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# EVALUATION OF BYPASS INFLUENCE ON REDUCING AIR POLUTION IN VILNIUS CITY

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**Abstract.** The segment of transport is a significant part of social and economic infrastructure and has a direct impact on certain economic or social territory development. It is known that production and/or trading scale development in a specific territory leads to increased requirements for infrastructure as well as to arising environmental protection issues. Therefore, this paper addresses a very significant problem of constantly increasing vehicle numbers that decrease the permeability of roads and increase traffic jams, which consequently, have an impact on the pollution of the environment. The main goal of this paper is to evaluate bypasses and high-speed streets based on data on Vilnius City using the multi-criteria evaluation method and to verify the hypothesis of the authors.

**Keywords:** pollution, bypass, vehicle, environmentalism, transport infrastructure, research

## 1. Introduction

As stated by the European Commission, transport infrastructure is directly related to the economic and social growth of a certain territory (Infrastructure Charging… 1998).

It is widely observed that the development of production and/or trading scale in a specific territory leads to tightening requirements for infrastructure as well as to arising environmental protection issues (Cuena *et al.* 1995; Hoogendoorn, Bovy 1998; Zhang 2000; Van Zuylen, Weber 2002; Van Zuylen 2002).

Many researchers (Baumol, Oates 1988; Alessandri *et al.* 1998; Barlovic *et al.* 1998; Bellemans *et al.* 2002; May, Milne 2000; Antov *et al.* 2009; Beljatynskij *et al.* 2009) have indicated that designing and building new highways and bypasses is the most important processes of infrastructure modernization. Long-term research points to the main means of improving traffic safety and environment (Quality Indicators for… 1998; Breton *et al.* 2002; Classidy, Bertini 1999; Cremer 1995; Daganzo 1994; Daganzo 1995a–c; Diakaki *et al.* 2000; Di Febbraro *et al.* 2001; Ho, Ioannou 1996; Chien *et al.* 1997; Seethaler 1999; Sommer *et al.* 1999; Pečeliūnas, Prentkovskis, O. 2006; Sokolovskij *et al.* 2007; Kinderytė-Poškienė, Sokolovskij 2008; Kapski et al. 2008; Junevičius, Bogdevičius 2007, 2009; Vansauskas, Bogdevičius 2009; Baltrėnas, Kazlauskienė 2009; Baltrėnas *et al.* 2008; Čygas *et al.* 2009; Jakimavičius, Burinskienė 2009, 2010; Pellegrino 2009; Laurinavičius *et al.* 2010; Al-Mofleh *et al.* 2010; Leipus *et al.* 2010).

The issues highlighted in this paper are relevant because of an increasing number of vehicles in the cities that cause a decreasing permeability of roads, increased traffic jams and environment pollution with exhaust products of vehicles (Diakaki *et al.* 2000).

The influence of building a bypass on air pollution is the crucial point of this research and seems to be a is very important issue not only for Vilnius City but also for the whole region as the capital of Lithuania generates the main flows of cargo and passenger transport and remains one of the main Baltic transit points.

The main goal of this paper is to carry out research on evaluating air pollution generated by motorized vehicles and to foresee possible positive environmental effects of bypasses.

The paper presents a systemic analysis of previous scientific works, a description of the carried out research and comes to conclusions.

## 2. Theoretical Evaluation of Air Pollution Generated by Road Transport

The problems of traffic safety and air pollution in the European Union have been discussed for quite a long time,

however, the tactics and strategy of transport development has not yet received sufficient attention (Infrastructure Charging… 1998). Only recently, it has been recognized that transport infrastructure and vehicle modernization need immediate substantial investments. Theoretical research, involving modelling and analyzing various situations dependable on various factors (e.g. traffic safety or environment pollution) is essential for aiming at the optimal solution (Daganzo 1994; Daganzo 1995a–c; Seethaler 1999; Sommer *et al.* 1999) .

The evaluation of vehicle ride quality along a certain distance can be carried out using the multi-criteria method (Žvirblis 2005, 2007; Žvirblis, Zinkevičiūtė 2008) and is made considering the following factors:

– weather conditions;
– traffic conditions;
– infrastructure conditions;
– vehicle technical conditions;
– driving quality and driver satisfaction.

Every factor consists of multiple elements. For instance, weather conditions include temperature, time of day, precipitation, wind, cloudiness.

These factors have a different level of significance on the general quality of riding on the road. The elements of the above introduced factors also have a different level of significance.

