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UNIFIED METHODOLOGY FOR ESTIMATING EFFICIENCY OF TRAFFIC CALMING MEASURES – EXAMPLE OF ESTONIA

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Abstract. Traffic calming is an integral part of contemporary traffic planning and traffic management being used for fulfilling different tasks such as reducing vehicle speed and traffic volume, and in final terms reducing number of accidents. Traffic calming measures are notstandardized internationally and have significant differences in geometric shape and layout in different countries, as well as in Estonia. At the same time impacts of different calming measures are unstudied well, and often the surveys are incomparable to each other. There are also no certain recommendation which measures should be implemented under different conditions. One of the reasons for that is lack of tested methodology for estimating the effectiveness of calming measures. This paper describes research that aimed at developing such a methodology and conducting a pilot study to test it. Effectiveness of traffic calming measures is estimated from the perspectives of vehicle speed and public acceptance. The new methodology assumes conducting an experiment. It allows comparing efficiency of two or more measures of the same type. The pilot study was conducted in Tallinn with a sample of 30 drivers. Results of this study proved that the new methodology is suitable for estimating effectiveness of traffic calming measures.

Keywords: efficiency, Estonia, Global Navigation Satellite System, methodology, traffic calming, traffic calming measures, traffic safety, traffic study.

1. Introduction

During the last decade different traffic calming measures (TCM) have been implemented in Estonian cities and built-up areas. Today there are plenty of different measures being introduced, however it is unknown which of them are more efficient. Respective studies are complicated due to significant differences in geometrical characteristics and layout of TCM of the same type. It means that the same TCM implemented in similar conditions potentially have different impact and efficiency. As a result, estimated efficiency is applicable only to the exact TCM studied. For the same reason results of surveys held abroad could not be applicable to Estonian conditions or the impacts might be different from the originals. Authors of this paper set a goal to develop and to test methodology for estimating efficiency of TCM, which could be used as a unified methodology for respective studies in Estonia. This could be taken as a first step to understand efficiency of TCM of different shape, size and layout, standardizing TCM and drawing recommendations to use the most effective TCM under certain conditions. Respective interest groups are local authorities and traffic management specialists.

2. Literature analysis

The Institute of Transportation Engineers (USA) in *Guide for Achieving Flexibility in Highway Design* defines traffic calming as the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behaviour and improve conditions for non-motorized street users. According to Estonian standard *EVS 843:2003 Town Streets* traffic calming assumes that drivers should feel themselves being in an area where safe speed limit is 50 km/h and where is a higher probability to meet a pedestrian. Sometimes it is said that traffic calming measures are used to replace enforcement. They place physical rather than legal restrictions on the actions of citizens and can be argued to provide a more socially equitable and efficient solution than regulation (Garrod *et al.* 2002).

There are various types of TCM depending on their character. For instance, there are distinguished vertical and horizontal TCM. Vertical TCM include any measure that alters the vertical profile of the carriageway such as road humps and speed cushions. Horizontal TCM include measures that alter the horizontal alignment of the carriageway such as mini-roundabouts, build outs and chicanes (Mountain *et al.* 2005).

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How can one understand TCM efficiency? Literature analysis shows that there is no widespread or commonly accepted definition of TCM efficiency. However, many sources connect efficiency to the goals of the traffic calming project. For instance, Corkle *et al.* (2002) state that to estimate efficiency of traffic calming measures one should set exact and measurable goals and base oneself on the fact whether these goals have been achieved or not.

