Paper for the Conference ”Urban Transport Systems”, Lund, Sweden, 1999-06-07--08. The following abstract is related to Topic 1 (thesis 1) ”Environment and energy”, ”Methods for calculating and measuring effects, measures”.

Estimating Vehicle Emissions and Air Pollution related to Driving Patterns and Traffic Calming

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Abstract

This paper is dealing with the methodological aspects and the difficulties of surveying environmental effects, especially air pollution, from speed changes and traffic calming. It describes the complexity of interpreting surveying and study results in terms of a ”best-worst alternative”. Results from a case study with two specific streets within the central and semi-central urban area in Gothenburg, Sweden, are presented in the paper.

The methodology used is traffic simulation and calculations of emissions related to singular vehicles’ driving patterns, using a specially developed computer programme. The aggregated results of total emissions, for various substances depending on certain ”real” traffic situations for different times of the day, give the possibility for a comparison of different alternatives. The results show the complexity of finding such a ”best alternative” to be feasably implemented. The emitted amounts are highly dependent on vehicle speed changes through the interaction between the varous vehicles in the traffic flow.

The paper will also explain the used methodology of estimating single vehicle’s emissions from specific driving patterns, either measured, simulated or calculated with kinematic methods. In combination with instant emission data from three-dimentional emission matrixes it is possible to create continous emission profiles for the specific vehicles. The method gives today amounts for emitted substances of CO_2, CO, NO_x, HC, particles and fuel consumption. The aggregated results from single vehicle’s emissions can then give the comparisons of total emission amounts over a certain street length and time unit for various infrastructural design alternatives such as traffic calming devices. Also different traffic mangement options and traffic signal control strategies could be handled by this method in combination with traffic simulation.

1 Background

Detrimental air pollution related to the traffic flow in the road and street infrastructure has reached the critical level in many cities, at least in some street canyons within urban areas. Road users and also residents in city centres amd human beings within the immediate vicinity of the traffic arteries, reaching their capacity, are dangerously exposed for hazardous components in the exhaust pollutants, especially in winter time.

The reduction of such ambient air concentrations, because of the high level of vehicle emissions, is a prime requisite for the future sustainable use of the individual transportation vehicle. At intersections, and other disturbance points in the traffic flow, the transient driving patterns, i. e. the decelerations and accelerations of vehicles, give substancial additional amounts of emmitted exhaust pollution. It is therefore necessary to pay attention to the infrastructural design aspects, when looking for ways of reducing the traffic related emissions to the ambient air.

The choice of the optimal design solution for a given intersection with a given flow intensity and flow distribution could therefore be crucial for the surrounding air quality situation. Methods for quantifying the amount of emitted air pollution on the real micro level use various parameters such as driving patterns and traffic managemnet conditions as well as vehicle category, engine type and specific emission factors. There has until now been very parsimonious R&D-activities within this area, see references [1] and [2].

2 Introduction

For traffic safety reasons, e.g. in Sweden, there is today a tendency of reducing vehicle speed levels to 30 km/h, especially in urban downtown areas, where the pedestrians in a high extent interact with the vehicle flow. We are here facing a goal conflict between traffic safety and environment, especially air pollution. It is therefore really essential to apply a sytems approach to the problem with the relationship between less emissions - set goals - measures to be taken.

There is thus essential to develop methods for estimating and quantifying the amount of emitted air pollution, based on the real vehicle driving patterns, in order to find alternative solutions for the urban infrastructural design and traffic management strategies. Emission models and emission calculations on the micro level are needed for making possible cost efficient comparisons between the effects of different measures to be taken, especially for evaluating different infrastructural design alternatives, or traffic management options, and the impact on the environment.

In many cases the now so popular ”environmentally adopted infrastructure” could even be a danger for the environment. It is worth asking the question - are environmentally adopted roads and streets with e.g. speed reducing humps etc an improvement of the envirionment for nearby residents and road users? We are here facing a serious goal conflict between the traffic safety and the environment goals. In most cases we also have a conflict between the traffic capacity and efficiency aspects, which could be described by the traffic flow parameters such as flow capacity, delays, amount of stopping vehichles etc, and the goals of traffic safety. Traffic flow capacity and flow efficiency can also be contradictory to the environment goals, but it is not always the case. A homogeneous traffic flow with a minimum of transient movements gives reduction of vehicle emissions as well as higher capacity and less delay.