The significance of different factors is expressed by a general format of the vector:

$$\{M^{(K)}\}=\begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}\begin{bmatrix} \{M_1\} \\ \{M_2\} \\ \dots \\ \{M_n\} \end{bmatrix}, \quad (1)$$

where: $a_{11}$, $a_{12}$, ..., $a_{nn}$ – the parameters of element significance affecting meteorological conditions for elements – vectors $\{M_1\}$, $\{M_2\}$, ..., $\{M_n\}$ in calculating factor significance of meteorological conditions – vector $\{M^{(K)}\}$;

$$\{E^{(K)}\}=\begin{bmatrix} b_{11} & b_{12} & \dots & b_{1n} \\ b_{21} & b_{22} & \dots & b_{2n} \\ \dots & \dots & \dots & \dots \\ b_{n1} & b_{n2} & \dots & b_{nn} \end{bmatrix}\begin{bmatrix} \{E_1\} \\ \{E_2\} \\ \dots \\ \{E_n\} \end{bmatrix}, \quad (2)$$

where: $b_{11}$, $b_{12}$, ..., $b_{nn}$ – the parameters of element significance affecting traffic conditions for elements – vectors $\{E_1\}$, $\{E_2\}$, ..., $\{E_n\}$ in calculating factor significance of traffic conditions – vector $\{E^{(K)}\}$;

$$\{I^{(K)}\}=\begin{bmatrix} c_{11} & c_{12} & \dots & c_{1n} \\ c_{21} & c_{22} & \dots & c_{2n} \\ \dots & \dots & \dots & \dots \\ c_{n1} & c_{n2} & \dots & c_{nn} \end{bmatrix}\begin{bmatrix} \{I_1\} \\ \{I_2\} \\ \dots \\ \{I_n\} \end{bmatrix}, \quad (3)$$

where: $c_{11}$, $c_{12}$, ..., $c_{nn}$ – the parameters of element significance affecting infrastructure conditions for elements – vectors $\{I_1\}$, $\{I_2\}$, ..., $\{I_n\}$ in calculating factor significance of infrastructure conditions – vector $\{I^{(K)}\}$;

$$\{T^{(K)}\}=\begin{bmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & d_{2n} \\ \dots & \dots & \dots & \dots \\ d_{n1} & d_{n2} & \dots & d_{nn} \end{bmatrix}\begin{bmatrix} \{T_1\} \\ \{T_2\} \\ \dots \\ \{T_n\} \end{bmatrix}, \quad (4)$$

where: $d_{11}$, $d_{12}$, ..., $d_{nn}$ – the parameters of element significance affecting technical conditions for vehicle elements – vectors $\{T_1\}$, $\{T_2\}$, ..., $\{T_n\}$ in calculating factor significance of technical vehicle conditions – vector $\{T^{(K)}\}$;

$$\{Q^{(K)}\}=\begin{bmatrix} f_{11} & f_{12} & \dots & f_{1n} \\ f_{21} & f_{22} & \dots & f_{2n} \\ \dots & \dots & \dots & \dots \\ f_{n1} & f_{n2} & \dots & f_{nn} \end{bmatrix}\begin{bmatrix} \{Q_1\} \\ \{Q_2\} \\ \dots \\ \{Q_n\} \end{bmatrix}, \quad (5)$$

where: $f_{11}$, $f_{12}$, ..., $f_{nn}$ – the parameters of element significance affecting the elements of driving quality and the factor of driver's satisfaction level – vectors $\{Q_1\}$, $\{Q_2\}$, ..., $\{Q_n\}$ in calculating factor significance of driving quality and driver's satisfaction – vector $\left\{Q^{(K)}\right\}$.

The general quality of driving on the road described as a complex factor consisting of multiple elements can be assessed according to the following model:

$$\{K\}=\begin{bmatrix} k_{m1} & k_{m2} & \dots & k_{mn} \\ k_{e1} & k_{e2} & \dots & k_{en} \\ k_{i1} & k_{i2} & \dots & k_{in} \\ k_{t1} & k_{t2} & \dots & k_{tn} \\ k_{q1} & k_{q2} & \dots & k_{qn} \end{bmatrix}\begin{bmatrix} \{M\} \\ \{E\} \\ \{I\} \\ \{T\} \\ \{Q\} \end{bmatrix}, \quad (6)$$

where: $k_{m1}$, $k_{e1}$, …, $k_{qn}$ – the parameters of element significance affecting certain elements – vectors $\{M\}$, $\{E\}$, $\{I\}$, $\{T\}$, $\{Q\}$ in calculating the factor of general driving quality – vector $\{K\}$.

The results of this part of the study show that all above-listed factors have a direct impact on a decrease in air pollution.

