1996, Smidfelt Rosqvist, 1998). Presented work had a large scale approach to what impact speed-reducing measures (humps) have on environmental effects by using measured driving patterns over an entire area rather than only for a specific street or part of street. The driving patterns measured in real traffic were analysed through linear regression.

2 Method

The data used in the study origin from 108 driving patterns measured in five different residential areas. The neighbourhoods were planned according to three different configurations, a traditional grid, feeding of traffic from the outside and also from the inside. All areas are located at the outskirts of Malmö or Lund, Sweden. The areas were chosen for a mixture of configuration design and because they were well situated with no through traffic.

A study by Ericsson (1996) using the chase-car method provided driving patterns from the different areas, measured in real traffic. The chase-car method significantly underestimates the highest accelerations and decelerations. The method does however not show any significant differences for the emissions and fuel consumption between followed and following cars (Ericsson, 1996). The measured trips are assumed to be representing a random variety of different driving patterns as they appear in such residential areas.

The chase-car measurements also contained information about exactly where in the street net each vehicle passed. Those recordings meant that the measurements could be classed according to type of streets that had been driven on and also made it possible to identify exactly what junctions or humps that had been passed for each trip. The streets in the areas were divided in two groups, here called larger and smaller streets. The larger streets are streets that feed the area, or parts of it, and smaller streets have the character of local residential street. There are reasons to believe that the behaviour on these street-functions differs significantly. Moreover each measurement has information attached telling the frequency of different characteristics, i.e. number of junctions passed with different directions and number of humps.

A driving cycle simulation model ASPEN[1] was used to calculate vehicular emissions (CO and NO_x) and fuel consumption. This kind of model simulates single vehicle's behaviour when driving a specific driving pattern and is based on specifications of vehicular characteristics such as weight, wheel diameter and motor map for the vehicle in question. The input to calculate the energy use and specific emission factors for CO and NO_x in ASPEN is driving patterns. From the very limited number of vehicles available in the model two as similar as possible were chosen for the analyses, one car with and one without a catalytic converter.

To describe the results from the measurements emission factors for the streets with as well as without humps were calculated by dividing the total sums of each emission with the total sum of meters driven.

The analyses of connections between street characteristics and environmental impact were done with results from the simulation model together with the complete data from the chase-car study including the amount of identified street characteristics. The results were analysed through regression analysis to obtain the effects on vehicle emissions and fuel consumption for each characteristic. The principle function used in the analyses is presented below.

$$E^Y = \sum \beta^Y{}_s * x_s + \sum\beta^Y{}_l x_l + \sum\beta^Y{}_h * x_h + \sum\beta^Y{}_{js} * x_{js} + \sum\beta^Y{}_{jr} * x_{jr} + \sum\beta^Y{}_{jl} * x_{jl} \qquad (1)$$

Where E = quantity of environmental impact, Y = different effects (FUEL, CO and NO_x), x= quantity of characteristics, β = parameter estimate for characteristics, s = smaller street, l = larger street, h = humps, js = junctions passed straight, jr = junctions passed turning right, jl = junctions passed turning left.

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[1] ASPEN; a driving cycle simulation model created by Rolf Egnell, ASPEN utvecklings AB, Lund, Sweden.

3 Results

3.1 Emission factors for driving patterns passing or not passing humps

To describe differences between pollution caused by streets with and without speed-reducing humps those respective calculations of emissions were added together and divided by the meters driven. In that way emission factors for the two different groups of streets were obtained, which is a very simple way of getting some indication of the impact humps have on vehicle emissions and fuel consumption. The measurements have been done in areas completely without any speed-reducing measurements as well as in areas with humps. The largest amounts of humps for one measured trip is three humps and have been recorded on larger streets as well as on smaller streets.

For most pollutants presented the pollution per meter is less for streets with speed-reducing humps than without. The exceptions were for emissions of NO_x for smaller streets and car without catalytic converter and emissions of CO and HC for smaller streets and car with catalytic converter, figure 1 and 2. The figures for HC are however uncertain.