The traffic safety aspects are not handled in this paper. Already here in the introduction it should be pointed out, that the aim of this paper is neither to give any comments on set goals, nor to debate the need of various traffic calmiong devices. The paper only describes the complexity of this field and gives certain quantifying methods for obtaining information and helping to a better understanding and a general knowledge in this area.

For environmental reasons, possible ways must be found for both increasing traffic safety togetrher with alternative measures, leading to the set targets for air pollution reduction in urban areas. The main traffic flow related measures should be a decreased amount of speed changes (accelerations), i.e. a more homogeneous traffic rytm and a decreased amount of stopping vehicles, i.e. shorter queues and less vehicle idling time. This could e.g. be achieved by an alternative, changed intersection design, such as a roundabout instead of a traffic signal or improved traffic signals with modern vehicle activated control strategies.

3 Methodology

3.1 General methodological approach

The methodology used for the case study in this paper is traffic simulation with specially designed additional computer programmes for the calculation of the fuel consumption and the exaust pollutions. The HUTSIM simulation model, [3] and [4], developed at the Laboratory of Transportation Engineering at Helsinki University of Technology, has given the traffic flow and capacity parameters, such as average delay, amount of stopping vehicles, average travel speed etc. HUTSIM also generates singular vehicle speed profiles containing information of acceleration, deceleration, stopping time (idling), cruising speed etc.

The general methodology described in this paper does not require traffic simulation. It is possible to use other methods for estimating single vehicle's emissions from specific driving patterns. Such driving patterns could be either measured in real field measurements and traffic conditions, calculated with kinematic methods or, as said before, simulated by micro simulation methods. To compare with real field measurements the use of traffic simulation is very cost efficient, and the only way you can create a real laborative situation with a built computer model of the reality, where various alternative solutions could be tested before real implementation and construction in the infratructure.
In combination with the computer programme EMCA for emission calculations, based on three dimentional instantaneous emission matrixes [5], and the singular vehicle driving patterns, we will get continuous emission profiles for each vehicle in the studied road or strreet infrastructure. The difficulty is to get sufficiently detailed data for instantaneous emissions in matrix forms.We can then calculate an aggregated result for total emissions of e.g. CO_2, CO, NO_x, HC, particles and fuel consumption during a certain time unit, e.g. one hour.

3.2 Accuracy in emission estimation

In scientific discussions regarding the accuracy problems for instantaneous emissions, it has sometimes been questioned, if given data can be used for satisfying the quantification needs. It is worth noticing, that this paper is only dealing with a comparative research methodology. The accuracy of an estimation giving absolute values for emission levels can be discussed, but for comparative studies the accuracy in given instantaneous point emissions is regarded sufficient. For further information concerning instantaneous emission data, see references [5] and [6].

Reerence [6], mentioned above, is a new published report within the European Commission SAVE programme project HESAID. From the report can be read: ”Systematic investigations on the emission database show.....the application range..... and how important a reliable consideration of *driving kinetics* is in an accurate estimation of fuel consumption and emissions for real world driving”. It is also stated that ”The estimation of emission changes due to changes in infrastructural design is reliable in a quantative way”.

3.1 Practical use of the method

The aggregated results of total emissions, for various substances depending on certain ”real” traffic situations for different times of the day, give the possibility for a comparison of different infrastructural design alternatives and traffic control systems. Obtained survey results show the complexity of finding a ”best alternative” to be feasably implemented. The *emitted amounts are highly dependent on vehicle speed changes in the traffic flow*.This survey method could also be combined with different ranking methods for choosing a suitable peformance alternative. One possible method is based on ”fuzzy logics” principles, taking in consideration both capacity, flow efficiency and the emission of exhaust pollution and also fuel consumption. See further references below (page 6) in ”5.3 Best performance alternative” and [8] Work report 1.