### 3. Prediction of Probable Benefits of Bypasses

A bypass, as a means of environment protection and improvement on driving quality, was chosen due to the importance of ecological aspects. Research data (Cuena *et al.* 1995; Diakaki *et al.* 2000) illustrate that the benefits of a bypass are obvious only when driving at a certain speed: higher speed reduces travelling time. Higher vehicle speed also reduces air pollution with exhaust fumes and the noise generated by a moving vehicle (Baumol, Oates 1988).

Let us consider the benefits of a bypass using marginal conditions: the bypass is 1/2 of the length of the perimeter of a circle while the length of a direct route equals to twice the perimeter of the same circle. The task is to measure the speeds that would bring us from point A to point C at the same time (Fig. 1).

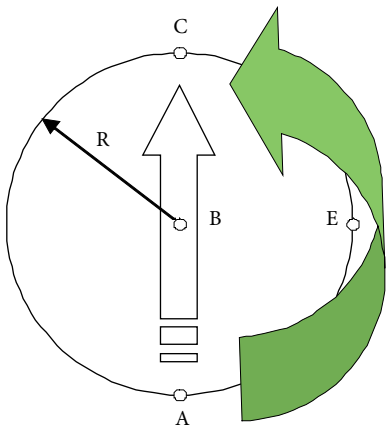


**Fig. 1.** An abstract scheme of bypass length

A bypass has benefits only when it takes less time to travel from point *A* to point *C*. The distance *AC* when travelling through the centre of the circle (point *B*) is:

$$AC^B = 2R. \tag{7}$$

The distance *AC* when travelling through point *E* is equal to half of the perimeter of the circle and makes

$$S = 2\pi R. \tag{8}$$

The distance is:

$$AC^E = \pi R. \tag{9}$$

A comparison of the distances draws that

$$\delta = \frac{AC^E}{AC^B} = \frac{\pi R}{2R} \approx 1.57. \tag{10}$$

The obtained results show that travelling from point *A* to point *C* through point *E* increases the distance by 1.57 times. This leads to a conclusion that to drive a vehicle from point *A* to point *C* (using a direct route and bypass), the travel speed through the bypass needs to be 1.57 times higher to reach point *C* at the same time. The ratio of speeds is presented in Fig. 2.

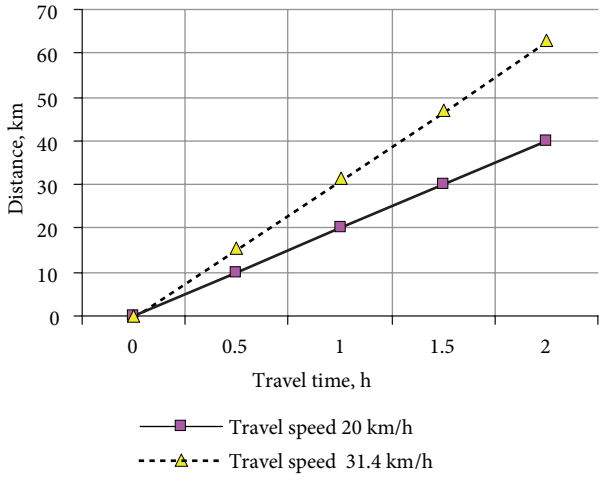


**Fig. 2.** Time and distance dependence (original)

A definition of the emission of exhaust fumes (the method of carbon monoxide measurement is the longest-used method for defining the emission of exhaust fumes) is based on the theoretical emission curve presented in Fig. 3.

Let us compare the emissions of exhaust fumes when taking a direct route in traffic jams at an average speed of 20 km/h with taking the bypass at an average speed of 40 km/h.

Using ECE 15-04 petrol would emit 17 g/km of fumes at a speed of 20 km/h or 8 g/km at a speed of 40 km/h (Fig. 3). Based on the abstract scheme (Fig. 1), taking the bypass would increase the distance by 1.57 times.

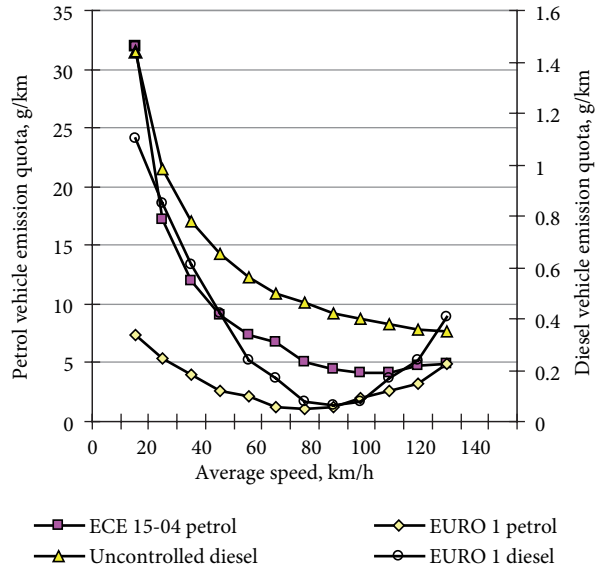


**Fig. 3.** The theoretical vehicle emission curve

Further data processing shows that taking a bypass would reduce the emissions of carbon monoxide by 35%.

