

CALCULATION PARAMETERS OF TOTAL TRANSPORT CONGESTION COSTS IN URBAN ROAD NETWORK

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Abstract. The extent of external transport congestion costs is described by the economic welfare theory as dead-weight loss, which results from ineffective use of transport infrastructure. Exact calculations are barely possible according to this theory and are thus often made by engineering methods, where instead of defining the extent of social welfare changes (as a consequence of modified equilibrium between transport supply and demand) functions are used which define costs of lost time and operational costs as: i) speed-flow relationships, ii) value of time, iii) other operational costs and iv) unit cost functions.

The implementation of this method in the interurban road network is successful and gives good results yet this is not the case when the method is implemented in the urban road network. The set of required data for the calculation (number of lines for each road segment, number of vehicles by category and time for each road segment, values of time by categories of transport, etc.) is unavailable in many cases for urban transport networks. This is the reason for implementing a modified engineering approach where the set of required data is reduced and supplemented by the set of parameters which lead to the same result. The article deals with the set of parameters and correction factors which supplement originally demanded data.

Keywords: traffic congestion, external costs of transport, external costs of traffic congestion, calculations of the external costs of traffic congestion.

1. Introduction

Modern society assures the highest level of mobility for people in history. The same fact is also true for economy. The price paid by modern society for these facts are negative influences caused by traffic. Some of them burden just transport users and others the society as a whole. Among the most common negative effects of transport we could list negative effects on people's health an environment (toxic gas emissions, greenhouse gas emissions, noise, ...), lower traffic safety and time losses. Besides these we should also consider effects which appear because of scarcity of space in cities, up- and downstream processes, etc. They all have common characteristics – they impose costs which must be paid by a user of a transport service (internal costs) or by society (external costs).

When external costs are not included in the price of transport service, the state gives wrong market signals. These consequently lead to lower transport system efficiency, which results in ever increasing traffic jams (congestion), problems in traffic safety and environmental problems. This is the reason why including external costs into a transport user decision process (internalization of

the transport external costs) became an important issue of transport policy in EU and other highly developed parts of the world. Internalization could be done by legislation or by market instruments (taxes, charges, ...). A prerequisite for this is a precisely known financial value of a particular kind of external transport costs.

One of the segments of the overall external transport costs is represented by congestion external costs which could be calculated by two different approaches – the economic and engineering approach. While the economic approach measures consequences of changed equilibrium between offer and supply, the engineering approach directly measures time losses in congestion and their value.

2. Traffic congestion

Traffic congestion appears when traffic load in a specific area reaches the capacity of infrastructure. It can be caused by numerous situations – simply as a result of excessive traffic loads or as a consequence of irregular events like traffic accidents, road works or weather conditions. It strongly depends on time and location, type of road network (urban/interurban), road category, time of

the day, day of the week and season (Cambridge Systematics 2005, European Commission 2007).

There are three typical kinds of traffic congestion (Brownfield *et al.* 2003):

- repetitious traffic congestion – regular users of road network are able to predict it (morning and afternoon traffic peaks, events which happen on the exact day of the week, ...);
- non-repetitious traffic congestion – congestion which appears unexpectedly and users cannot predict it (traffic accidents, vehicle breakdowns, road works, ...);
- condition just before the congestion – in free traffic flow disturbance appears which does not represent traffic congestion by itself but it can cause it.

Traffic congestion costs are composed of an internal and an external component. Internal (personal) traffic congestion costs appear when the load of transport system approaches its capacity. Users feel them as costs of lost time and enlarged operation costs. External traffic congestion costs are related to entrance of new users into a transport system and affect all users of this system. Because transport users usually do not take into account transport external costs for their decisions, these costs are the target of measures for transport costs internalization.

3. Total Transport Congestion Costs

The engineering approach to calculate total transport congestion costs is based on functions which define costs of lost time and operational costs. The basic ones are:

- speed-flow relationships;
- value of time;
- other operating costs and
- unit cost function.