There are many efficiency parameters being used in studies aimed at estimating TCM impacts. Among the different speed-related parameters known in the literature, mean speed is very often used as measure for safe driving, mainly because elevated crash risk and severity have been related to an increase in mean speed (Ariën *et al.* 2013). Other speed related efficiency parameters are 85th percentile speed, standard deviation of longitudinal acceleration and deceleration, percentage of drivers exceeding the speed limit, the highest speeds, 10 mph pace (Ariën *et al.* 2013, 2014; Corkle *et al.* 2002; Mountain *et al.* 2005). Among other commonly used TCM efficiency parameters are reduction of traffic volume, change in the number of fatal and injury accidents, traffic noise level, vehicle emission and public health impact (Čygaitė *et al.* 2014; Huang, Cynecki 2001; Lee *et al.* 2013). Some authors measure TCM efficiency as a delay per TCM during emergency transport (Berthod 2011), or delay time for crossing the road (Garrod *et al.* 2002), cost of traffic calming project and maintenance costs (Garrod *et al.* 2002, Langdon 2003). Other authors estimate such effeciency parameters as private expenditures in fuel and vehicle maintenance (Jazcilevich *et al.* 2015), impact on public transport (Banister 2009) and cyclists (Pinkerton *et al.* 2013). Literature analysis shows that public acceptance has become an important TCM efficiency component (Čygaitė *et al.* 2014; El-Basyouny, El-Bassiouni 2013; Garrod *et al.* 2002). Nevertheless the most common efficiency parameters of TCM are connected to speed, traffic volume and number of accidents.

Analysis shows that the most common method used to determine efficiency of TCM is a before-and-after study. It assumes that a road is divided into road sections each of them having a TCM implemented on it. Selected efficiency parameters are measured on each road section before implementing TCM and after that. Afterwards these parameters for each road sections are compared to each other and respective conclusions are made. However, despite its popularity, a before-and-after study can give misleading conclusions. It happens because of lack in control for regression-to-the-mean (or long-term trends in accident occurrence) or because of ignoring the presence of potentially important confounding factors such as change in traffic volume and modifications in land use (Granà *et al.* 2010).

Among the other common TCM efficiency research methods are interviews, microscopic traffic simulation as well as comparison analysis. Another research method is the meta-analysis method. It assumes collecting and examining data from different studies on a specific theme in order to identify the common effect of a treatment, when this is consistent from one study to the next. On the contrary, the meta-analysis can be applied to explain the variation when the effect size is a little bit different in all the studies (Granà *et al.* 2010).

TCM efficiency study methods assume acquisition of different efficiency parameters. Some of them can be gathered from databases, for instance the statistic of accidents, while other parameters such traffic volume and vehicle speed should be measured by researchers. In respect of the latter parameter, it is recommended to hide the presence of the data acquisition devices and to avoid possible alterations of natural behaviour of drivers (i.e. reductions of speed), which often occur when devices (such as pneumatic tubes or radar placed on a tripod, etc.) are clearly visible at the side of the street or on it (Pau, Angius 2001). In this context a good option is using GPS trackers placed in the car, but it assumes working conducting experiments with focus groups.

To sum up, according to literature the main goals of traffic calming can be set as improvement of safety of street users and reduction of negative effects of motor vehicles. There is unclear definition of traffic calming efficiency. The latter is mostly measured by means of parameters connected to speeds, traffic volumes and number of accidents. The most widespread method of measuring traffic calming efficiency is before-and-after study, but it sometimes give untruthful results. Other common TCM efficiency research methods are interviews, microscopic traffic simulation and comparison analysis.

3. The new methodology for studies in Estonia

Authors of this paper set a goal to develop and to test a unified methodology that would be suitable for estimating efficiency of TCM implemented in Estonia. Under the term efficiency authors understand practical value of the implemented TCM, i.e. whether they perform their task (for example, reduce speed to desired limit) or not. It should be noted that the goal of researchers was to introduce methodology for studying isolated TCM, not their combinations or traffic calming schemes.