If EURO1 petrol were used for the same conditions, the results would be 5 g/km for the direct route and 2.5 g/km for the bypass. That means 27% less of carbon monoxide when taking the bypass.

Diesel is a popular fuel among cargo and passenger transport companies. Let us analyze the emissions of carbon monoxide based on this fuel type.

Uncontrolled diesel: 22 g/km emission at an average speed of 20 km/h and 49 g/h emission at an average speed of 40 km/h.

Further data processing shows that the emissions are the same. The numbers would be reduced if the average speed was higher – 40 km/h.

EURO1 diesel: 19 g/km emissions at an average speed of 20 km/h and 9 g/km at an average speed of 40 km/h. The results show that taking a bypass would reduce the emission of carbon monoxide by 34.4%.

To sum up, taking the bypass at an average speed of 40 km/h instead of the direct route with an average speed of 20 km/h reduces the emission of carbon monoxide despite the fact that the distance is 1.57 times longer.

## 4. Summary of Research Results

Research on emissions was carried out to estimate the impact of bypasses on ecology. During this research, a vehicle was driven alongside Vilnius streets and newly built bypasses to measure the following entities:

– travel duration;
– travel distance;
– the number of traffic lights.

The carried out research included two stages. The obtained results are presented in Tables 1 and 2.

*Stage 1: Driving at the off-peak time.*

This stage took place from 11:00 p.m. to 12:00 a.m. Observations in the selected stretches were taken 3 times. A summary of the received results is presented in Table 1.

*Stage 2: Driving at the peak (rush hour) time.*

This stage took place from 7:00 a.m. to 8:30 a.m. Observations in the selected stretches were taken 3 times. A summary of the received results is presented in Table 2.

The modernization of a stretch of Pilaitė Avenue reduced travel distance from 3.7 km to 3.1 km. The number of traffic lights was reduced from 3 to 0 and speed limits were increased from 50 km/h to 70 km/h. Off-peak driving time was reduced from 5.47 min to 4.03 min. Driving at the peak time was reduced from 15.26 to 8.06 min. The average speed increased from 14.38 km/h to 45.92 km/h. This data leads to a conclusion that carbon monoxide emissions were reduced from 23 g/km to 8 g/km, which is 2.875 times less.

The modernization of a stretch of Laisvė Avenue under a multi-level interchange with Ukmergės street reduced travel distance from 1.4 km to 0.9 km. The number of traffic lights remained unchanged. Off-peak driving time was reduced from 2.51 min to 1.27 min. Driving at the peak time was reduced from 7.43 to 2.53 min. The average speed increased from 11.30 km/h to 37.24 km/h. This data leads to a conclusion that carbon monoxide

**Table 1.** Research data on off-peak time

| Stretch (before /after modernization) | | Travel time (min/s) | Average speed (km/h) | Distance (km) | No of traffic lights |
|---|---|---|---|---|---|
| Pilaitės pr. | after | 4:03 | 45.9 | 3.1 | 0 |
| | before | 5:47 | 38.4 | 3.7 | 3 |
| Laisvės pr. – Ukmergės g. | after | 1:27 | 37.2 | 0.9 | 2 |
| | before | 2:51 | 29.5 | 1.4 | 2 |
| Vilnius southern bypass | after | 3:58 | 52.9 | 3.5 | 0 |
| | before | 11:00 | 25.6 | 4.7 | 10 |
| Old-town southern bypass | after | 4:41 | 33.3 | 2.6 | 3 |
| | before | 7:01 | 23.9 | 2.8 | 4 |
| Geležinio Vilko g. viaduct | after | 2:40 | 56.0 | 2.5 | 0 |
| | before | 4:00 | 34.5 | 2.3 | 1 |
| Multi-level road near 'Spaudos rūmai' | after | 2:28 | 43.2 | 1.8 | 1 |
| | before | 3:56 | 29.2 | 1.9 | 3 |
| Ulonų str. | after | 0:42 | 42.8 | 0.5 | 1 |
| | before | 2:39 | 38.3 | 1.7 | 1 |