The speed-flow relationship represents the basis for defining user costs functions. The shape of the speed-flow function leads to the function of social marginal costs. But we must be aware of two problems which arise at this point (Banfi *et al.* 2000, Maibach *et al.* 2008):

- transition from free traffic flow to traffic congestion is very sharp and results in an enormous increase of marginal social costs in a relatively small interval which represents the biggest traffic load. Because of this fact the estimation of costs becomes very sensitive;
- when traffic load exceeds road capacity, traffic starts to move at a low constant speed. The diagram shows that social marginal costs equal zero in such situation. In such cases this method is not applicable.

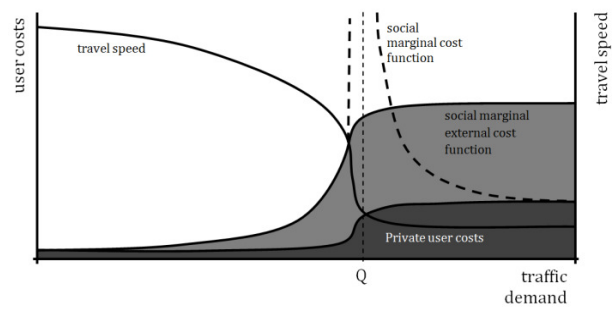


Fig 1. Example of speed-flow diagram

The value of time represents the most important component of user costs in traffic congestion. For exact calculation of time lost in traffic congestion the below parameters must be defined (Nash *et al.* 2000):

- structure of trips by purposes;
- structure of trips by transport means;
- load factor according to different purposes of trips and
- structure of traffic according to transport means choice.

Other operating costs are a considerable factor of total user costs. In freight traffic elements should be taken into account such as: driver salaries, capital costs of rolling stock, administrative costs and fuel costs. In road passenger transport enlarged fuel consumption is usually taken as another operating cost (Nash *et al.* 2000).

Combining the functions which describe the value of time and other operating costs with speed-flow functions, we can estimate costs of each transport unit in each part of transport network.

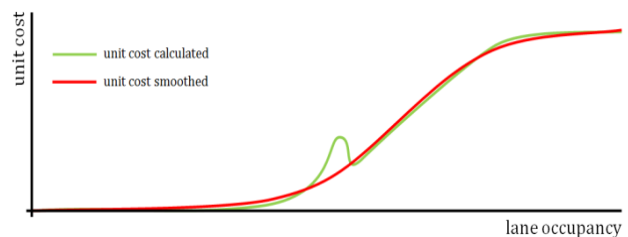


Fig 2. Unit costs by lane occupancy

Defining the unit cost function together with traffic loads (by transport means) and the value of time enables the calculation of total transport congestion costs per kilometer (or traffic lane or hour) for each road segment. The equation could be written as (Banfi *et al.* 2000):

$$S = \sum_I \sum_T \sum_M (VP_T \cdot Q_{I,T,M} \cdot EOVM \cdot SF(Q_{I,T,M} \cdot EOVM) \cdot VOT_{M,I} \cdot D) \quad (1)$$

where:

- S total annual congestion costs
- I index of road link

T	hour of day
M	transport mode
VPI	number of lanes on section I
$Q_{(I,T,M)}$	traffic volume of mode M on section I in hour T
EOV_M	passenger car units of mode M
$SF_{(Q,P)}$	unit costs per passenger car unit
$VOT_{(M,I)}$	value of time
D	days per year

4. Total transport congestion costs in urban road network

The basic equation of the engineering approach is only exceptionally directly applicable for the whole transport network. For the calculation, it requires a wide set of input data which is rarely accessible for bigger areas. It also does not take into account essential differences between congestion in urban and interurban networks. While its use for interurban road network does not represent problems, it must be slightly modified for the urban network (Lep *et al.* 2004).

Essential parameters for the calculation of total congestion costs in the urban road network are users' time lost in congestion and its value. Users' lost time depends on parameters, like:

- total amount of traffic in urban road network;
- amount of traffic in urban road network by transport modes;
- amount of traffic in urban road network by trip purposes and
- correction factors.