In Estonia TCM are unstandardized. For instance, a speed hump can consist of thermoplastic as well as of asphalt concrete. It can have a height of 10 cm up to 20 cm. It can be marked with white pavement marking, special road posts or road signs, or it can be unmarket at all. Thus it is obvious that even the TCM of the same type have different impact. The new methodology allows comparing efficiency of two or more TCM of the same type (for instance, a horizontal calming measure can be compared to another horizontal measure and a vertical measure can be compared to another vertical measure). At the same time, methodology allows comparing efficiency of two or more TCM of the same type, but with various design parameters (for instance, can be compared to speed hump with a height of 10 cm and speed hump with a height of 20 cm).

In their work authors based on international practice, particularities of traffic management in Estonia and availability of data. These facts were also considered when choosing TCM efficiency parameters. Further the developed methodology is described in detail, starting with efficiency parameters to be measured, proceeding with description of the study method and finishing with the pilot study held in Tallinn to test the methodology.

3.1. Efficiency parameters

Efficiency parameters have been chosen based on results of literature analysis as well as on availability of data. Analysis has shown that the most common TCM efficiency parameters are connected to vehicle speed, traffic volume and accident. Another important parameter is public acceptance. However, incomplete data is available for researchers. For instance, in Estonia there is unreliable traffic incident data for calmed roads. At the same time some parameters such as traffic calming impact on traffic volume can be adequately measured only by means of before-and-after studies. Unfortunately, such studies are untaken in Estonia and as a result there is no "before" data for existing TCM. Unlike the other parameters, researchers can successfully estimate drivers' speed behaviour and public acceptance. The chosen efficiency parameters are described in deeper detail further on.

85th percentile location speed. When estimating drivers' speed behaviour, it makes sense to proceed from the fact that traffic calming aims at choosing safe speed. Safe speed is usually shown by respective traffic signs. Wherein, it is assumed that drivers choose safe speed inparticular when crossing a TCM, but on the whole calmed road section. Therefore, drivers' speed behaviour is estimated in different locations (points). These points have been selected on the basis of based pre-study experiments and are shown on Fig. 1. In Point 1 drivers are approaching the TCM; at this point they have not jet started reacting at it. Speed in Point 3 shows how quickly the first axle of the vehicle runs on the TCM. Speed in the Point 4 shows how quickly the rear axle of the vehicle drives down the obstacle. In Point 6 drives have finished interacting with the TCM. Speeds in Points 2 to 5 are transitional and are used for better understanding of drivers' speed behavior when crossing TCM. 85th percentile location speeds at the Points 1 and 6 are compared to the established speed limit on particular road section. The closer these speeds are to the speed limit, the more efficient TCM is considered to be. 85th percentile speed is chosen as an efficiency parameter, as it is inaffected by extremes and characterizes drivers' speed behaviour in the most objective way. Therefore, this speed parameter suits the set purposes the best.

Location speeds can be measured using contemporary GNSS (Global Navigation Satellite System) equipment. Contemporary GNSS devices work with frequency of 10–20 Hz and allow determining position of vehicle with high accuracy. For instance, *Vbox*-type equipment allows determining position of vehicle with accuracy of 10 cm and determining speed with accuracy of 0.01 km/h.

Change in mean location speed. When speaking about speed, there should be considered not only compliance with speed limit, but also such parameter as smoothness of traffic flow. Drivers should drive without reducing operating speed considerably in front of TCM, as it is connected to increased risk of rear-end collision, difficulties for emergency vehicles as well as excess air pollution and noise level. Therefore, authors propose to estimate change in mean location speeds when running TCM. For these purpose mean speeds are calculated for Points 1–6 (Fig. 1). After that there is calculated change in mean location speeds in relation to mean speed in Points 1 (Fig. 2). The higher is percentage ratio of mean speed in Point 3 to mean speed in Point 1, the more efficient is the TCM. It means that drivers are unnecessary to decelerate operating speed considerably in front on the TCM. Mean speeds in Points 2, 4, 5 and 6 are used for better understanding of drivers' speed behavior when crossing TCM.