**Table 2.** Research data on peak time (rush hour)

| Stretch (before /after modernization) | | Travel time (min/s) | Average speed (km/h) | Distance (km) | No of traffic lights |
|---|---|---|---|---|---|
| Pilaitės pr. | 12.75 mm | 8:06 | 23.0 | 3.1 | 0 |
| | before | 15:26 | 14.4 | 3.7 | 3 |
| Laisvės pr. – Ukmergės g. | after | 2:53 | 18.7 | 0.9 | 2 |
| | before | 7:26 | 11.3 | 1.4 | 2 |
| Vilnius southern bypass | after | 3:58 | 52.9 | 3.5 | 0 |
| | before | 32:00 | 8.8 | 4.7 | 10 |
| Old-town southern bypass | after | 6:03 | 25.7 | 2.6 | 3 |
| | before | 15:20 | 10.9 | 2.8 | 4 |
| Geležinio vilko g. viaduct | after | 7:23 | 20.3 | 2.5 | 0 |
| | before | 13:52 | 9.9 | 2.3 | 1 |
| Multi-level road near 'Spaudos rūmai' | after | 3:04 | 37.2 | 1.8 | 1 |
| | before | 14:43 | 7.7 | 1.9 | 3 |
| Ulonų g. | after | 2:46 | 10.8 | 0.5 | 1 |
| | before | 7:03 | 14.6 | 1.7 | 1 |

emissions were reduced from 28 g/km to 10 g/km, which is 2.8 times less.

Vilnius Southern bypass reduced travel distance from 4.7 km to 3.5 km. The number of traffic lights was reduced from 10 to 0. Off-peak driving time was reduced from 11.00 min to 3.58 min. Driving at the peak time was reduced from 32.00 to 3.00 min. The average speed increased from 8.81 km/h to 52.94 km/h. This data leads to a conclusion that carbon monoxide emissions were reduced from 32 g/km to 7 g/km, which is 4.57 times less.

Vilnius Old-town southern bypass, a newly built road, reduced travel distance from 2.8 km to 2.6 km. The number of traffic lights was reduced from 4 to 3, speed limits were increased from 50 km/h to 60÷70 km/h. Off-peak driving time was reduced from 7.02 min to 4.41 min. Driving at the peak time was reduced from 15.33 to 6.05 min. The average speed increased from 10.95 km/h to 33.33 km/h. This data leads to a conclusion that carbon monoxide emissions were reduced from 30 g/km to 11 g/km, which is 2.7 times less.

Geležinio Vilko street interchange, a new road, reduced travel distance from 2.5 km to 2.3 km. The number of traffic lights was reduced from 1 to 0, speed limit was increased from 50 km/h to 60 km/h. Off-peak driving time was reduced from 4.00 min to 2.40 min. Driving at the peak time was reduced from 13.52 to 7.38 min. The average speed increased from 9.94 km/h to 56.00 km/h. This data leads to a conclusion that carbon monoxide emissions were reduced from 32 g/km to 7 g/km, which is 4.57 times less.

An interchange near 'Spaudos Rūmai', a new road, reduced travel distance from 1.9 km to 1.8 km. The number of traffic lights was reduced from 3 to 1, speed limits were increased from 50 km/h to 60 km/h. Off-peak driving time was reduced from 3.93 min to 2.47 min. Driving at the peak time was reduced from 14.72 to 3.07min. The average speed increased from 7.74 km/h to 43.20 km/h. This data leads to a conclusion that carbon monoxide emissions were reduced from 34 g/km to 8 g/km, which is 4.25 times less.

Ulonų street, a new road, reduced travel distance from 1.7 km to 0.5 km. Changes in speed limits gave the following results: off-peak driving time was reduced from 2.65 min to 0.7 min. Driving at the peak time was reduced from 7.05 to 2.77min. The average speed increased from 10.83 km/h to 42.85 km/h. This data leads to a conclusion that carbon monoxide emissions were reduced from 29 g/km to 9 g/km, which is 3.22 times less.

These results are based on theoretical carbon monoxide emissions. Real emissions depend on the factors described in the next chapter.