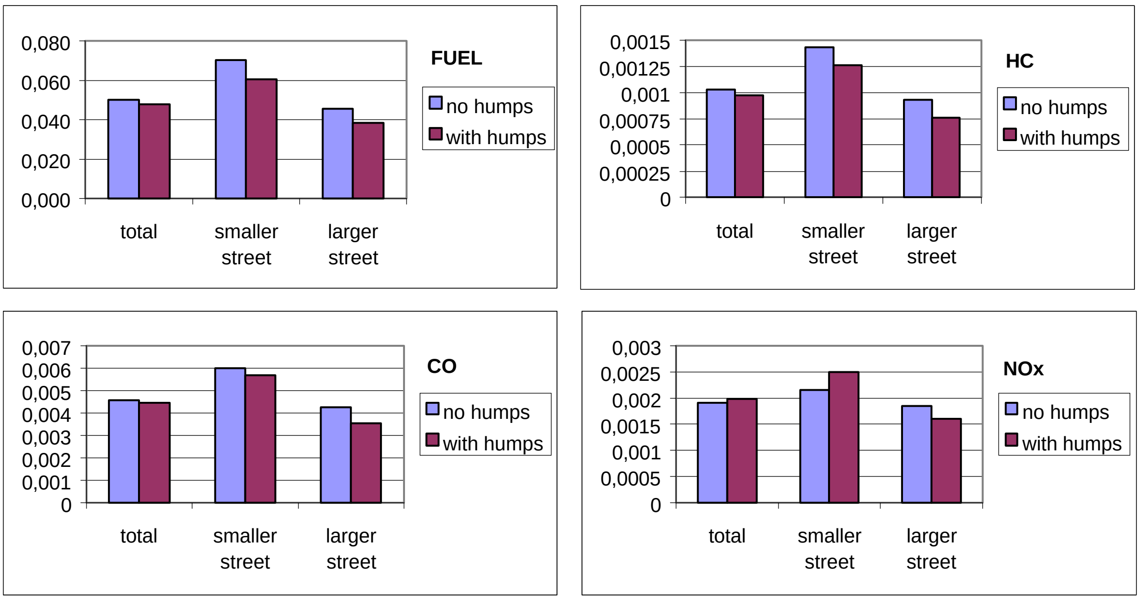

Figure 1 Emissions per meter for a car without catalytic converter.

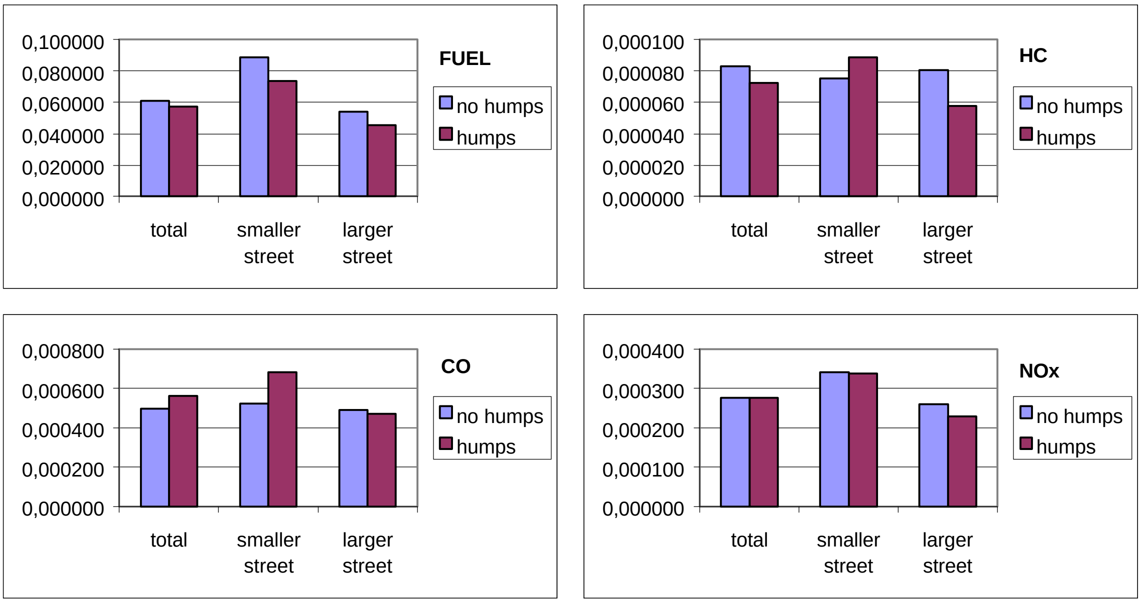

Figure 2 Emissions per meter for a car with catalytic converter.