Mean speed is chosen here as an efficiency parameter, as it is more informative for the chosen locations than 85th percentile speed. Pre-study showed that extremes undeform results significantly, as the majority of drivers cross TCM with similar speed.

Public acceptance. Literature analysis has shown that along with other parameters public acceptance is also widely used for estimating efficiency of traffic calming. Under public acceptance authors understand attitude of road users towards the TCM. By its nature traffic calming is connected to certain limitations. Therefore, acceptance of a TCM assumes that people are aware of traffic calming goals and are ready to scarify their comfort to some extent

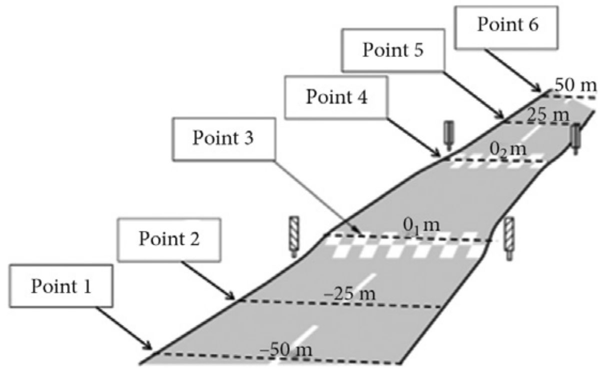

Fig. 1. Scheme of the speed measurement points

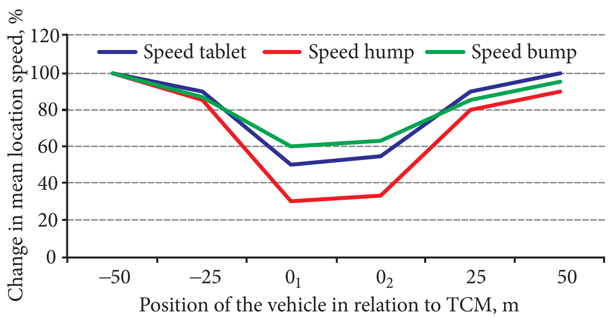

Fig. 2. Change in mean speed when running traffic calming measures (example)

to help these goals achieved. Estimating public acceptance seems to be logical as opinion of the actual road users (although it is very subjective) could be also considered along with the other more objective parameters. The authors propose to make a connection between efficiency of TCM and attitude of road users towards them – the better is public attitude, the more efficient the TCM is considered to be.

Public acceptance is estimated by means of survey with multiple choice questions. Respondents should assess their attitude towards TCMs on bases of five point scale (very poor, poor, fair, good, very good). For each TCM there is calculated the total number of voices for "good" and "very good" and respective rankings is made. The higher is place in this ranking, the more efficient the TCM is. In order to get reliable results, it is highly recommended to accompany questions with pictures of the TCM being studied. The easiest way to get reliable results is to conduct the survey among drivers who participate in the experiment. In such case for logical reasons survey should be conducted after the route is passed.

3.2. Test survey

The proposed method for estimating efficiency of traffic calming measures was tested in an experiment. The experiment was conducted with a sample of drivers, which gender and age structure corresponds to gender and age structure of all the Estonian drivers. The bigger is sample size, the more precise are the results of the experiment. Selected drivers pass a certain route, which has calmed road sections on it. Each section is being dealt with separately representing one TCM being situated on it. It is essential that drivers should not know the real aim of the experiment.