The total yearly transport congestion cost in urban network can be calculated by the following equation:

$$S_{Urb} = \sum_U \sum_M \sum_N TI_{U,M,N} \cdot VOT_{U,M,N} \quad (2)$$

where:

S_{Urb}	total yearly transport congestion cost in urban network
U	urban area index
M	transport mode
N	trip purpose
$TI_{U,M,N}$	lost time in urban area U of transport mode M by transport means N
$VOT_{U,M,N}$	value of one hour of lost time in urban area U of transport mode M by transport means N

The first step in calculation is to define the amount of traffic in urban area network. This could be acquired on the basis of statistical analyses, traffic studies of the considered urban area or recommendations from reference studies:

$$PDV = \sum_U PDV_U \quad (3)$$

where:

PDV	total amount of traffic in urban areas (in vehicle kilometers)
U	urban area index
PDV_U	total amount of traffic in urban area U (in vehicle kilometers)

For the exact calculation it is not enough to know the total amount of traffic in urban areas only. It is essential to know the extent of the total amount handled by a particular transport mode, because each transport mode handles a different share of transport, it has different vehicles' occupancy rate and it is used for different trip purposes. The shares of traffic handled by a particular transport mode could be acquired on the basis of measurements or with statistical analyses of data available for a considered area:

$$PDV = \sum_U \sum_M PDV_U \cdot DPD_{U,M} = \sum_U \sum_M PDV_{U,M} \quad (4)$$

where:

M	transport mode index
$DPD_{U,M}$	share of traffic handled by transport mode M in urban area U
$PDV_{U,M}$	total amount of traffic handled by transport mode M in urban area U (in vehicle kilometers)

The next element for calculation is defining purposes of trips (commuting, business trips, etc.):

$$PDV = \sum_U \sum_M \sum_N PDV_{U,M,N} \cdot DPD_{U,M,N} = \sum_U \sum_M \sum_N PDV_{U,M,N} \quad (5)$$

where:

N	trip purpose index
$DPD_{U,M,N}$	share of traffic in urban area U handled by transport mode M of trip purpose N
$PDV_{U,M,N}$	total amount of traffic in urban area U handled by transport mode M of trip purpose N (in vehicle kilometers)

The total amount of traffic in the urban area (PDV) must be further corrected by numerous correction factors, which ensure a more accurate result of congestion costs calculation. These are:

- correction factor for the average occupancy of vehicles ($FZ_{U,M,N}$)
- correction factor for interference of urban and interurban trips ($FU_{U,M,N}$) – a great part of congestion appears on the border between urban and interurban areas (city access roads). This factor is used to avoid counting the same trips in urban and interurban network twice;
- correction factor for the amount of traffic work done in peak times ($FK_{U,M,N}$) – external costs of congestion are calculated, by definition, as costs of

additionally used time for a particular trip. With this factor we take into account those trips only which are actually taken in traffic peak times;

- time loss factor ($FV_{U,M,N}$) – depends on speed difference in peak and off-peak time. The calculation of total congestion costs only takes into account the additionally used travel time which is a consequence of traveling in peak or off-peak time.

The final time loss is calculated as:

$$TI = \sum_U \sum_M \sum_N PDP \cdot FZ_{U,M,N} \cdot FU_{U,M,N} \cdot FK_{U,M,N} \cdot FV_{U,M,N} \quad (6)$$

After defining the value of time (VOT) we have obtained all necessary input data to calculate total transport congestion costs for urban area networks with equation (2).

5. Conclusion

The article shows possibilities for the modification of the engineering approach to calculate total congestion costs in urban transport network. The suggested modification enables the substitution of traffic loads data for each link of the network with data for total transport provided in a road network and series of statistically measurable quantities, physical quantities and social economic quantities. With such approach it is possible to overcome the lack of detailed data for each link of urban areas road networks (irrespective of the size of the urban area).

A similar methodology was already successfully implemented in the calculation of transport congestion costs in the Slovene national road network, which was integral part of Slovene study “Analysis of transport external cost” (Lep *et al.* 2004).

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