3.2 The regression models describing connections between characteristics and pollution

The results showed that the models well describe fuel consumption and vehicular emissions for the areas studied (table 1 and table 2). The models initially were run with intercepts. The intercepts were however small and showed no significance. Since it can be assumed that if there is no length of driving there will not be any consumption of fuel or emissions the intercepts were excluded from the further analysis and the only adding to the length of driving was junctions and humps. For the case where a vehicle is idling there will obviously be both fuel consumption and emissions. The driving patterns measured in this study did however not contain parts where vehicles were idling to any relevant extent. The estimates for the different parameters were found highly significant and consistent for the different models.

Table 1 The models describing the different environmental impacts based on the analysed characteristics. For the car without catalytic converter.

Prediction model for	FUEL (ml/char.)		CO (gram/ char.)		NO_x (gram/ char.)	
Adjusted R^2 (as SPSS calculates it)	0,948		0,969		0,968	
Variable	*b*	*Sign*	*b*	*Sign*	*b*	*Sign*
one meter SMALLER street	0,103	0,00	0,0067	0,00	0,0018	0,00
one meter LARGER street	0,068	0,00	0,0045	0,00	0,0017	0,00
one HUMP	-7,382	0,00	-0,4453	0,00	0,1041	0,03
one junction STRAIT ahead					-0,0059	0,51
one junction TURNING					0,0643	0,02
one JUNCTION	-0,998	0,01	-0,0485	0,02		

Table 2 The models describing the different environmental impacts based on the analysed characteristics. For the car with catalytic converter.

Prediction model for	FUEL (ml/char.)		CO (gram/ char.)		NO_x (gram/ char.)	
Adjusted R^2 (as SPSS calculates it)	0,926		0,925		0,982	
Variable	*b*	*Sign*	*b*	*Sign*	*b*	*Sign*
one meter SMALLER street	0,131	0,00	0,0003	0,00	0,0003	0,00
one meter LARGER street	0,083	0,00	0,0004	0,00	0,0003	0,00
one HUMP	-10,075	0,00	0,0863	0,00	-0,0113	0,03
one junction STRAIT ahead			-0,0004	0,91		
one junction TURNING			0,0222	0,05		
one JUNCTION	-1,486	0,01			-0,0017	0,07

3.3 The environmental impact of the different street characteristics

By comparing the estimates for the emission and fuel consumption factors for each of the characteristics the picture of their relevance for the emissions and fuel consumption gets clearer. The results showed, not surprisingly, that kilometre driven on larger streets added somewhat less to fuel consumption and emissions than kilometre driven on smaller streets. The analyses however also showed that junctions and humps passed had a reducing effect on fuel consumption and most emissions. The reductions for humps showed around ten times the reductions for junctions. The reducing effect of one hump was as much as 100 meters driven on larger residential streets. The results showed that the car without catalytic converter had a clearer tendency than for the car with catalytic converter. The results for the two cars can not be compared straight off since the cars are not identical, see the Method section.