4 Surveys

The methodology dscribed above can be used for practical surveys and comparative studies in the road- and street network. The method uses traffic simulation and micro-modelling of both traffic behaviour (driving patterns), exhaust pollution and fuel consumption. The main aim is not quantative studies of absolute values for the amount of emitted substances. This has been described above under ”3.2 Accuracy...”. The method should instead be used for comparative studies for finding ”best-worst” alternatives in the specific infrastructure design and the choice of traffic control strategy. We have here a very practical tool for comparative studies of infrastructural design options.

With this method separate intersections, as well as small networks up to 10 intersections, can be studied. For larger areas with many links and nodes you can combine this micro methodological approach with meso scale models for traffic network assignment.

In combination with instant emission data from three-dimentional emission matrixes it is possible to create continous emission profiles for the specific vehicles. The method gives today amounts for emitted substances of CO_2, CO, NOx, HC, particles and fuel consumption. The aggregated results from single vehicle's emissions can then give the comparisons of total emission amounts over a certain street length for various infrastructural design alternatives such as traffic calming devices and also control strategies.

5 Case Study

5.1 Location and description of the study

The above described methodology has ben used for many different case studies. In this paper a study of traffic calming for two specific streets within the central area (Västra Hamngatan) and semi-central urban area in Gothenburg (Kungsladugårdsgatan), Sweden, have been studied. The aim of this study was to compare the exhaust pollution and fuel comsumption related to the traffic flow before and after speed reducing ”humps” are applied. Also traffic efficiency performance parameters were studied, such as average delay and average speed. Comparisons were made for different flow intensities during the day, peak hour traffic, mid-day traffic (50 % of peak hour traffic) and low intensity (25 % of peak hour traffic). The reason for this is the different interactions between the vehicles in the traffic flow depending of the flow intensity.

Two permitted speeds, 50 km/h and 30 km/h were studied for both streets and different flow intensities. The study was performed with traffic simulation and computerized emission calculations as described above under ”3 Methodology”. The case study has shown, that for the studied street with given different traffic flow conditions at different times of the day, the different permitted speed levels of 50 km/h and 30 km/h with and without traffic calming devices, such as e.g. humps, will give different performance alternatives with regards to emissions of CO_2, CO, NOx, HC and also fuel consumtion.

As pionted out above, the traffic safety aspects are not included in this study. Another methodological conclusion will be, that the results are site specific, i.e. it is very difficult to generalize obtained results, and therefore studies should be performed for each specific case with a certain street-, road- or intersection configuration and for different flow conditions during the day.

5.2 Results from the specific case study

The results of the study from the semi-central street (Kungsladugårdsgatan) are given in tables 1 to 4 below. Table 1-3 shows the differences between traffic flow parameters, fuel consumption and emitted substances totally during one hour for different flow intensities and times of the day. Permitted speed is 50 km/h. Table 4 shows the same as in tables 1 for maximum traffic flow, peak hour, but for the permitted speed of 30 km/h.

Speed limit 50 km/h	Average delay sec	Average speed km/h	Fuel consumption l (liter)	Emissions NOx g (gram)	Emissions CO g (gram)	Emissions HC g (gram)
no humps	4.6	44.4	39.65	533.0	4867.4	827.9
humps	24.4	31.5	47.18	672.1	6418.7	1338.5
difference	+19.8	-12.9	+7.53	+139.1	+1551.3	+510.6

Table 1. Kungsladugårdsgatan. Differences between traffic flow parameters, fuel consumption and emitted substances during one hour, peak hour, speed limit 50 km/h.