Table 1. Example of ranking efficiency of traffic calming measures

Traffic calming measure	85th percentile location speed	Change in mean speed	Public acceptance	Ranks in total
Speed bump	1	1	2	4
Speed hump	2	3	1	6
Speed tablet	3	2	3	8

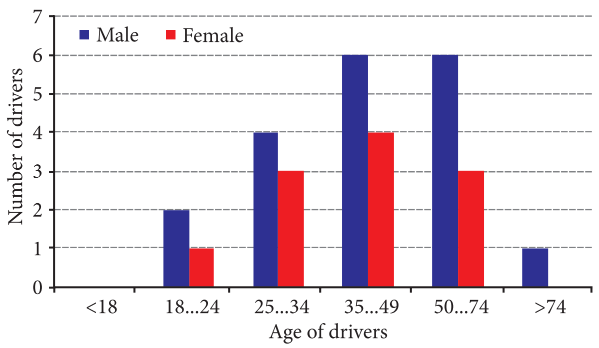

Fig. 3. Age and gender of the drivers who participated in the pilot study

Experiment is conducted in free-flow traffic conditions, i.e. no obstacles like slower moving vehicles or pedestrians crossing the road should influence choice of speed. Ideally, there should be no other vehicles on the route at all. In case of any conditions that affect purity of the experiment, respective data is ignored.

Efficiency of TCM is estimated on the bases of three parameters:

– 85^{th} percentile location speed,
– change in mean location speed,
– public acceptance.

The study method assumes that efficiency parameters are being collected on each road section. For each parameter the TCM are ranked according to their efficiency. If there are three TCM studied like its shown in Table 1, they are ranked by efficiency from 1 to 3 where "1" is the most efficient TCM and "3" is the least efficient TCM. If there are four TCM studied, there would be four ranks where "1" is the most efficient TCM and "4" is the least efficient TCM and so on.

Ranks are summarized. As "1" stays for the most efficient TCM, the TCM should get as less points in total as possible. In the example given in Table 1 the most efficient TCM would be the speed bump. However, one should take into consideration that ranks are given on an interval scale and, therefore, they do not show, but rather indicate the leaders. Sometimes these leaders should be thoroughly compared to reveal the most effective measure. If effectivness of two or more measures is practically the same, an additional efficiency parameter can be applied such as cost of implementing the TCM. It should be noted, that as TCM are unstandardized respective conclusions are applicable only to the TCM studied and to the TCM similar in size, shape and markings.

The experiment for testing the new methodology (pilot study) took place in Tallinn in March 2014 and lasted for one month. During a study there was formed a sample of 30 drivers whose age and gender are shown on Fig. 3. As it comes from the methodology the age and gender structure of the sample corresponds to the age and gender structure of all the Estonian drivers.

During the study TCM were grouped by types (number of studied TCMs in each group is given in brackets) – speed bumps (3), raised pedestrian crossings (3), junctions with priority-to-the-right rule (4) and raised junctions with priority-to-the-right rule (6). All the TCM of the same type have the same parameters and markings. As the TCMs were considered in groups, efficiency parameters for the TCM inside each group were averaged.

In order to exclude factors that could affect behaviour of drivers such as slower moving cars, test trips were held outside rash hours, mainly on the weekends. Speed limit on the calmed road sections studied was 30 km/h. All the drivers were driving one and the same car. They were told that the aim of the experiment is to estimate mean speeds of male and female drivers of different age in different road conditions, so they misunderstand the real aim of the experiment.

Table 2. Mean 85th percentile location speed, km/h

Traffic calming measures	–50 m	–25 m	0_1 m	0_2 m	25 m	50 m
Speed bumps	32.44	29.25	16.98	16.47	30.89	32.60
Raised pedestrian crossings	43.14	37.56	19.90	20.30	33.43	36.70
Junctions with priority-to-the-right rule	46.15	42.18	38.30	39.37	38.76	40.99
Raised junctions with priority-to-the-right rule	37.32	35.94	23.01	23.35	34.01	36.26

Table 3. Mean location speed, km/h

Traffic calming measures	–50 m	–25 m	0_1 m	0_2 m	25 m	50 m
Speed bumps	26.18	24.75	13.11	12.75	26.85	29.77
Raised pedestrian crossings	36.62	32.65	14.76	15.63	27.86	31.07
Junctions with priority-to-the-right rule	38.75	34.75	25.97	29.63	32.62	33.98
Raised junctions with priority-to-the-right rule	32.39	30.86	16.97	19.85	29.87	32.22

Table 4. Public acceptance

Traffic calming measure	Very good	Good	Fair	Poor	Very poor	Do not know
Speed bumps	1	7	12	7	2	1
Raised pedestrian crossings	3	12	12	0	1	2
Junctions with priority-to-the-right rule	1	6	7	8	6	2
Raised junctions with priority-to-the-right rule	2	15	12	2	1	1

Note: numbers correspond to the number of drivers who gave the respective estimations.