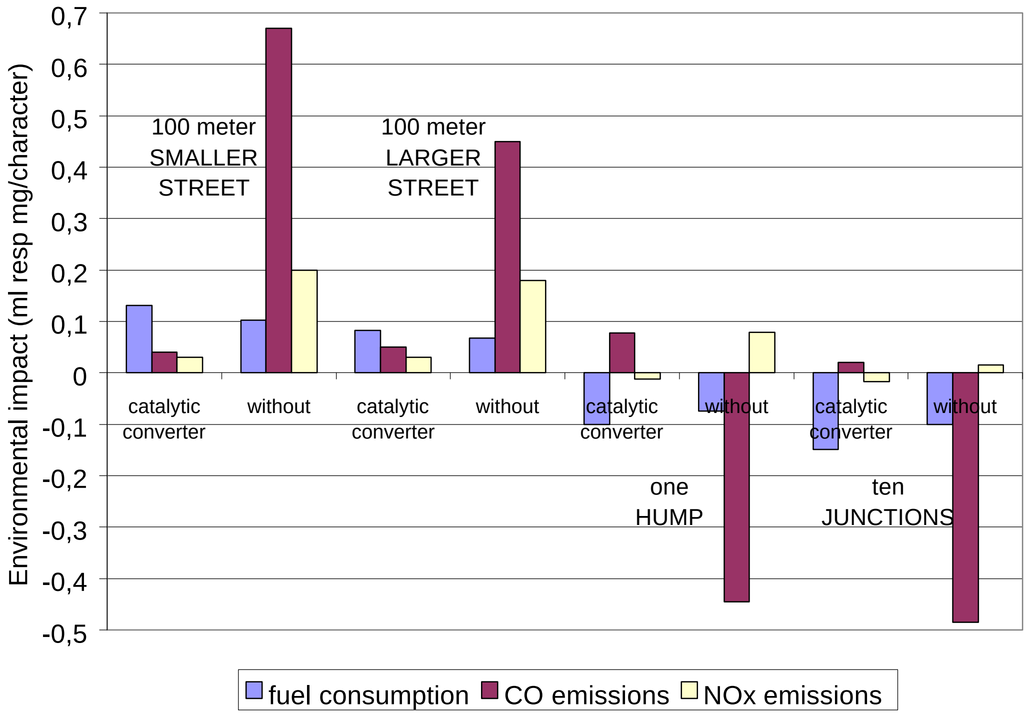

Figure 3 *Environmental impact due to the existence of different characteristics in the street net.*

Speed-reducing humps showed some reducing environmental impact on fuel consumption and emissions. Further analyses showed that all effects positive as well as negative were larger for humps when situated on larger than on smaller streets. All estimates for the speed-reducing humps on larger streets are highly significant where humps on smaller streets are not (see table 3 and 4).

Table 3 *The models describing the different environmental impacts based on the analysed characteristics, with humps grouped after street type. For the car without catalytic converter.*

Prediction model for	FUEL (ml/char.)		CO (gram/ char.)		NO_x (gram/ char.)	
Adjusted R^2 (as SPSS calculates it)	0,945		0,966		0,968	
Variable	*b*	*Sign*	*b*	*Sign*	*b*	*Sign*
one meter SMALLER street	0,074	0,00	0,0063	0,00	0,0018	0,00
one meter LARGER street	0,050	0,00	0,0046	0,00	0,0017	0,00
one HUMP SMALLER street	**-3,706**	**0,16**	**-0,0089**	**0,96**	**0,0693**	**0,38**
one HUMP LARGER street	**-5,715**	**0,00**	**-0,5093**	**0,00**	**0,1100**	**0,03**
one junction STRAIT ahead					-0,0056	0,53
one junction TURNING					0,0667	0,01
one JUNCTION	-0,763	0,01	-0,0548	0,01		

Table 4 The models describing the different environmental impacts based on the analysed characteristics, with humps grouped after street type. For the car with catalytic converter.

Prediction model for	FUEL (ml/char.)		CO (gram/ char.)		NO_x (gram/ char.)	
Adjusted R^2 (as SPSS calculates it)	0,922		0,925		0,981	
Variable	*b*	*Sign*	*b*	*Sign*	*b*	*Sign*
one meter SMALLER street	0,095	0,00	0,0004	0,00	0,0003	0,00
one meter LARGER street	0,062	0,00	0,0004	0,00	0,0003	0,00
one HUMP SMALLER street	**-5,816**	**0,13**	**0,0607**	**0,07**	**-0,0064**	**0,45**
one HUMP LARGER street	**-7,689**	**0,00**	**0,0907**	**0,00**	**-0,0121**	**0,02**
one junction STRAIT ahead			-0,0002	0,95		
one junction TURNING			0,0240	0,04		
one JUNCTION	-1,122	0,01			-0,0017	0,06