Speed limit 50 km/h	Average delay sec	Average speed km/h	Fuel consumption l (liter)	Emissions NOx g (gram)	Emissions CO g (gram)	Emissions HC g (gram)
no humps	3.2	46.0	19.62	275.1	2343.4	363.4
humps	21.8	31.4	20.53	271.1	2735.2	527.7
difference	+18.6	-14.6	+0.91	-4.0	+391.8	+164.3

Table 2. Kungsladugårdsgatan. Differences between traffic flow parameters, fuel consumption and emitted substances during one hour, middle intensity, speed limit 50 km/h

Speed limit 50 km/h	Average delay sec	Average speed km/h	Fuel consumption l (liter)	Emissions NOx g (gram)	Emissions CO g (gram)	Emissions HC g (gram)
no humps	2.1	45.8	4.40	60.9	517.5	74.8
humps	22.7	32.3	5.00	72.3	682.9	131.8
difference	+20.6	-13.5	+0.6	+11.4	+165.4	+57.0

Table 3. Kungsladugårdsgatan. Differences between traffic flow parameters, fuel consumption and emitted substances during one hour, low intensity, speed limit 50 km/h.

Speed limit 30 km/h	Average delay sec	Average speed km/h	Fuel consumption l (liter)	Emissions NOx g (gram)	Emissions CO g (gram)	Emissions HC g (gram)
no humps	18.6	22.9	54.57	400.4	6848.0	1105.5
humps	20.3	22.5	56.18	420.9	6878.7	1184.7
difference	+1.7	-0.4	+1.61	+20.5	+ 30.7	+79.2

Table 4. Kungsladugårdsgatan. Same as above, peak hour, but speed limit 30 km/h.

It is also possible to compare the total amount of fuel consumption and emitted substances from a certain road length in another way. Here below, in table 5, a comparison is done between different driving patterns (vehicle kinetics) for a traffic flow consisting of either non catalyst or catalyst passenger vehicles. The total fuel consumption and emissions in one street direction is here expressed in form of an index comparison. Data is here also taken from the case study survey and from the other studied street, the central street (Västra Hamngatan).

The complexity of the obtained results is shown by the discrepanses between the figures for the different flow directions in the street as well as between non catalyst and catalyst cars. The fuel consumption and emitted substances for a constant vehicle speed of 50 km/h is taken as the comparison level with the index 1. Both a lower constant speed of 30 km/h and different transient driving paterrns of speed changes between 50-20-50 km/h and 50-0-50 km/h gives considerably higher amounts of both fuel consumption and emissions.

Non cat / cat Driving direction	Driving pattern	Fuel consumption index	Emissions CO2 index	Emissions CO index	Emissions NOx index
non cat N-S	50-20-50	2.37	3.35	6.11	2.32
non cat N-S	50-0-50	2.86	4.04	6.17	2.86
non cat N-S	50	1	1	1	1
non cat N-S	30	1.36	1.44	0.73	1.36
non cat S-N	50-20-50	1.96	2.74	4.67	1.36
non cat S-N	50-0-50	2.66	3.73	5.46	2.66
non cat S-N	50	1	1	1	1
non cat S-N	30	1.36	1.44	0.73	1.36
cat N-S	50-20-50	1.94	4.30	4.70	1.94
cat N-S	50-0-50	2.23	3.88	4.77	2.23
cat N-S	50	1	1	1	1
cat N-S	30	1.22	0.96	1.07	1.22
cat S-N	50-20-50	1.47	3.39	3.51	1.47
cat S-N	50-0-50	1.98	3.46	4.16	1.98
cat S-N	50	1	1	1	1
cat S-N	30	1.22	0.95	1.06	1.22

Table 5. Västra Hamngatan. Total fuel consumption and emissions for non catalyst and catalyts cars in one street direction expressed in form of an index comparison.

5.3 Best performance alternative

The performed survey shows the complexity of interpreting the results in terms of ”best performance alternative” to be feasably implemented. The emitted amounts of the detrimental air pollutants are highly dependent on vehicle speed changes in the traffic flow. There are methods to judge ”best-worst” alternatives in situations similar to this case study. In order to find a ”best” alternative out of different alternatives in different groups, it has here been used a modified method related to ”fuzzy logics”, where the different characteristics have been given a certain weight, see the references in this page below. [1]

[1] Referencees for the ranking method related to ”fuzzy logics” theory:

1. Journal of Transportation Engineering, Vol. 118, No. 5, September/October 1992, Paper No. 1932, written by C.H. Juang and S.N. Amirkhanian