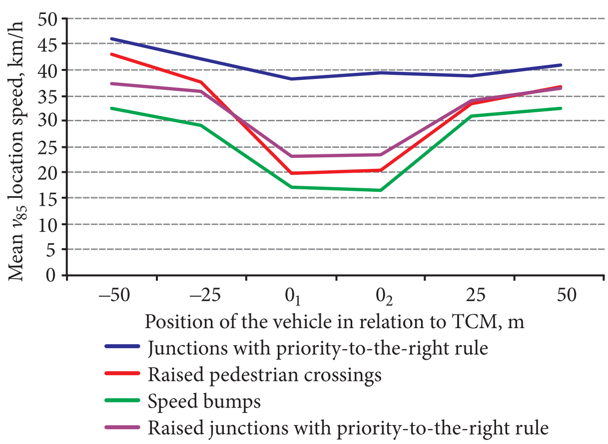

Fig. 4. Mean 85th percentile location speed (speed limit 30 km/h)

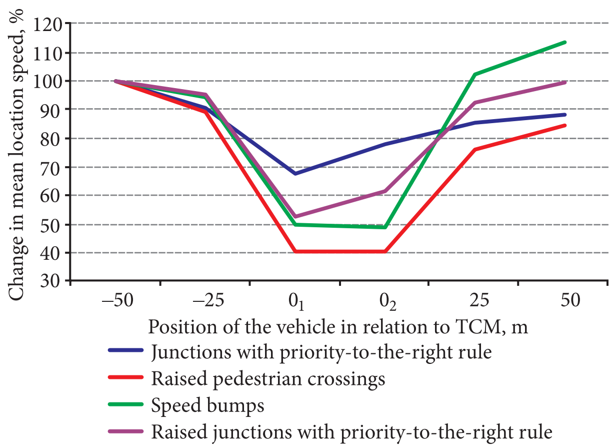

Fig. 5. Change in mean location speed in relation to location speed in Point 1

Speeds were measured by means of *Video Vbox* device. Public acceptance was estimated by means of survey held with all the drivers after each trip. Respective efficiency parameters for each TCM group are shown on Figs 4–6 and are summed up in Table 2.

Study results are given in Table 5. The best total rank that is possible to get is 3 and raised junction with priority-to-the-right rule has 4. Other TCM are far behind with ranks 7 to 9.

Raised junction with priority-to-the-right rule has the best total rank. However, as it was mentioned before, ranks are given on an interval scale and one cannot make single valued conclusions, but has to pay attention to other circumstances besides the total rank.

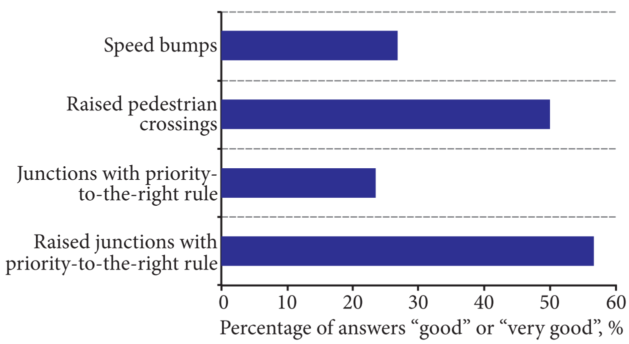

Fig. 6. Percentage of drivers who estimated their attitude towards the TCM as "good" or "very good"