## 5. Relations between a Theoretical and Practical Evaluation of Air Pollution Generated by Vehicle Exhaust Fumes

Practical and theoretical (Fig. 3) data may differ due to specific actions taken by the driver. Some of them are listed in the recommendations for reducing vehicle emitted exhaust fumes and fuel saving published by JAMA (Japan Automobile Manufacturers Association):

- Stopping the car gradually and avoiding aggressive braking (speed reduction of 20 km/h in 5 seconds) leads to 11% improved fuel economy.
- Keeping the speed of a vehicle as constant as possible. Sudden speed changes lead to lower economy: in the city – 2%, on the highway – 6%.
- The maximal usage of braking with the engine leads to 2% improved fuel economy.
- Using air-conditioning decreases fuel economy by 12%, so it should be used only when necessary.
- Stopping the engine of a vehicle immediately after arriving at destination. A running engine set in neutral gear with the air-conditioning turned off uses 100 grams of fuel every 10 minutes.
- No heating of the engine of the vehicle before driving. Slowly beginning is enough.
- Planning the route in advance and marking it on a map or satellite navigation is essential due to the fact that 10 minutes of useless driving in an hour's journey decreases the fuel economy by 14%.
- Checking tire-pressure is important. Insufficient pressure leads to a decrease in fuel economy: in the city 2%, on the highway 4%.
- Avoiding unnecessary cargo. Every 100 kg of cargo decreases fuel economy by 3%.
- Respecting car parking rules. Parking in prohibited places may lead to traffic jams. Therefore, speed reduction from 40 km/h to 20 km/h may lead to the reduction of fuel economy by 30%.

## 6. Conclusions

1. The factors of ride quality on the roads are presented. The significance of these factors is presented in a general theoretical format of the vector.
2. The results of the conducted research on the probable benefits of bypasses showed that:
   - the average speed on a bypass should be 1.57 times higher than taking the direct route in order to avoid the loss of travel time,
   - vehicles, running on any kind of fuel, emit up to 35% less of carbon monoxide on a 1.57 times longer bypass driving at 40 km/h than taking the direct route at 20 km/h.
3. Research data on the impact of Vilnius high-speed streets (throughways) and bypasses on environment pollution underline the following results:
   - bypasses and high-speed streets generate less noise due to the increased speed of vehicles;
   - setting up bypasses and high-speed streets leads to the reduction of carbon monoxide from 2.7 to 4.57 times;
   - during off-peak time, driving speed on bypasses and high-speed streets increases up to six times. At the peak time, it is increased up to three times;
   - setting up bypasses and high-speed streets reduces traffic jams as well as travelling time (the latter is reduced up to eight times at the peak time and up to three times at the off-peak time);

- the benefits of bypasses and high-speed streets is up to 2.6 times higher at the peak time than those at the off-peak time in terms of caused pollution, travel speed and travel time.

4. Recommendations for drivers on the reduction of the emission of exhaust fumes and improvement in fuel economy are presented.

## References


Alessandri, A.; Di Febbraro, A.; Ferrara, A.; Punta, E. 1998. Optimal control of freeways via speed signalling and ramp metering, *Control Engineering Practice* 6(6): 771–780. doi:10.1016/S0967-0661(98)00083-5

Al-Mofleh, A.; Taib, S.; Salah, W. A. 2010. Malaysian energy demand and emissions from the transportation sector, *Transport* 25(4): 448–453. doi:10.3846/transport.2010.55

Antov, D.; Abel, K.; Sürje, P.; Rõuk, H.; Rõivas, T. 2009. Speed reduction effects of urban roundabouts, *The Baltic Journal of Road and Bridge Engineering* 4(1): 22–26. doi:10.3846/1822-427X.2009.4.22-26

Baltrėnas, P.; Kazlauskienė, A. 2009. Sustainable ecological development reducing negative effects of road maintenance salts, *Technological and Economic Development of Economy* 15(1): 178–188. doi:10.3846/1392-8619.2009.15.178-188

Baltrėnas, P.; Morkūnienė, J; Vaitiekūnas, P. 2008. Mathematical simulation of solid particle dispersion in the air of Vilnius city, *Journal of Environmental Engineering and Landscape Management* 16(1): 15–22. doi:10.3846/1648-6897.2008.16.15-22

Barlovic, R.; Santen, L.; Schadschneider, A.; Schreckenberg, M. 1998. Metastable states in cellular automata for traffic flow, *The European Physical Journal B – Condensed Matter and Complex Systems* 5(3): 793–800. doi:10.1007/s100510050504

Baumol, W. J.; Oates, W. E. 1988. *The Theory of Environmental Policy*. 2nd edition. Cambridge University Press. 312 p.

Beljatynskij, A.; Kuzhel, N.; Prentkovskis, O.; Bakulich, O.; Klimenko, I. 2009. The criteria describing the need for highway reconstruction based on the theory of traffic flows and repay time, *Transport* 24(4): 308–317. doi:10.3846/1648-4142.2009.24.308-317

Bellemans, T.; De Schutter, B.; De Moor, B. 2002. Model predictive control with repeated model fitting for ramp metering, in *Proceedings of the IEEE 5th International Conference on Intelligent Transportation Systems*, 3–6 September 2002, Singapore, 236–241.