4 Discussion

The results in this study very clearly showed that the connections between different characteristics in the street configuration and environmental impact are complex. Speed-reducing measurements are often thought to have negative environmental impact (Höglund & Niittymäki, 1999, Vi bilägare, 1998). This could very well be the case when looking at the very vicinity of the speed-reducing device. But it is important not to forget the influence such measurements have on speed choice and driving pattern on a larger scale over a more extended part of the trips. To understand in what ways the impact on the environment is affected by traffic it is not sufficient to study certain characteristics in the configuration locally only (Newman & Kenworthy, 1984). The traffic environment as a whole has great influence on driving patterns and therefore also on the environmental effects, e.g. driving patterns vary more between different street types than they do between individuals (Ericsson, 1999). This implicates that the environmental impact of different trip characteristics, e.g. speed-reducing humps are important factors and also must be studied and considered over a larger area than most often done.

Differences between fiercely and calm traffic behaviour fuel consumption and emissions of CO and NO_x have been shown to be significantly larger for speed limit 50 km/h than for 30 km/h (Erlandsson, 1998). That implicates that with a speed limit of 30 km/h the space for the individual driver to choose jerkiness in driving behaviour is considerably less than in the case with 50 km/h. This corresponds well with results describing differences in variability in urban driving patterns for different street types (Ericsson, 1999) as well as the differences in environmental impact between different driving patterns with the same average speed that have been shown by Ericsson (1999 II). Ferreira (1985) show that fuel consumption due to speed fluctuations between intersections is 39% of total run fuel consumption and that total acceleration and deceleration stages is as much as 74.4% in urban driving.

Presented study showed that different characteristics in the street configuration can have an impact on the driving patterns which reduces fuel consumption and emissions. One explanation for this could be that the average speed is lowered or that the possible space for the drivers to drive with a high level of jerkiness is reduced when these characteristics are there. The explanations for speed limiting measures to have a reducing effect on pollution are probably several. The driving pattern changes in some pollution reducing way. A less polluting driving pattern is one with smaller amplitudes, a more even driving pattern (Hammarström, 1997). An average speed of 30 is better than 50 km/h when comparing the total environmental impact for a street with a short stop in the middle. This is shown by Richard & Steven, (1991) in a study built on simulated driving patterns. Comparing excess fuel consumed due to a start/stop manoeuvre the excess fuel consumed is almost twice as high for the initial/final speed of 50 km/h as for initial/final speed of 30 km/h (Ferreira, 1985). The impact of jerkiness is obviously larger than the fact that constant speed 30 gives higher emissions than 50 km/h. The driving patterns on an app 800 metres thoroughfare, with speed-reducing measures are more even than on the thoroughfare without (Sikrere-Roligere-Renere). The same pattern has been shown for a test-route driven with respectively without dynamic speed adaptation in a vehicle (Almqvist and Nygård, 1997). An interesting aspect with their results is that the dynamic speed adopter not only cuts of the high peaks of the driving pattern (by cutting the actual possibility) but also to a great extent cuts out the down peaks in the driving pattern.

5 Conclusion

The results in this paper founded on driving patterns measured in real traffic showed that passing of speed-reducing humps and also junctions when making trips in the residential area street-net had a reducing impact for most pollutants. This clearly shows that the connection between characteristics and measurements in the street net is complicated and that we do not know enough about this yet.

Today we do not know enough what kind of impact different characteristics has on the driving patterns in real traffic situations and how far different impacts go. This study however showed that the existence of humps and junctions in street configurations have an impact on the driving patterns in a way that make fuel consumption and emissions less. Conclusions that could be drawn from these results were that junctions and especially humps encourage a driving pattern that has a reducing effect on vehicle emissions and fuel consumption as a whole. This has implications for traffic planning where regard should be taken to traffic safety as well as environmental concerns. Characteristics of the street configurations affect the driving pattern in a way that can not be limited to a certain spot in space or time. The reducing environmental effect of humps, and to a certain degree also junctions, showed that they have a wider impact on the driving pattern than usually assumed.

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