Table 5. Results of the pilot study

Traffic calming measure	85^{th} percentile location speed	Change in mean speed	Public acceptance	Ranks in total
Speed bumps	1	3	3	7
Raised pedestrian crossings	3	4	2	9
Junctions with priority-to-the-right rule	4	2	4	8
Raised junctions with priority-to-the-right rule	2	1	1	4

The study revealed that using raised junction with priority-to-the-right rule and junction with priority-to-the-right rule is connected to traffic hazards. At such junctions drivers have to give way to vehicles approaching from the right. However, vertical visibility before these junctions is severely limited by buildings and fences, so drivers are able to see vehicles on the intersected road only entering the junction (if applied to Fig. 1 drivers start seeing vehicles approaching from the right in point 3). Such junctions are used to calm traffic, because it is assumed that drivers choose low speed when approaching them, otherwise they will not be able to give way. However, study showed that in Point 3 mean speed for junctions with priority-to-the-right rule is 25.97 km/h and mean speed for raised junctions with priority-to-the-right rule is 16.97 km/h. In the first case, stopping distance would be 12.3 m and for the second case, stopping distance would be 7.2 m. If driver enters a junction with such a speed and there is a vehicle approaching from the right, he will not have enough room to stop and will not be able to give way. It means that using junctions with priority-to-the-right rule is potentially connected to hazards.

So, taking into account conclusion made above, study results should be specified. Raised junction could be considered to be the most efficient TCM among the other TCMs studied, but it is recommended to step aside from priority-to-the-right rule and to use rather priority signs ("Main road" and "Give way") or make it a stop-controlled intersection with four-way stops (with "Stop" signs from each direction).

In conclusion, one can state that the pilot study gave trustful results and confirmed that the developed methodology is suitable for estimating TCM efficiency in contemporary Estonian conditions. Although the pilot study aimed at comparing types of TCM, the same method can be used for comparing TCM of the same type. Such a comparison makes sense, if TCM of the same type have different parameters and markings.

4. Conclusions

1. The aim of this study was to develop and to test a unified methodology, which could be used for estimation of efficiency of traffic calming measures in Estonia. Authors see the unified methodology as the first step to understanding efficiency of traffic calming measures of different shape, size and markings, standardizing traffic calming measures and drawing recommendations to using the most effective traffic calming measures under certain conditions.

2. The developed methodology assumes conducting an experiment. It suits for studying isolated traffic calming measures, not their combinations or traffic calming schemes. The experiment was conducted with a sample of drivers who pass a certain road section, which has traffic calming measure. Each road section is being dealt with separately representing one traffic calming measure being situated on it.

3. Effectiveness of traffic calming measures is estimated from the perspectives of vehicles speed and public acceptance. These parameters have been chosen based on results of literature analysis as well as on availability of data. Speeds are determined by means of Global Navigation Satellite System equipment such as *Video Vbox* device situated in the car. Speeds are measured in certain locations and are used to understand how traffic calming measures contribute to compliance with speed limits and to smoothness of traffic flow. The closer is a vehicle speed to the speed limit and the smoother is change in speeds when running a traffic calming measure, the more efficient it is considered to be. Public acceptance, i.e. road user's attitude towards the TCM, is estimated by means of survey held with all the drivers after each trip. The higher is rating of traffic calming measures, the more efficient it is considered to be.

4. The traffic calming measures being studied are ranked according to the efficiency parameters. Ranks indicate the "leaders" and researchers have to study the results of experiments thoroughly in order to make conclusions. These conclusions are valid only for the traffic calming measures studied and for traffic calming measures having the same shape and markings.

5. In order to test the new methodology, a pilot study with a sample of 30 drivers was conducted in Tallinn. The study gave trustful results and proved that the new methodology is suitable for estimating effectiveness of traffic calming measures in Estonia.

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