2. Fuzzy Sets and Systems, 21(2), 183-199. ”Fuzzy weighted averages and implementation of the extension principle” by W. Dong and F.S. Wong (1987)

3. International Journal of Microcomputers in Civil Engineering, 3(2), 157-165. ”Development of a decision support system using fuzzy sets” by C.H. Juang (1988)

For exemple, the case study shows, that for given limits and made assumptions of equal weight for the studied variables, a permitted speed level of 50 km/h without traffic calming devices, such as e.g. humps, in most cases will give the best performance alternative if both the aspects of capacity, flow efficiency and air pollution are taken in consideration. The traffic safety aspects are not included in this study.

If only the ”environment parameters”, i.e. amount of exhaust pollution and fuel consumption, are taken in consideration, the results will be different. The results are then more complex and vary with the traffic intensities. In this case study, the ”best alternative” for the central street was then for the peak hour 50 km/h with humps. For the semi-central street the ”best alternative” for the peak hour was 30 km/h without speed reduction equipment (humps), but for medium and low traffic intensity the ”best alternative” was 50 km/h without humps.

The performed case study also shows, that for the studied semi-central street with given traffic flow conditions, a permitted speed level of 50 km/h without traffic calming devices such as e.g. humps, will give the best performance alternative with regards to emissions of CO_2, CO and also fuel consumption, but not for NOx. As pointed out above, the traffic safety aspects are not included in this study. Another methodological conclusion is, that the results are site specific, i.e. it is very difficult to generalize obtained results, and therefore studies should be done for each specific case with a certain street-, road- and intersection configuration and different traffic flow intensity.

6 Conclusions and comments

The obtained results from the case study, given above, show the complexity of the in this paper described research area. The vehicle exhaust emissions are dependent on the driving patterns (speed, deceleration and acceleration) and therefore it is necessary to have sufficient quality of the in-data, especially for the instantaneous emission matrixes. The vehicle driving patterns (vehicle kinetics) are depending on the interactions between sigular vehicles and thus vary with different flow intensities. We need therefore also good quality data for the input to the traffic simulation. A more detailed knowledge regarding the traffic flow parameters, such as capacity, flow efficiency, delay, amount of stopping vehicles, flow composition etc, will give better output data from the traffic simulation and a better description of the ”real” traffic situation. The final conslusion is therefore that *the accuracy, reliability and thus the quality of the result is very much depending of the vehicle kinetics and the intantaneous emission data.*

Another extremely important conclusion is, that the *results are site specific,* i.e. it is very difficult to generalize obtained results, and therefore *studies should be done for each specific case with a street- and intersection configuration*. Because of the different flow intensity during different times of the day, the surveys should *at least study peak-hour, middle intensity (middle of the day) and low intensity traffic situations*.

The survey results also give the important information, that *the ”best” solutions, considering capacity and efficiency as well as environmental aspects, often give different results when only the environmental parameters (emitted pollution and fuel consumption)* *are taken in consideration*. We also in many cases have a goal conflict between the environmental goals and the traffic safety goals. This question is however so complex, that every specific object must be studied carefully and for different traffic flow situations.

I is here appropriate to give a final warning for the increased risks of unwanted exposure from detrimental pollutants for human beeings in the vicinity of intersections or other traffic flow disturbance points. This problem is very often neglected because of the difficulty of applying feasable spacial measurment techniques for concentration variations alongside the street. The final conclusion and recommendation from this paper will be to observe those risks, and carefully monitor locations with a significant increase in vehicle emissions. *If the calculated vehicle emissions at certain locations in the road- and street infrastructure will be significantly higher because of forced speed reduction, it is necessary also to study the level of ambient pollution concentrations. Within street canyons, in densely populated urban areas with special wind situations, the concentration levels can be critical for human health.*

Acknowledgements

This paper is mostly based (i.e. the case study results) on a survey done by the consulting company Transforsk-Transearch for the City of Göteborg (Gothenburg), Sweden, Department of Traffic [8], which has financially supported the work.

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