Breton, P.; Hegyi, A.; De Schutter, B.; Hellendoorn, H. 2002. Shock wave elimination/ reduction by optimal coordination of variable speed limits, in *Proceedings of the IEEE 5th International Conference on Intelligent Transportation Systems*, 3–6 September 2002, Singapore, 225–230.

Cassidy, M. J.; Bertini, R. L. 1999. Some traffic features at freeway bottlenecks, *Transportation Research Part B: Methodological* 33(1): 25–42. doi:10.1016/S0191-2615(98)00023-X

Chien, C.-C.; Zhang, Y.; Ioannou, P. A. 1997. Traffic density control for automated highway systems, *Automatica* 33(7): 1273–1285. doi:10.1016/S0005-1098(97)00050-2

Cremer, M. 1995. On the calculation of individual travel times by macroscopic models, in *1995 Vehicle Navigation & Information Systems Conference Proceedings – 6th International VNIS/Pacific Rim TRANSTECH Conference – A Ride into the Future*, 30 July – 2 August 1995, Seattle, USA, 187–193.

Cuena, J.; Hernández, J.; Molina, M. 1995. Knowledge-based models for adaptive traffic management systems, *Transportation Research Part C: Emerging Technologies* 3(5): 311–337. doi:10.1016/0968-090X(95)00013-9

Čygas, D.; Jasiūnienė, V.; Bartkevičius, M. 2009. Assessment of special plans ant technical designs with regard to traffic safety, *Journal of Civil Engineering and Management* 15(4): 411–418. doi:10.3846/1392-3730.2009.15.411-418

Daganzo, C. F. 1994. The cell transmission model: A dynamic representation of highway traffic consistent with the hydrodynamic theory, *Transportation Research Part B: Methodological* 28(4): 269–287. doi:10.1016/0191-2615(94)90002-7

Daganzo, C. F. 1995a. A finite difference approximation of the kinematic wave model of traffic flow, *Transportation Research Part B: Methodological* 29(4): 261–276. doi:10.1016/0191-2615(95)00004-W

Daganzo, C. F. 1995b. Requiem for second-order fluid approximations of traffic flow, *Transportation Research Part B: Methodological* 29(4): 277–286. doi:10.1016/0191-2615(95)00007-Z

Daganzo, C. F. 1995c. The cell transmission model, part II: Network traffic, *Transportation Research Part B: Methodological* 29(2): 79–93. doi:10.1016/0191-2615(94)00022-R

Di Febbraro, A.; Parisini, T.; Sacone, S.; Zoppoli, R. 2001. Neural approximations for feedback optimal control of freeway systems, *IEEE Transactions on Vehicular Technology* 50(1): 302–313. doi:10.1109/25.917952

Diakaki, C.; Papageorgiou, M.; McLean, T. 2000. Integrated traffic-responsive urban corridor control strategy in Glasgow, Scotland: application and evaluation, *Transportation Research Record* 1727: 101–111. doi:10.3141/1727-13

Ho, F.-S.; Ioannou, P. 1996. Traffic flow modeling and control using artificial neural networks, *IEEE Control Systems Magazine* 16(5): 16–26. doi:10.1109/37.537205

Hoogendoorn, S. P.; Bovy, P. H. L. 1998. Modeling multiple user-class traffic, *Transportation Research Record* 1644: 57–69. doi:10.3141/1644-07

*Infrastructure Charging: A Stepwise Concept for a Harmonised Approach in the EU*. 1998. EU-Commission. Brussels. COM (1998) 466.

Jakimavičius, M.; Burinskienė, M. 2009. Assessment of Vilnius city development scenarios based on transport system modelling and multicriteria analysis, *Journal of Civil Engineering and Management* 15(4): 361–368. doi:10.3846/1392-3730.2009.15.361-368

Jakimavičius, M.; Burinskienė, M. 2010. Route planning methodology of an advanced traveller information system in Vilnius city, *Transport* 25(2): 171–177. doi:10.3846/transport.2010.21

Junevičius, R.; Bogdevičius, M. 2007. Determination of traffic flow parameters in different traffic flow interaction cases, *Transport* 22(3): 236–239.

Junevičius, R.; Bogdevičius, M. 2009. Mathematical modelling of network traffic flow, *Transport* 24(4): 333–338. doi:10.3846/1648-4142.2009.24.333-338

Kapski, D.; Leonovich, I.; Ratkevičiūtė, K.; Miškinis, D. 2008. Implementation of experimental research in road traffic: theory and practice, *The Baltic Journal of Road and Bridge Engineering* 3(2): 101–108. doi:10.3846/1822-427X.2008.3.101-108

Kinderytė-Poškienė, J.; Sokolovskij, E. 2008. Traffic control elements influence on accidents, mobility and the environment, *Transport* 23(1): 55–58. doi:10.3846/1648-4142.2008.23.55-58

Laurinavičius, A.; Miškinis, D.; Vaiškūnaitė, R.; Laurinavičius, A. 2010. Analysis and evaluation of the effect of studded

tyres on road pavement and environment (III), *The Baltic Journal of Road and Bridge Engineering* 5(3): 169–176. doi:10.3846/bjrbe.2010.24

Leipus, L.; Butkus, D.; Januševičius, T. 2010. Research on motor transport produced noise on gravel and asphalt roads, *The Baltic Journal of Road and Bridge Engineering* 5(3): 125–131. doi:10.3846/bjrbe.2010.18

May, A. D.; Milne, D. S. 2000. Effects of alternative road pricing systems on network performance, *Transportation Research Part A: Policy and Practice* 34(6): 407–436. doi:10.1016/S0965-8564(99)00015-4

Pečeliūnas, R.; Prentkovskis, O. 2006. Influence of shock-absorber parameters on vehicle vibrations during braking, *Solid State Phenomena* 113: 235–240. doi:10.4028/www.scientific.net/SSP.113.235

Pellegrino, O. 2009. An analysis of the effect of roadway design on driver's workload, *The Baltic Journal of Road and Bridge Engineering* 4(2): 45–53. doi:10.3846/1822-427X.2009.4.45-53

*Quality Indicators for Transport Systems: QUITS*. 1998. European Commission, ISIS (Organization). 100 p.

Seethaler, R. 1999. *Health Costs due to Road Traffic-Related Air Pollution: An Impact Assessment Project of Austria, France and Switzerland: Synthesis Report*. Prepared for the WHO Ministerial Conference on Environment and Health, London June 1999. 86 p. Available from Internet: <http://www.airimpacts.org/documents/local/traffic_health_cost.pdf>.

Sokolovskij, E.; Prentkovskis, O.; Pečeliūnas, R.; Kinderytė-Poškienė, J. 2007. Investigation of automobile wheel impact on the road border, *The Baltic Journal of Road and Bridge Engineering* 2(3): 119–123.

Sommer, H.; Seethaler, R.; Chanel, O.; Herry, M.; Masson, S.; Vergnaud, J.-S. 1999. *Health Costs due to Road Traffic-Related Air Pollution: An Impact Assessment Project of Austria, France and Switzerland: Economic Evaluation, Technical Report on Economy*. Prepared for the WHO Ministerial Conference on Environment and Health, London June 1999. 114 p. Available from Internet: <http://www.ecoplan.ch/download/ges2_ber_en.pdf>.

Van Zuylen, H. J.; Weber, K. M. 2002. Strategies for European innovation policy in the transport field, *Technological Forecasting and Social Change* 69(9): 929–951. doi:10.1016/S0040-1625(02)00191-9

Van Zuylen, H. J. 2002. The assessment of economic benefits of dynamic traffic management, in *Proceedings of the European Transport Conference*, 9–11 September 2002, Cambridge, United Kingdom. 21 p. Available from Internet: <http://www.etcproceedings.org/paper/download/558>.

Vansauskas, V.; Bogdevičius, M. 2009. Investigation into the stability of driving an automobile on the road pavement with ruts, *Transport* 24(2): 170–179. doi:10.3846/1648-4142.2009.24.170-179

Zhang, H. M. 2000. Structural properties of solutions arising from a nonequilibrium traffic flow theory, *Transportation Research Part B: Methodological* 34(7): 583–603. doi:10.1016/S0191-2615(99)00041-7

Žvirblis, A. 2005. *Rinkovados analizės principai ir metodologija* [The principles and methodology of marketing analysis. Monograph]. Vilnius: Ciklonas. 208 p. (in Lithuanian).

Žvirblis, A. 2007. Verslo makroaplinkos komponentų ir veiksnių kompleksinis vertinimas [Complex evaluation of business macro environment components and factors], *Ekonomika* (80): 103–116 (in Lithuanian).

Žvirblis, A.; Zinkevičiūtė, V. 2008. The integrated evaluation of the macro environment of companies providing transport services, *Transport* 23(3): 266–272. doi:10.3846/1648-4142.2008.23.266-272